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# Surface Water Treatability and Demineralization Study

## District Project No. SE 406AA

Prepared for

St. Johns River Water Management District

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| abs/cm | absorbance per centimeter |
| AF/GF | Actiflo/granular media filtration |
| ATR/FTIR | attenuated total reflectance Fourier transform infrared |
| °C | degrees Celsius |
| cfs | cubic feet per second |
| CFU | colony forming units per milliliter |
| CIP | clean-in-place |
| CV | coefficient of variance |
| D/DBP | Disinfectant/Disinfectant Byproduct Rule |
| DO | dissolved oxygen |
| DOC | dissolved organic carbon |
| DPC | differential pressure coefficient |
| EPA | Environmental Protection Agency |
| ESWTR | Enhanced Surface Water Treatment Rule |
| FC | fecal coliforms |
| FDEP | Florida Department of Environmental Protection |
| ft/s | feet per second |
| GF | granular media filtration |
| GIS | geographic information system |
| gal/hr | gallons per hour |
| gpm | gallons per minute |
| gsfd | gallons per square foot per day |
| HRT | hydraulic residence times |
| ICR | Information Collection Rule |
| IWRM | Integrated Water Resource Monitoring |
| LFC1 | Low Fouling Composite |
| LT2 | Long Term 2 |

## ACRONYMS AND ABBREVIATIONS, CONTINUED

| | |
|---|---|
| µg/L | micrograms per liter |
| MCL | maximum contaminant level |
| MF | microfiltration |
| mgd | million gallons per day |
| mg/L | milligrams per liter |
| NF | nanofiltration |
| NOM | natural organic matter |
| NPDES | National Pollutant Discharge Elimination System |
| NPDOC | non-purgable dissolved organic carbon |
| NPF | normalized product flow |
| NSF | National Sanitation Foundation |
| NSP | normalized salt passage |
| NTU | nephelometric turbidity units |
| PAC | powdered activated carbon |
| PDC | pressure drop coefficient |
| PDT | pressure decay testing |
| psi | pounds per square inch |
| PVC | polyvinyl chloride |
| RO | reverse osmosis |
| ROSA | Reverse Osmosis System Analysis |
| SCADA | supervisory control and data acquisition |
| SDI | silt density index |
| SJRWMD | St. Johns River Water Management District |
| S/m | Siemens per meter |
| SP/GF | Superpulsator/granular media filtration |
| Super Pulsator | SuperP |
| SWIM | Surface Water Improvement and Management |

# ACRONYMS AND ABBREVIATIONS, CONTINUED

| | |
|---|---|
| SWQMP | Surface Water Quality Monitoring Program |
| TC | total coliforms |
| TDS | total dissolved solids |
| TMP | trans-membrane pressure |
| TO | taste and odor |
| TOC | total organic carbon |
| TSS | total suspended solids |
| TTHM | total trihalomethanes |
| UCF | University of Central Florida |
| UF | ultrafiltration |
| UFRV | unit filter run volume |
| USGS | U.S. Geological Survey |
| UVA | UV absorbance |
| UVT | UV transmittance |
| WET | Whole Effluent Toxicity |
| WTP | water treatment plant |
| WQBEL | water quality-based effluent limit |
| ZN/UF | Zenon ultrafiltration |
| ZW | ZeeWeed |

# EXECUTIVE SUMMARY

The St. Johns River Water Management District (SJRWMD) and CH2M HILL conducted an extensive pilot study involving the use of integrated membrane systems to produce potable water from the St. Johns River. The study identified treatment processes and costs involved in using the St. Johns River as an alternative water supply. This source is one alternative being evaluated to offset a large water supply deficit projected in eastern central Florida.

The raw water source for the pilot study was Lake Monroe in Sanford, Florida. This lake is part of the St. Johns River system, and is characteristic of typical Florida surface water with low turbidity and high dissolved organics. In addition, the lake periodically becomes brackish from saline groundwater inflow during low rainfall periods.

Prior to testing, a preliminary raw water characterization study was conducted. Raw water data collected by the U.S. Geological Survey (USGS) was used in the evaluation and selection of appropriate treatment processes for the pilot program. The characterization study identified the treatment requirements necessary for St. Johns River water and a potential treatment facility to be located in the reach between Titusville and DeLand on the St. Johns River.

The basis of this study was to evaluate pretreatment technologies that would sufficiently reduce the organic and turbidity levels in the water (e.g., coagulation, clarification, and filtration) so that effective salt removal could be conducted with RO membranes.

The purpose of this study is to demonstrate the treatability of this source water, identify the appropriate technology and basic design parameters for treatment, and determine both the capital and operational costs for this potential facility. The intent is that the information in this report will assist an entity in implementing a surface water treatment facility in this reach of the St Johns River and facilitate the next step for a water supply project of this type.

The findings of this study are that the source water in this reach of the St. Johns River is treatable and can be used as a source for potable drinking water. All of the technologies identified and selected by the stakeholders for testing in this study demonstrated feasibility and can be recommended for use on this water. The design criteria and costs for these treatment alternatives are summarized at the end of this report.

The costs for these systems, as well as the land requirement information, from this report are being used as the basis for the affordability (*Affordability Analysis of Alternative Water Supplies*, Burton and Associates, 2004) and siting (TM D2B *Surface Water Treatment Plant Siting Study*, HDR, 2004) elements of this project. Those results are being published under separate cover.

# PILOT SYSTEM PROCESS SELECTION

The first step of the pilot program was to meet with the stakeholders for the project and select the treatment processes for the study.

The process selection included stakeholder development of goals and criteria for water treatment. Based on these goals and criteria more than 17 potential treatment alternatives were developed. The goals and criteria were then used to build a multi-attribute analysis model. The model was employed to calculate the relative benefit of each alternative and compare the benefit to the cost. Considering both the cost and benefit, the stakeholders were then able to select the treatment alternatives for pilot testing.

During the workshops, the stakeholders developed five major criteria which were used to select the treatment technologies to be tested in this study. These criteria were then weighted and applied in a multi-attribute analysis model to evaluate 17 different treatment alternatives. Based on the evaluation, three pretreatment technologies were selected to pretreat the water before demineralization with RO membranes. The three pretreatments selected for pilot testing were:

- the Super Pulsator (SuperP) blanket clarifier followed by dual media gravity filtration;
- the Actiflo micro-sand ballasted clarifier followed by dual media gravity filtration; and
- the Zenon ZeeWeed 500 immersed ultrafiltration membrane.

## Pilot Plant

The pilot plant design was developed based on the treatment alternatives selected by the stakeholders. The pilot plant included facilities for raw water supply from the river, pretreatment (i.e., coagulation, clarification, and filtration), followed by desalting processes using RO membranes.

The major necessary elements included in the pilot plant were as follows:

- Raw water supply and pump station
- Chemical feed for coagulant with ferric chloride
- Chemical feed for pH adjustment with caustic and sulfuric acid
- Actiflo flocculation and clarification
- SuperP flocculation and clarification
- Zenon Ultrafilter (membrane filtration)
- Single element RO treatment units
- High recovery RO treatment units
- Chemical feeds for RO system operations and maintenance including antiscalant, biofouling control chemicals (chloramine and Bioguard )
- Pilot plant SCADA and control system

Based on the process design previously described, the mechanical design included pumps, pipes, tanks, valves, and controls necessary to connect and operate the pilot plant.

The pilot site was located at the Sanford South Water Reclamation Facility in Sanford, Florida. Water was pumped from Lake Monroe to the pilot plant and treated water was discharged into a manhole at the headworks of the wastewater treatment facility.

# PRELIMINARY BENCH SCALE STUDIES

Before the pilot testing began, preliminary bench-scale work was conducted to select the coagulant and RO membranes evaluated during the study. Coagulant jar testing of four different coagulant types determined the best coagulant for coagulation of organics and particles as well as the best to optimize clarification. Membrane flat sheet testing was used to screen more than 25 membrane types. Four membranes were selected for field testing.

## Coagulant Screening and Selection

UCF evaluated the following four coagulants for use in this study:

- Ferric chloride ($FeCl_3$)
- Ferric sulfate ($Fe_2(SO_4)_3$)
- Aluminum sulfate (alum ($Al_2(SO_4)_3$))
- PAX-XL19 (aluminum chlorohydrate)

The four coagulants were evaluated at varying dose and pH levels. The goal of the coagulant jar testing was to determine an appropriate coagulant dose and pH for TOC and $UV_{254}$ removal while ensuring adequate particle removal during clarification and filtration.

Based on the jar test results, ferric sulfate was selected as the coagulant for this study based on the higher level of organic removal achieved with the iron coagulant.

**Flat Sheet Membrane Screening and Selection**

Due to the variety of commercially-available nanofiltration (NF) and RO membranes, a bench scale screening process was conducted to select the appropriate membranes to evaluate during the pilot study. The membrane screening and selection was conducted by the University of Central Florida (UCF) on 25 different membrane types. The 25 membranes tested were selected by UCF using manufacturer provide data. The membranes evaluated included RO membranes as well as NF membranes. NF membranes were tested to determine if they were “tight enough” to remove chloride and bromide ions. Identifying a “tight” NF membrane could yield a savings in energy costs due to the lower feed pressure requirements for these membranes.

To produce water for the flat sheet tests, water from Lake Monroe was coagulated with ferric sulfate at the dose determined above and filtered prior to application to the flat sheets. For the purposes of this discussion, this water is referred to as coagulated, settled, and filtered (CSF) water. Membranes were selected using the following criteria:

- Non-purgable dissolved organic carbon (NPDOC) removal
- Inorganics rejection
- Surface characterization

The selectivity of organics was ranked based on NPDOC rejection. Membranes with permeate NPDOC levels greater than 0.5 mg/L were eliminated.

Fouling potential was not directly determined in flat sheet experiments, but rather based on surface properties. Generally, the rate and extent of membrane fouling are greatly affected by membrane surface properties such as roughness, charge, and hydrophobicity; membranes with low surface roughness, neutral charge, and less hydrophobicity are expected to be ideal for high organic surface water treatment.

Based on the results of flat sheet testing, the following four membranes were selected for field pilot evaluation:

- Filmtec BW30FR
- TriSep X-20
- Hydranautics LFC1
- Osmonics SG

## PILOT TESTING

After completing the pilot design and construction, pilot plant operations began in August 2001. The pilot testing program was conducted during the 19 month period from September 2001 to April 2003. During the course of the pilot testing, five pretreatment combinations and four RO membranes were evaluated.

As describe above, the pilot facilities included the following three basic pretreatment technologies in five combinations. The five pretreatment combinations included two high-rate clarification followed by media filtration, two high-rate clarification followed by membrane filtration, and one direct membrane filtration. These five combinations are as follows:

- Actiflo ballasted sand clarifier followed by dual media filtration
- Superpulsator (SuperP) blanket clarifier followed by dual media filtration
- Zenon ultrafilter operating in direct filtration mode (coagulation in the membrane tank)
- Zenon ultrafilter operating as a filter after clarification (following Actiflo)
- Memcor microfilter operating as a filter after clarification (following Actiflo)

These five pretreatment combinations were used throughout the entire pilot testing program.

The testing was divided into these phases: Phase 1A, 1B, 2A, 2B, and 3. The pretreatment evaluation was based on the ability to remove organics, turbidity, and pathogens. In addition, the pretreatment systems were also evaluated on their process stability and operability.

In each phase, the pretreatments provided treated water to RO membranes for desalting. Therefore, the pretreatments were also evaluated for their ability to provide a suitable feed water to the RO desalting membranes. Suitable performance was assessed by changes in RO performance parameters, including normalized product flow (NPF), differential pressure coefficient (DPC), and normalized salt passage (NSP).[1]

Detailed timelines for all phases of the pilot testing are included in the report.

## Raw Water Quality

Raw water quality, in large part, determines the treatment requirements necessary to process Lake Monroe water into drinking water and to meet drinking water goals and regulations. For example, NOM in the raw water will generally control the coagulant dosage required to successfully treat the water. Also, TDS will generally control the level of demineralization required and the percent of water that must be processed by RO. Raw water quality characterization is the initial step in the selection, evaluation, and design of water treatment facilities.

During this study, grab samples were collected biweekly by the USGS and analyzed for various general, organic, inorganic, and nutrient analytes. Samples were collected at four points along the reach of the river. The USGS began sampling at these locations in January 2000 and continued until August 2002 (a total of 31 months). This water quality characterization defines the expected range of raw water quality parameters and correlates lab measured organic and inorganic parameters to simple field measurements.

Further, grab samples were collected daily during pilot testing and analyzed for easily measured field parameters such as pH,

[1] Each of these parameters will be defined in a subsequent section of the report.

turbidity, color, and alkalinity. These samples were collected from August 2001 to April 2003 when pilot plant was operational.

## Pretreatment Testing

As discussed earlier, the raw water for the St. Johns River is seasonally brackish with TDS exceeding 1,200 mg/L. This TDS can only be removed by RO membranes. However, the organic and turbidity levels in the raw water need to be reduced significantly for the RO membranes to perform properly. Therefore, pretreating the water before it passes through the RO membranes is an important step in treating this water and was, therefore, a critical focus for this pilot study.

Pretreatment testing was conducted throughout the entire pilot testing program. The testing, as described earlier, was divided into distinct phases: Phase 1A, 1B, 2A, 2B, and 3.

The Phase 1A testing was the only phase in which all three pretreatment technologies (Actiflo, Super-P, and Zenon 500C direct filtration) were tested side-by-side.

The purpose of Phase 1A was to select the best pretreatment process which would then be used for the remainder of the testing with the RO membranes. However, all three pretreatment processes worked well in Phase 1A. Therefore, based on this result, all three of the pretreatment processes were used in the subsequent phases. The pretreatment technologies used in Phases 1B, 2, and 3 depended on availability and schedule. The pretreatments used in the different phases of this study are as follows:

| | |
|---|---|
| Phase 1A | SuperP, Actiflo, and Zenon Ultrafilter |
| Phase 1B | Super P and Zenon Ultrafilter |
| Phase 2A | Super P and Zenon Ultrafilter |
| Phase 2B | Actiflo and Zenon Ultrafilter |
| Phase 3 | Actiflo, Zenon Ultrafilter, and Memcor Microfilter |

It is important to note that in each phase, these pretreatments provided treated water to the RO membranes for desalting.

### Phase 1A Testing

As previously mentioned, the Phase 1A testing was the only phase in which all three pretreatment technologies (Actiflo, Super-P, and Zenon 500C direct filtration) were tested side-by-side. The purpose of Phase 1A was to select the best pretreatment process which would then be used for the remainder of the testing with the RO membranes. However, all three pretreatment processes worked well in Phase 1A.

All three pretreatments were able to produce potable water quality without RO membrane treatment. Organics removal by each pretreatment exceeded regulatory requirements. The filtered water turbidity from each process was significantly below 0.1 NTU, and each process demonstrated a stable operation throughout the test phase.

In addition, the treated water produced from each of these pretreatment systems provided for stable RO membrane performance without membrane fouling.

### Phase 1B, 2, and 3 High Rate Clarification Testing

SuperP and Actiflo were further tested as clarification technologies for organics and turbidity removal with further particle removal by granular media filtration. These systems continued to feed the selected RO membranes to demonstrate that SuperP with granular media filtration (SP/GF) and Actiflo with granular media filtration (AF/GF) could produce treated water that meets drinking water goals..

#### Super-P Conclusions

The Super-P tests indicated that average turbidities were less than 0.05 NTU at all filtration rates (4, 7, and 10 gpm/$ft^2$) and average particle counts were less than 33.7 counts/ml. This filtered water turbidity level exceeds the water quality and regulatory goal for the study. The SuperP clarified water was filterable. The water production measured by UFRV was acceptable ranging from 9,000 gal/$ft^2$ to over 20,000 gal/$ft^2$ depending on the loading rate Loading rates from 4 to 7 gpm/$ft^2$ resulted in filter runs from 30 to 99 hours.

#### Actiflo Conclusions

The Actiflo clarified water was filterable. All of the data indicated that filtration up to a rate of 8 gpm/$ft^2$ will produce filtered water quality meeting the drinking water regulations. The average filtered water quality was less than 0.1 NTU with average particle counts less than 34.1 counts/ml. For design of filters with Actiflo clarification, filtration rates up to from 4 to 8 gpm/$ft^2$ maybe used, with filter run times ranging from 24 hours to 100 hours depending on the loading rate used.

### Phase 1B, 2 and 3 Microfiltration/Ultrafiltration Testing

Microfiltration (MF)/Ultrafiltration (UF) was tested as a pretreatment to RO and to demonstrate that UF could produce a treated water meeting drinking water goals. One MF system, Memcor CMF-S, and one UF system, ZeeWeed 500-C, were tested during the study. Both were operated following clarification as an alternative for media filters. In addition, the ZeeWeed 500-C was tested in direct filtration mode, in which the Zenon was a stand alone pretreatment with coagulation occurring in the process tank.

#### Zenon Direct Filtration Testing and Conclusions

The purpose of Zenon direct filtration testing was to evaluate the Zenon process as a stand alone pretreatment system for direct comparison to Actiflo/SuperP clarification followed by granular media filtration. In direct filtration mode, flocculation is performed prior to ZeeWeed UF, but coagulation and filtration occur in the same tank.

The objective of direct filtration testing was to gather the necessary data to develop full scale design recommendations for optimized flux, recovery, cleaning interval, and coagulant dosage and to accurately estimate full scale costs for a ZeeWeed based pretreatment system.

Based on the results of testing conducted during the period September 2001 to October 2002, the Zenon membrane was adequate for treating this source water in a direct filtration mode. The design parameters that were developed for the ZeeWeed 500-C membrane operating in direct filtration mode suggest a design flux of 20 gfd with a recovery of 90 percent. These operating parameters resulted in a cleaning interval of greater than 6 weeks.

#### Zenon and Memcor Clarified Water Testing and Conclusions

Both the Zenon Ultrafilter and the Memcor CMF-S microfilter were tested on clarified water to evaluate their performance in place of media filters. Testing included operation at a variety of flux rates and recoveries with the goal to optimize membrane productivity and develop criteria for full-scale design of a Memcor MF plant.

The Memcor CMF-S membrane was tested on clarified water from January 2003 to April 2003. The CMF-S pilot testing demonstrated that on properly clarified water, a 6 week cleaning interval was possible at a flux of 39 gfd, backwash interval of 30 minutes, and recovery of 94.3 percent. Further, a daily maintenance clean using a chlorinated feed solution of 200 mg/L as $Cl_2$ would be required.

The Zenon membrane was tested on clarified water from November 11, 2002 to January 16, 2003. The Zenon pilot testing resulted in the recommendation of the ZW-1000 membrane for this application. The pilot testing demonstrated that on properly clarified water, a 4 to 6 week cleaning interval was possible at a flux of 20 gfd, and recovery of 92 percent.

**Reverse Osmosis Membrane Testing**

The previous sections summarized the results and performance of the high rate clarifiers and micro/ultrafilters in removing organics and turbidity. As mentioned earlier, during this pilot study, these pretreatments continuously provided treated water to the RO membranes for desalting. The membrane performance data was summarized from both the single element membrane units as well as the high recovery pilot unit.

The following summarizes the performance of these membranes in treating water provided from these pretreatment processes. The membrane performance was assessed with regards to differential and net driving pressure, salt passage, and net product flow.

The RO membranes were tested over a 19 month period with a variety of pretreatments. As mentioned earlier, Phase 1 A was the only time in which all three pretreatments provided water to the membranes side-by-side. For the remaining phases, the pretreatment depended on schedule and availability. A number of different combinations of pretreatments and membranes were evaluated during this phased testing.

The RO membrane data collected was quite extensive over the 19-month period during which over 11,000 hours of membrane field data was gathered.

Refer to the *Pilot Timeline* section of this report for detailed information regarding which membranes were tested with different pretreatments, dates for the testing, conditions for the testing, as well as process flow schematics for the testing.

As described above, the membrane screening and selection was conducted by UCF on 25 different membrane types. The RO membranes selected for pilot testing were the following:

- Osmonics SG Brackish Water Membrane
- Hydranautics Low Fouling Composite (LFC1) Membrane
- TriSep X-20 Membrane
- Filmtec BW30FR Membrane
- Filmtec BW30LE Membrane[2]

The first four of the above membranes were selected from the flat sheet testing. The fifth membrane is a conventional low energy fouling resistant membrane. This membrane was added for testing to determine if such a membrane type could be cost effectively operated on the pretreated Lake Monroe water.

Based on all of the membrane field testing, the following conclusions can be drawn regarding the pretreatment (including biofouling control) and RO membrane evaluations.

All three pretreatment trains (UF and the Super P and Actiflo high rate clarification followed by GMF) are acceptable for full-scale use in pretreating Lake Monroe water. Each will provide an RO feed water of appropriate turbidity and SDI; however, UF provides a lower and more consistent SDI feed.

Chloramination of the pretreated Lake Monroe water is necessary to control biological (bacterial) fouling, both on the RO membranes and the cartridge pre-filters. Where high rate clarification is used, chloramines should be dosed to clarified water to optimize filtered water quality and filter run lengths and to reduce chloramine usage.

Due to the chloramination of the membranes for biofouling control, as well as fouling that was occurring from normal operation, increases in salt passage through the membrane were observed during the pilot testing. Under recommended operating conditions, the salt passage increase was found to range between 2.1 to 2.4 percent per year.

Based upon this salt passage rate, and a maximum allowable permeate water TDS of 200 mg/L, the membrane replacement frequency under these conditions would be approximately 5 years. This membrane replacement frequency met the replacement goal set for this study.

[2] The BW30LE membrane is a conventional (non-fouling resistant membrane) having lower cost and energy consumption compared to the other fouling resistant membranes. This membrane was not selected during the *Flat Sheet Membrane Screening and Selection* previously discussed. Testing was performed on this membrane to determine if such a membrane type could be cost effectively operated on the pretreated Lake Monroe water.

### Concentrate Discharge Risk Analysis

A risk analysis of discharging the RO concentrate back to the St. Johns River was conducted. The evaluation of toxicity was based on an empirical toxicity database compiled into the model GRI-FW-STR (Mount et al., 1997). The model predicts acute toxicity of seven common ions to three standard freshwater test organisms, using stepwise probit regression to find a best fit for effects. The model results are reflective of what is likely to happen in a whole effluent toxicity (WET) test. The focus of this approach is the summed effect of all the materials in the effluent, and in typical application may be followed up with specific toxicity tests if the material fails the WET test.

The results of the analysis suggest that the discharge of this concentrate stream is a relatively low risk. The results of this analysis indicate that a discharge of this type in the Middle St. Johns River may be accomplished in ways that are protective of the environment and meet current regulatory criteria and statutes while understanding that other issues in addition to toxicity must be considered.

## DISINFECTION AND T&O REMOVAL EVALUATIONS

Taste and odor control was also evaluated for this source water. For control of taste and odor causing compounds, specifically 2-methylisoborneol (MIB) and geosmin, PAC testing and membrane flat sheet testing were performed on Lake Monroe water spiked with MIB and geosmin.

PAC dosage of 40 mg/L achieved 40 percent removal of MIB and nearly 70 percent removal of geosmin at a 15 minute contact time. Flat sheet testing resulted in more than 93 percent removal of both compounds. The testing also indicated that membrane degradation due to chloramines and fouling may result in more passage of these taste and odor compounds over time. However, any decrease in rejection of these compounds by the membranes, as they approach replacement, can be mitigated with higher PAC dosages during pretreatment. Therefore, the use of PAC in conjunction with the RO membranes is an effective approach for taste and odor control for this source water.

Final recommendations were also developed for disinfection based on the DBP testing conducted. Testing was performed on two finished waters, the RO permeate and on filtered water which had been pretreated by Actiflo clarification (clarified / filtered). These two waters were tested to illustrate the recommended disinfection strategy for a number of reasons. First, a number of different end uses are possible for this treated water. The final blend characteristics of this water with other utilities will not be determined at this time. The intent of this testing is to evaluate the two extreme conditions, the highest organic levels with no desalting (clarified / filtered water) and then the lowest organic levels (RO permeate). The premise is to identify the available contact time for each alternative as well as if chlorine or chloramines can be used as the residual disinfectant.

Based on the DBP formation, if split stream RO is used (75 percent membrane treatment for TDS reduction or higher, but not including 100 percent) virus inactivation will be done with free chlorine with *Giardia* and *Cryptosporidium* inactivation being accomplished with UV. Since a significant level of organics will be present in the finished water, chloramines will have to be used for a residual disinfectant.

Due to the concerns of emerging contaminants and the conversion many utilities will face if chloramines have to be used as the residual disinfectant, 100 percent membrane treatment is likely the preferred alternative for desalting. The primary disinfectant for the RO permeate with 100 percent membrane treatment will be free chlorine. Free chlorine can also be used as the residual disinfectant in the distribution system. UV can also be used on the RO permeate for *Cryptosporidium* inactivation if the membranes have to be bypassed during a maintenance event or shutdown.

## MICROBIAL CHARACTERIZATION AND CHALLENGE TESTING

Microbial testing was conducted to examine the water quality of Lake Monroe for natural microbial contaminants that are of concern in drinking water. This study was done to provide data to assess the microbial characteristics of the St. Johns River both above and below Lake Monroe to evaluate the potential areas at which a surface water plant may be sited. Specifically, levels of *Cryptosporidium*, *Giardia*, enteric viruses, several indicator organisms, and algal toxins were sampled.

An evaluation of treatment processes that reduce the levels of these contaminants during water treatment was also conducted. Microbial challenge studies were conducted during Phase 2A, 2B, and 3 with the three pretreatment systems. The pilot feed streams to the treatment units were challenged with polystyrene micro-beads as a surrogate to *Cryptosporidium* oocysts. The challenge was conducted to evaluate the pathogen removal efficacy of the pretreatments.

Three sites were monitored at Lake Monroe to develop a comprehensive characterization of the natural microbial water quality in Lake Monroe. The sites were monitored monthly for 12 months to assess the influent raw water to the Lake Monroe watershed, the raw water at the pilot plant intake, and the effluent raw water of the Lake Monroe watershed.

The characterization included the pathogens *Cryptosporidium* and *Giardia*, human enteric viruses, and *Clostridium* spp., in addition to indicator organisms: total coliforms, fecal coliforms, *Escherichia coli* (*E. coli*), *Enterococci* spp., and coliphages. Cyanobacteria, algal toxins, and several physical parameters were also analyzed.

The challenge testing suggested that under proper coagulation and treatment conditions, all three pretreatment systems were effective at removing total coliform, fecal coliform, and 3 µm beads. As expected, the Zenon system had a much higher removal of beads compared to the clarification/granular media filtration systems.

Effective removal of 3 µm beads is significant because these beads are a surrogate for *Cryptosporidium*, a microorganism regulated under the enhanced surface water treatment rules from EPA. *Cryptosporidium* is also one of the smaller regulated pathogens which suggest that these data also indicate that removal of the larger organisms such as *Giardia* can be achieved as well. These data provide the basis that compliance with current and future enhanced surface water treatment rules will be possible with these pretreatment technologies.

In addition, these data also indicate the log removals for the combined processes such as coagulation/clarification followed by media filtration or membrane filtration were very high. These combined removals ranged up to 6 to 8 log removal of the 3 µm bead surrogate.

## EXPECTED FINISHED WATER QUALITY

In conjunction with pilot testing, extensive analyses were conducted on filter and RO permeate water. Daily samples were collected and analyzed from the raw water, pretreatment systems, RO membrane permeate, and RO membrane concentrate. The results of these evaluations facilitated the projection of water quality parameters.

In addition to these analyses, Safe Drinking Water Act sampling and evaluation was conducted to ensure that a surface water facility on this reach of the St. Johns River would be able to meet the existing regulatory requirements of the EPA and the FDEP. Two sampling events were conducted on the raw water, filtered water, and RO permeate.

Volatile organics or Group I or Group II Unregulated Contaminants were not present in the raw water during the two sampling events and therefore were not present in the finished water.

Trace levels of 2 compounds including Pesticides, PCBs, and Group III contaminants were present in the raw water. The coagulation/filtration and RO membrane technologies removed these compounds to below the regulatory limit.

Some inorganics and Secondary contaminants were present in the raw water. However, pretreatment with coagulation/clarification followed by filtration, as well as treatment with the RO membranes were able to remove all of these compounds to below the regulatory limits.

Therefore, in summary, the finished water produced from pretreatment with coagulation/clarification and filtration, followed by RO membranes, met or exceeded all current USEPA regulatory standards as well as anticipated future regulatory standards.

## TREATMENT SYSTEM RECOMMENDATIONS

Based on the pilot testing, the pretreatment alternatives tested were able to sufficiently treat the St. Johns River water to meet potable standards as well as pretreat the water to allow the use of RO membranes for desalting. These treatment alternatives are as follows:

- Actiflo ballasted sand clarifier followed by dual media filtration
- SuperP blanket clarifier followed by dual media filtration
- Zenon ultrafilter operating in direct filtration mode (coagulation in tank)
- Zenon ultrafilter operating as a filter after high-rate clarification
- Memcor microfilter operating as a filter after high-rate clarification

Further, the following RO membrane types recommended for desalting this pretreated source water based on the pilot study are:

- Filmtec BW30FR
- TriSep X-20

Considering the use of the MF / UF membrane used for either direct filtration or filtration after clarification, as well as the percentage of desalting with RO membranes, the following six potential treatment combinations can be recommended for treating this waster based on the pilot results:

1. Zenon ZW-500-C (direct filtration) with 100 percent RO treatment
2. Zenon ZW-500-C (direct filtration) with 75 percent RO treatment
3. Actiflo / Granular Media Filtration with 75 percent RO treatment
4. SuperP / Granular Media Filtration with 75 percent RO treatment
5. Actiflo / Memcor CMF-S or Zenon 1000 with 100 percent RO treatment
6. Super-P / Memcor CMF-S or Zenon 1000 with 100 percent RO treatment

As discussed previously, these six alternatives provide the average benefit and cost with clarification and partial desalting and microfiltration with partial desalting (Alternatives 2, 3, and 4) and the highest benefit and highest cost dual membrane alternatives with 100 percent desalting (Alternatives 1, 5, and 6). These represent the range of technologies and cost benefits selected by the stakeholders at the beginning of the study.

The study found that these are all feasible water treatment technologies, each with each having a unique set of benefits and corresponding costs.  The costs for these alternatives as well are included in the last section of this report.

# INTRODUCTION

The St. Johns River Water Management District (SJRWMD) and CH2M HILL have completed an extensive pilot study involving the use of integrated membrane systems to produce potable water from the St. Johns River. The purpose of the study was to identify treatment processes and the respective costs involved in using St. Johns River as an alternative water supply source to offset a large water supply deficit projected in eastern central Florida.

The raw water source for the pilot study was Lake Monroe in Sanford, Florida. This lake is part of the St. Johns River system, and is characteristic of typical Florida surface water with low turbidity and high dissolved organics. In addition, the lake periodically becomes brackish from saline groundwater input during low rainfall periods. Total dissolved solids (TDS) levels in Lake Monroe can reach 1,200 milligrams per liter (mg/L) with chloride levels of 500 mg/L. This water, therefore, requires some form of organics and particle removal by chemical coagulation/clarification and filtration followed by demineralization for salt removal by reverse osmosis (RO) membranes.

Prior to testing, a preliminary raw water characterization study was conducted. Raw water data collected by the U.S. Geological Survey (USGS) was used in the evaluation and selection of appropriate treatment processes for the pilot program. The characterization study identified the treatment requirements necessary for St. Johns River water and a potential treatment facility to be located in the reach between Titusville and DeLand on the St. Johns River.

Selecting treatment technologies for any water treatment system is driven primarily by drinking water regulations and the need to meet consumer expectations. For surface water treatment, the primary regulations are the Enhanced Surface Water Treatment Rules (ESWTR) and the Disinfectant/Disinfectant By-Product (D/DBP) Rules. The planning process for any treatment facility on the St. Johns River has a 5 to 10 year window. Therefore, by the time construction of this facility is complete, compliance will be required with the Long Term 2 (LT2) ESWTR and Stage 2 D/DBP rules. To meet these regulations, the following primary analytes were targeted for removal in the pilot plant:

- Organics
- Turbidity

- Giardia
- Viruses
- Cryptosporidium

The approach to removing these analytes is multibarrier treatment involving the following unit processes:

- Coagulation and flocculation
- Clarification
- Filtration
- Disinfection

This approach requires each process to remove water-borne pathogens, operating at a high rate of efficiency. The effectiveness is cumulative, in that each unit process helps the subsequent unit process work more effectively than if operated alone. For instance, effective coagulation and flocculation will improve the performance of the clarification process, and effective clarification will improve the performance of filtration. After filtration, the filtered water is considered "clean," which increases the effectiveness of disinfection. Disinfection is used to inactivate any of the pathogens that may have passed through the previous barriers. In this manner, each step plays an important role in the removal and inactivation of water-borne pathogens.

Additionally, as previously mentioned, the St. Johns River has unique characteristics due to the brackish content of the water with seasonally high TDS and chloride levels. Because of these unique characteristics, some form of demineralization for salt removal must be used with conventional treatment.

Therefore, the basis of this study was to evaluate pretreatment technologies that would sufficiently reduce the organic and turbidity levels in the water so that effective salt removal could be conducted with the RO membranes.

# PILOT SYSTEM PROCESS SELECTION

The first step of the pilot program was to meet with the stakeholders for the project and select the treatment processes for the study.

The process selection included stakeholder development of goals and criteria for water treatment. Based on these goals and criteria, more than 17 potential treatment alternatives were developed. The alternatives were then combined with the goals and criteria and a multi-attribute decision model was developed that ranked the relative benefit of each alternative with the cost. Considering both cost and benefit, the stakeholders were then able to select the treatment alternatives for pilot testing.

This process was conducted during the course of three meetings with the stakeholders and the District—Goal Meetings 1 and 2, and Evaluation Meeting 1. The stakeholders included local government officials and utility staff from east Central Florida cities and counties, regulatory officials from the Florida Department of Environmental Protection (FDEP), and one county health department.

## GOALS

During April and May of 2001, the project team conducted workshops with the utility stakeholders of this project to develop the overall goals of the study as well as identify the water quality goals and selection criteria to be used in choosing the appropriate technologies to test in the pilot study.

Based on stakeholder input, the overall goals of the pilot study were as follows:

- Determine the treatment requirements necessary to produce varying levels of finished water quality for different end uses, including potable water, reuse augmentation, and aquifer recharge.
- Determine the associated cost of each of the levels of treatment evaluated.
- Provide the design criteria and operating parameters necessary for the design of a full-scale treatment plant.
- Allow stakeholders to become familiar with the surface water treatment technologies that are being evaluated.

# TREATMENT PROCESS SELECTION

During the workshops, the stakeholders developed five major criteria for use in selecting the treatment technologies to be tested. The five major criteria and the associated subcriteria are summarized in Table 1. These criteria were then ranked using a forced ranking approach and were applied to a multi-attribute decision model to evaluate 17 different treatment alternatives. The decision model then calculated the relative benefit for each alternative using the treatment scores and weighted criteria. Each alternative was then ranked according to relative benefit. In addition the process cost for each alternative was then estimated and compared to the relative benefit. This information was displayed graphically facilitate stakeholder selection of the final treatment processes for piloting. The relative benefit ranking with the costs for each alternative is shown in Figure 1a. Using this figure, the stakeholders were able to identify alternatives with the higher relative benefit and lower costs. Any treatment alternatives that had lower relative benefits and higher costs were easily identified and eliminated using this approach.

Based on the evaluation, three pretreatments were selected by the stakeholders to treat the water before demineralization with RO membranes. The three pretreatments selected for pilot testing included:

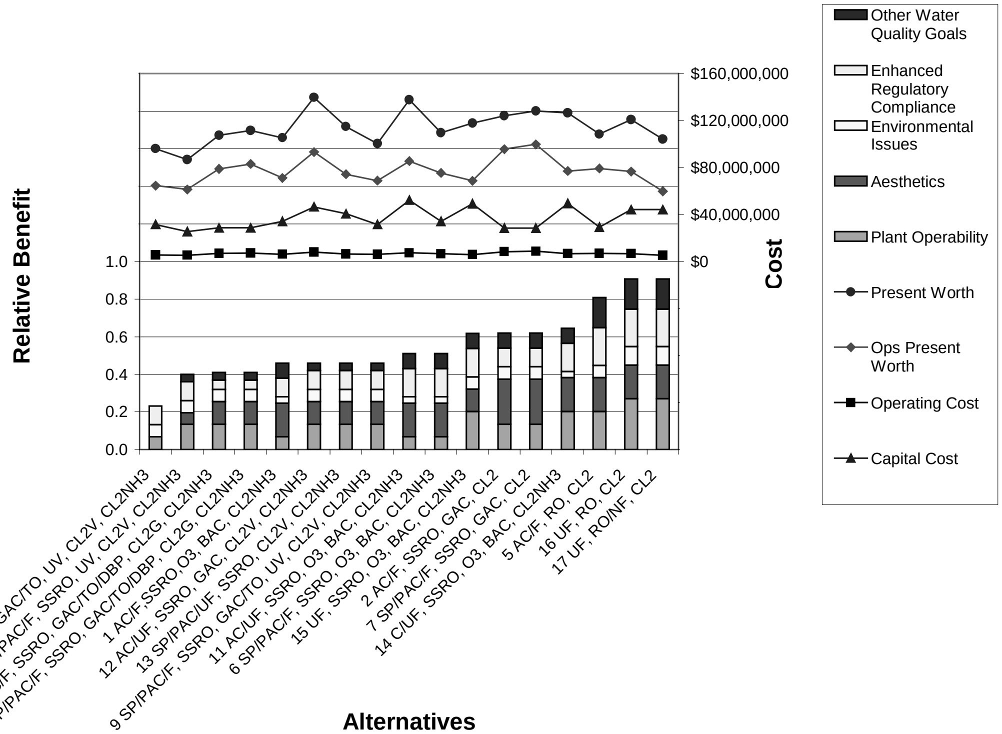
- the Super Pulsator (SuperP) blanket clarifier followed by dual media gravity filtration;
- the Actiflo micro-sand ballasted clarifier followed by dual media gravity filtration; and
- the Zenon ZeeWeed 500 immersed ultrafiltration membrane.

These pretreatments were selected based on their ability to reduce turbidity and organics, their relative operability, and their ability to produce a suitable feed water for RO membrane treatment. Using Figure 1a, these treatment alternatives ranged from average benefit and average cost to highest benefit and highest cost. This selection allowed the stakeholders to evaluate a range of technologies and benefits in the pilot study. This range included clarification/filtration followed by RO membranes (average benefit and cost) and MF/UF filtration followed by RO membranes (dual membrane highest benefit and highest cost).

**Table 1. Stakeholder Selection Criteria**

| Category | Criteria | Goal |
|---|---|---|
| **Enhanced Regulatory Compliance** | **Disinfection By-products** | |
| | THMs | Meet Regulations |
| | HAAs | Meet Regulations |
| | Bromate | Meet Regulations |
| | Chlorite | Meet Regulations |
| | **Pathogens** | |
| | Giardia | Meet Regulations |
| | Crypto | Meet Regulations |
| | Virus | Meet Regulations |
| | **Inorganics** | |
| | Total Dissolved Solids | Meet Regulations |
| | Chloride | Meet Regulations |
| | Corrosion Control | Meet Regulations |
| | **Organics** | |
| | TOC | Meet Regulations |
| | SOCs/VOCs | Meet Regulations |
| **Aesthetics** | Taste and Odor | Meet Regulations |
| | Color | Meet Regulations |
| **Other Water Quality Goals** | Algal Toxins | Minimize |
| | Chloride | <250 |
| | TOC | Minimize |
| | Regrowth | Minimize |
| | Sodium | Minimize |
| **Environmental Issues** | Residuals-Solids | Minimize |
| | Traffic | Minimize |
| | Plant Odors | Minimize |
| | Sustainable | Maximize |
| | Environmental Hazards | Minimize |
| | Residuals-Liquid | Minimize |
| | Foot Print | Minimize |
| | Navigational Impairment | Minimize |
| | Noise | Minimize |
| **Plant Operability** | Automation | Maximize |
| | Maintenance | Minimize |
| | Operating Complexity | Minimize |
| | Flexibility to handle WQ degradation | Maximize |
| | Interruptible operations | Maximize |

## Figure 1a. Alternatives Cost and Benefit




It is important to note that riverbank filtration was also considered by the stakeholders to further reduce or eliminate pretreatment requirements for the RO membranes. However, due to the site specific nature of bank filtration testing, it was not selected for evaluation. The premise of this decision is that this project is a demonstration study to identify an implementable solution for a treatment plant to be located anywhere between Lake Monroe and Deland. Since testing bank filtration at our specific pilot plant location would not prove, or disprove, it's applicability at other locations, it was not tested. However, if a specific treatment plant location in this reach of the river is selected for implementation, some site specific bank filtration testing can be conducted to evaluate it's effectiveness.

For further information on treatment process selection see Appendix A.

# PILOT PLANT DESIGN

This section summarizes the pilot plant design to test the stakeholder selected treatment alternatives. The design includes the facilities for raw water supply from the river, the treatment equipment required for coagulation and pretreatment of the river water, and the treatment equipment required for desalting with RO membranes.

The major elements required for the pilot plant design included:

- Raw water supply and pump station
- Chemical feed for coagulant
- Chemical feed for pH adjustment including caustic and sulfuric acid
- The Actiflo pretreatment alternative
- The SuperP pretreatment alternative
- The Zenon Ultrafilter alternative
- Single element RO treatment units used for membrane alternatives testing
- High recovery RO treatment unit used for membrane system design testing
- Chemical feeds for RO system including antiscalant for the membranes, chemical feed for biofouling control (chloramines and Bioguard were tested)
- Pilot plant SCADA and control system

Figure 1 illustrates the pilot plant process and instrumentation diagram. The figure shows the pilot plant treatment processes, chemical feed locations, and instrumentation. Each of the unit processes are discussed in more detail below.

## RAW WATER SUPPLY

Water was pumped from Lake Monroe to the pilot site and split among the various pretreatment trains as illustrated in Figure 1. The raw water intake was provided by the City of Sanford. The intake was an old outfall pipe in which the flow was reversed to a manhole. A 500 gpm submersible pump was placed in the manhole to supply raw water to the pilot plant.

Chloramination was one of the alternatives tested to control biofouling on the RO membranes. Therefore, a design was provided to chloraminate the raw water prior to entering pretreatment. Raw water chloramination was tested so that all streams received the same dose of monochloramine, prior to splitting them among the pretreatment trains. The chemicals were fed by chemical metering pumps which maintained a chloramine residual of 5 mg/L as $Cl_2$ throughout the process trains.

In addition, a chloramine application point was also designed at a location following clarification. This was done due to chloramine deterioration at the low coagulation pHs and chloramine adsorption in the powdered activated carbon (PAC) blanket of the SuperP. Further, chloramination after clarification was tested to assess suspected RO membrane effects from interaction of the chloramines with the high organic raw water.

# PRETREATMENT

As previously discussed, three pretreatment alternatives were selected for testing during this pilot study. All pretreatments used the ferric sulfate coagulant ($Fe_2(SO_4)_3$), selected from jar test experiments performed on Lake Monroe water by the University of Central Florida (UCF). The jar test results are discussed in the Pre-Pilot Bench Scale Studies section of this report. All coagulation was done at a low pH to maximize organic removal. The pH of the water during coagulation was adjusted using either sulfuric acid ($H_2SO_4$) or sodium hydroxide (NaOH) in order to maximize the removal of color and dissolved organics.

Each pretreatment process uses a different technology to clarify and remove the coagulated solids (sludge) from the water. The following sections provide brief descriptions of the pretreatment technologies.

## High Rate Clarification

### Actiflo®

Actiflo® is a high rate clarification process that uses microsand-enhanced flocculation and lamella settling to produce clarified effluent. The process consists of rapid mixing where the coagulant is added, an injection tank, where micro-sand and a polymer are applied, and a maturation zone, where low energy mixing is applied to build the floc. The water then enters the settling tank where the sand-based flocs quickly settle. Further clarification occurs as the treated water flows through inclined tube settlers prior to exiting the process via effluent channels. The micro-sand sludge at the bottom of the settling tank is pumped to a hydrocyclone, where the sand is separated from the sludge by centrifugal force. The sand is then returned to the head of the process for reintroduction into the injection tank.

For this study, polymer and micro-sand addition rates for this study were determined by the manufacturer. The optimum coagulation pH was between 4.0 to 4.5, which achieved the optimum organics removal. This is further discussed in the Pretreatment Evaluation section of this report.

### SuperP

The SuperP is an upflow solids blanket clarifier (also known as a solids contact clarifier) which combines rapid mixing, flocculation, and sedimentation in one unit. These clarifiers are designed to maintain a large volume of flocculated solids within the unit, which enhances flocculation by encouraging interparticle collisions. Further interparticle collisions are achieved through the use of a vacuum system which pulses the sludge blanket, causing the blanket to expand and contract. The flocculated solids (blanket) are usually maintained at a set volume in the contactor. Blanket cohesion is achieved through the use of a polymer in addition to the coagulant. Often, PAC is also used with the SuperP to enhance total organic carbon (TOC) removal and improve taste and odor.

For this study, polymer and PAC dosages were determined by the manufacturer. The optimum coagulation pH was between 4.0 to 4.5, for optimum organics removal. This is further discussed in the Pretreatment Evaluation section of this report.

### Granular Media Filtration

As previously discussed, both Actiflo and SuperP require filtration following clarification. Filtration was performed at a target pH of 6.5 in order to minimize residual iron in the filtrate. The pH was adjusted using sodium hydroxide (NaOH) fed with a chemical metering pump. An inline pH meter monitored by the plant supervisory control and data acquisition (SCADA) system controlled the rate of sodium hydroxide addition to maintain the target pH.

As illustrated in Figure 1, clarified water was pumped from the Actiflo and SuperP units to both the CH2M HILL Pilot Trailer and the pilot building. A small side stream (2 gallons per minute [gpm]) of clarified water was directed to the CH2M HILL Pilot Trailer to collect detailed filtration data using 4-inch sand/anthracite pilot filters. A process stream of 30 gpm for both Actiflo and SuperP was pumped to the pilot building for filtration through the granular media pressure filters to produce water for RO operation.

The SCADA system monitored filtration pH, turbidity, and flow in order to protect the RO membranes from poor water quality during operation. The pressure filter effluent turbidity was continuously monitored using an inline turbidimeter. Once turbidity reached a predetermined set point, the SCADA system stopped the transfer pump and sodium hydroxide pump. The SCADA system also monitored a flow switch located on the suction line to the transfer pumps. When flow to the transfer pump was interrupted, the SCADA system automatically stopped the transfer pump and sodium hydroxide pump.

When pump shutdowns occurred, feed water to the RO membranes was fed from the 3,000 gallon break tanks. Subsequently, uninterrupted operation of the RO membranes was possible.

## Immersed Microfiltration

### Zenon

With the Zenon ZeeWeed® (ZW) 500-C process, hollow fiber ultrafiltration (UF) membranes, configured in a module, are installed (immersed) in an unpressurized tank containing feed water and a small vacuum is applied to the inside (lumen) of the fibers. Under vacuum, the water flows through the fiber wall and is collected as treated water (filtrate). Membrane filtration, using UF or MF membranes, can be used in place of granular media filtration for particulate removal. However, UF and MF membranes are not capable of removing dissolved contaminants, such as natural organic matter (NOM) or salts, such as chloride.

During the initial phase of testing, the coagulant was dosed upstream of a flocculation chamber from which flow passed into the membrane tank. To reduce cake buildup on the membrane fibers, air was introduced at the bottom of the membrane feed vessel to create turbulence in the tank effectively scrub solids from the membrane surface. In this application, the immersed UF unit served for both clarification and filtration. During subsequent phases, the ZW-500-C was evaluated following clarification.

As illustrated in Figure 1, the treated water from the Zenon pilot unit was pumped to a 3,000 gallon break tank. Influent, effluent, and concentrate flow were monitored using the pilot unit's SCADA system. The pH of the water was adjusted using sodium hydroxide (NaOH) fed via a chemical metering pump. An inline pH meter monitored by the ZW pilot unit SCADA controlled the sodium hydroxide feed rate to maintain a coagulated water target pH of 5.6-6.0. This pH was selected to provide good organics coagulation while minimizing the level of dissolved iron in the UF permeate.

## REVERSE OSMOSIS MEMBRANE PILOT SYSTEM

The RO membrane pilot system consisted of eight single element RO skids as well as a multi-element high recovery membrane system. Figure 1 illustrates the flow from the break tanks to the single element skids and the high recovery membrane system. The single element units, illustrated in Figure 2, used 4-inch by 40-inch RO membrane elements[3]. Each single element skid had pressure gauges and flow indicators for the influent, permeate, concentrate, and recycle streams.

The high recovery system was configured in a 2-1 array. The first stage contained four vessels, while the second stage had two vessels. Each vessel contained three elements with a total of 18 elements for the entire high recovery system. The high recovery system also contained three single pass low recovery vessels used to simulate the lead vessel of the high recovery system.

Since the 3,000 gallon break tanks provided feed water to the RO units during pretreatment interruptions or granular media filter backwashes, the RO units could be operated continuously. Level indicators in the break tanks were monitored by the plant SCADA system.

As illustrated in Figure 1, the chemical feed pumps added antiscalant to the membrane feed supplied from the break tanks. The antiscalant was necessary to reduce the membrane feed water scaling potential.

[3] Membrane selection, conducted by UCF, is discussed later in this protocol.

The booster pumps, illustrated in Figure 1, supplied the necessary flow and pressure to the membrane high pressure pumps. To protect the booster pumps, a level switch in the break tank monitored the water level. If the break tank water level dropped below a set level, the SCADA system stopped the booster pump and antiscalant pump.

The pressure switch on the single element skid, illustrated in Figure 2, monitored the feed stream pressure. When the booster pump was not supplying adequate pressure to the membrane feed pump, the SCADA system shut down the skid to prevent damage to the membrane feed pump.

### Pilot Plant Discharge

The pilot plant discharge, consisting of all process waters, was sent to a manhole at the headworks of the Sanford Water Reclamation Facility. A chemical metering pump supplied sodium hypochlorite to maintain a chlorine residual of 0.5 mg/L as $Cl_2$ to the water. Further, the flow rate was monitored via pitot tube flow meter.

During times of wet weather discharge, the Sanford Water Reclamation Facility required CH2M HILL to stop operation.

## MECHANICAL DESIGN

Based on the process design previously described, the mechanical design, summarized below, provides appropriate equipment sizes and equipment for use in the pilot facility. This section summarizes the mechanical design of the pipes, pumps, break tanks, and filters used in this pilot plant. Figure 3 provides the pilot plant pipe sizes and maximum flows.

### Raw Water Supply

The raw water withdrawal point was at "Manhole J" illustrated in Figure 4, at the northeast corner of the Sanford Water Reclamation Facility. The raw water pipe installed at grade was a 6-inch Schedule 40 PVC pipe. The raw water was supplied by a 4-inch Gorman-Rupp 20-HP pump.

### Process Water Transfer Pumps

As illustrated in Figure 1, transfer pumps between unit processes were required. Both Actiflo and SuperP required transfer pumps to provide pressure to filter the clarified water and subsequently send the filtrate to the break tanks. The pumps selected were 1-1/2 HP self-priming centrifugal pumps with a discharge pressure of 40 to 50 pounds per square inch (psi).

The single element skids required a minimum suction pressure of 30 psi at a maximum design flow of 10 gpm. The 10 gpm flow was required because one unit may supply four single element skids, each with a 2.5 gpm maximum design flow. Therefore, booster pumps were required after each break tank. The selected booster pumps were 1/2 HP self-priming centrifugal pumps with a discharge pressure of 30 to 40 psi.

## Chemical Metering Pumps and Feed Locations

Various chemical metering pumps were required for chemical addition throughout the process trains as illustrate in Figure 1.

Chloramines were necessary to prevent biological growth on the membranes. Therefore, prior to pretreatment, chlorine and ammonia were applied to chloraminate the water, prior to and/or after clarification.

Chemical metering pumps for acid and coagulant addition were provided by the pretreatment manufacturers. However, metering pumps for pH adjustment after clarification were required for both Actiflo and SuperP.

Table 2 describes the chemical metering pumps. Stock concentrations are the commercially available chemical concentrations. Chemical metering pumps for chlorine, ammonia, and sodium hydroxide had a maximum dosing capacity of 0.42 gal/hr. The chemical application solutions were diluted using RO permeate to achieve the desired feed concentration.

**Table 2. Pilot Plant Chemical Feed System Design Summary**

| Chemical | Stock Concentration | Stock SG | Desired Feed Conc. | Water Flow | Min Dose | Max Dose | Min. Chem. Flow Rate* | Max Chem. Flow Rate* |
|---|---|---|---|---|---|---|---|---|
| | (%) | (lb/gal) | (%) | (gpm) | (mg/L) | (mg/L) | (gal/hr) | (gal/hr) |
| Chlorine | 15% | 10.2 | 7% | 400 | 5 | 10 | 0.21 | 0.42 |
| Ammonia | 20% | 1.9 | 13% | 400 | 1.25 | 2.5 | 0.20 | 0.41 |
| Sodium Hydroxide | 50% | 6.38 | 18% | 32 | 30 | 60 | 0.21 | 0.42 |
| Antiscalant | 100% | 10.3 | 1% | 2.5 | 1.35 | 2.7 | 0.016 | 0.033 |

SG = Specific gravity at stock concentration

**Flow rate at desired feed concentration

Antiscalant, which prevents metal scaling/precipitation on the membrane surface, was applied before the membrane units. Antiscalant was dosed to each single element system. To supply one single element skid, a maximum feed water flow of 2.5 gpm was required. The required flow rate for antiscalant at the feed water flow and a 1:100 dilution was 0.016 gal/hr to 0.033 gal/hr.

### Filters

Dual media filtration removed coagulated particles not removed during clarification. This treatment step included pressure filters following Actiflo and SuperP. This step was required before RO membrane treatment. The media filters were sized to treat 30 gpm each, with a 4 gpm/ft$^2$ design loading rate. The filter media design was 42 inches of anthracite over 12 inches of sand.

### Break Tanks

Break tanks were installed for pretreated water storage prior to RO membrane treatment. The break tanks were sized to 3,000 gallons, allowing additional single element RO runtime during pretreatment train downtime and granular media filter backwashes. The single element skids had a 2.5 gpm maximum design flow, with each break tank supplying two single element RO units. With 3,000 gallons and both single element units operating, 10 hours of additional membrane run time was possible. The break tank feed flow was 30 gpm with single elements using 5 to 10 gpm. The remaining 20 to 25 gpm was discharged from the break tank via overflow, which allowed for turnover of the break tank water as shown in Figure 1.

### Piping

Using the flows from the process schematic in Figure 1, process pipe diameters were determined based on a maximum flow velocity of 4 feet per second (ft/s). Table 3 summarizes pipe diameters based on these maximum flows.

**Table 3. Pipe Design Diameter Based on Maximum Flow**

| Flow | Pipe Diameter | Velocity |
|---|---|---|
| (gpm) | (in) | (ft/s) |
| 628 | 8" | 4.0 |
| 353 | 6" | 4.0 |
| 157 | 4" | 4.0 |
| 39 | 2" | 4.0 |
| 22 | 1-1/2 " | 4.0 |
| 9.8 | 1" | 4.0 |
| 5.5 | 3/4" | 4.0 |
| 2.5 | 1/2" | 4.0 |

### Drain Piping

Process drains were designed using a 1/8 inch drop per linear foot slope. All drain laterals were 6-inch PVC pipes and connected to an 8-inch manifold. At the given slope, the 6-inch drains were able to convey 230 gpm of flow while the 8-inch manifold was able to convey up to 500 gpm. The 8-inch manifold discharged all of the pilot flow to the Sanford Water Reclamation Facility manhole.

## SITE PLAN AND BUILDING PLAN

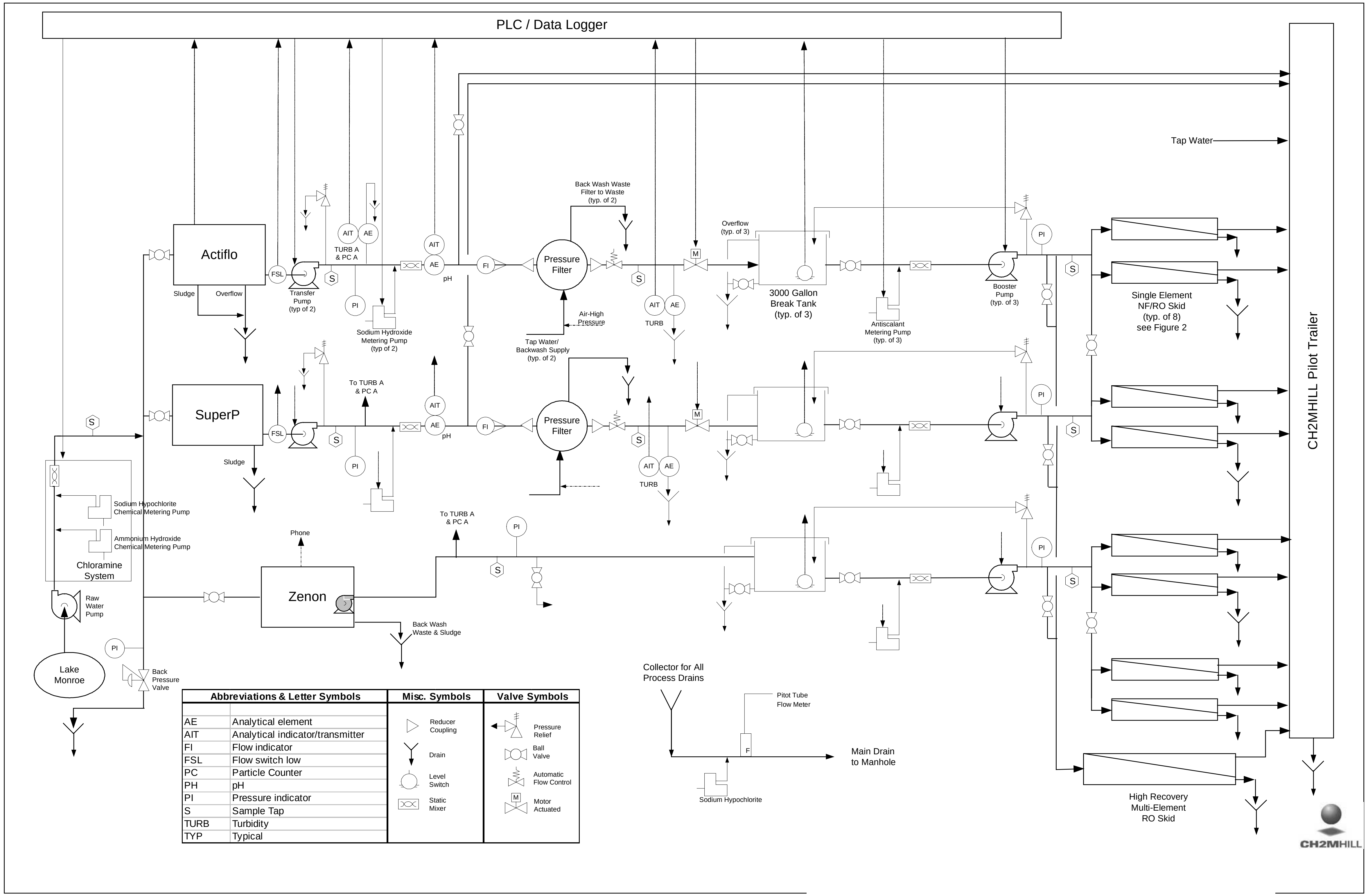
The pilot site was located at the Sanford South Water Reclamation Facility in Sanford, Florida. Figure 4 illustrates the overall pilot site plan in relation to the City of Sanford facilities, with the pilot site located on the south side of the treatment plant. The pilot plant waste discharged into a manhole at the facility headworks. The pilot plant discharge pipe was an 8-inch schedule 80 PVC pipe. Flow was by gravity at a 1/8-inch per linear foot slope.

Figure 5 presents the pilot plant site plan and shows the locations of manufacturer trailers, CH2M HILL Pilot Trailer, and pilot building. The manufacturer trailers were located north of the pilot building. The trailers supplied pressure filters inside the building and the CH2M HILL Pilot Trailer, adjacent to the manufacturer trailers.

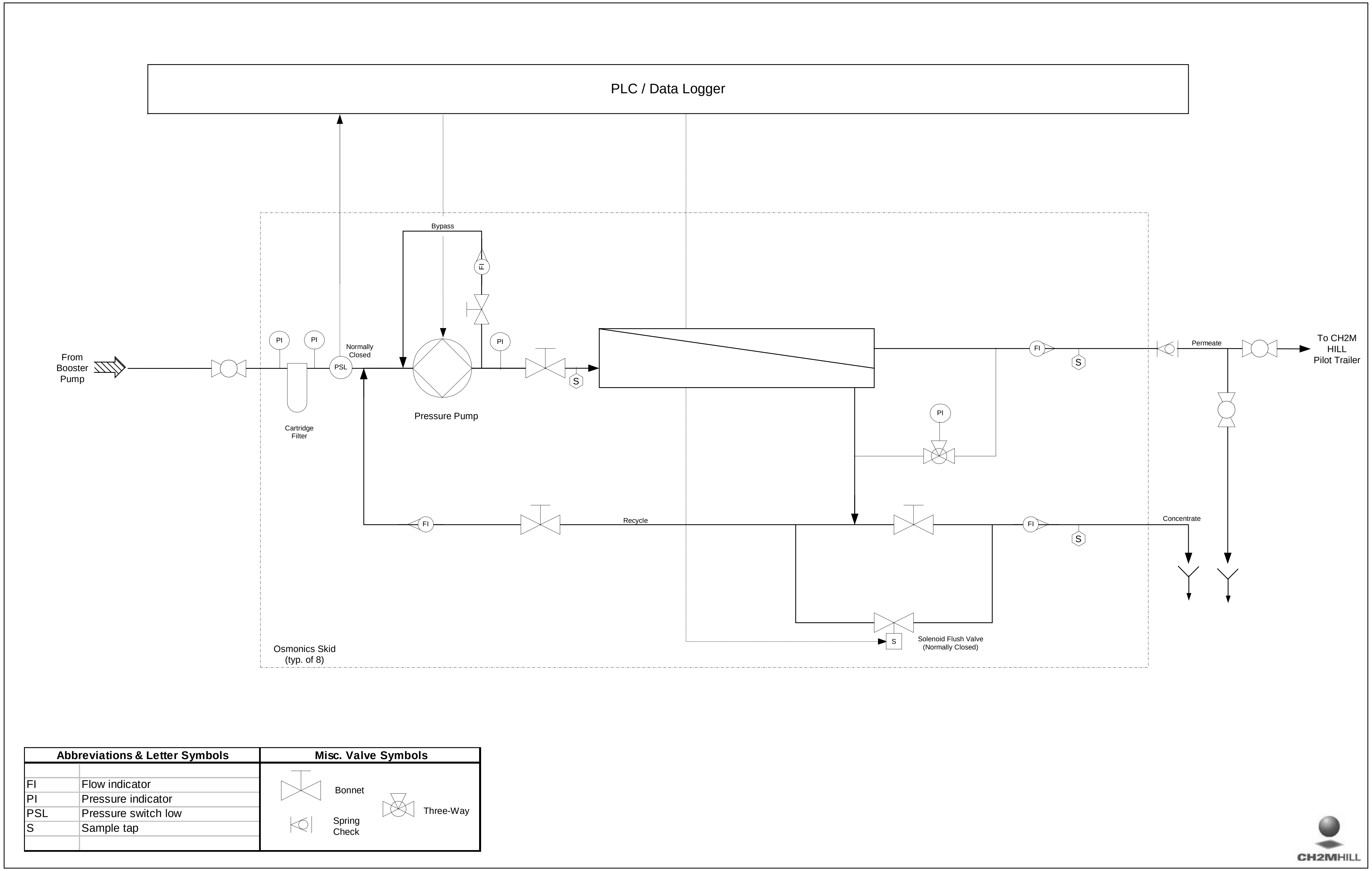
The Zenon pilot unit was located inside the pilot building as well as the RO membrane systems and breaktanks. Figure 6 illustrates the building plan and pilot equipment layout.

Soil testing was conducted at the pilot site due to concerns of break tank weights when full, pilot equipment weights, and soil settling. The soil under the building was tested using eight cone penetrometer tests as well as digging test pits. These tests suggested that the soil under the pilot area was disturbed. Therefore, the foundation of the building was excavated 12 to 18 inches, a high quality fill was added in 6-inch lifts, and the fill was compacted to greater than 95 percent maximum proctor. The building slab was designed with a double mat rebar cage under the break tanks and in the footing, with a single mat rebar design in the rest of the slab. The slab was poured with a 4,000 psi concrete.

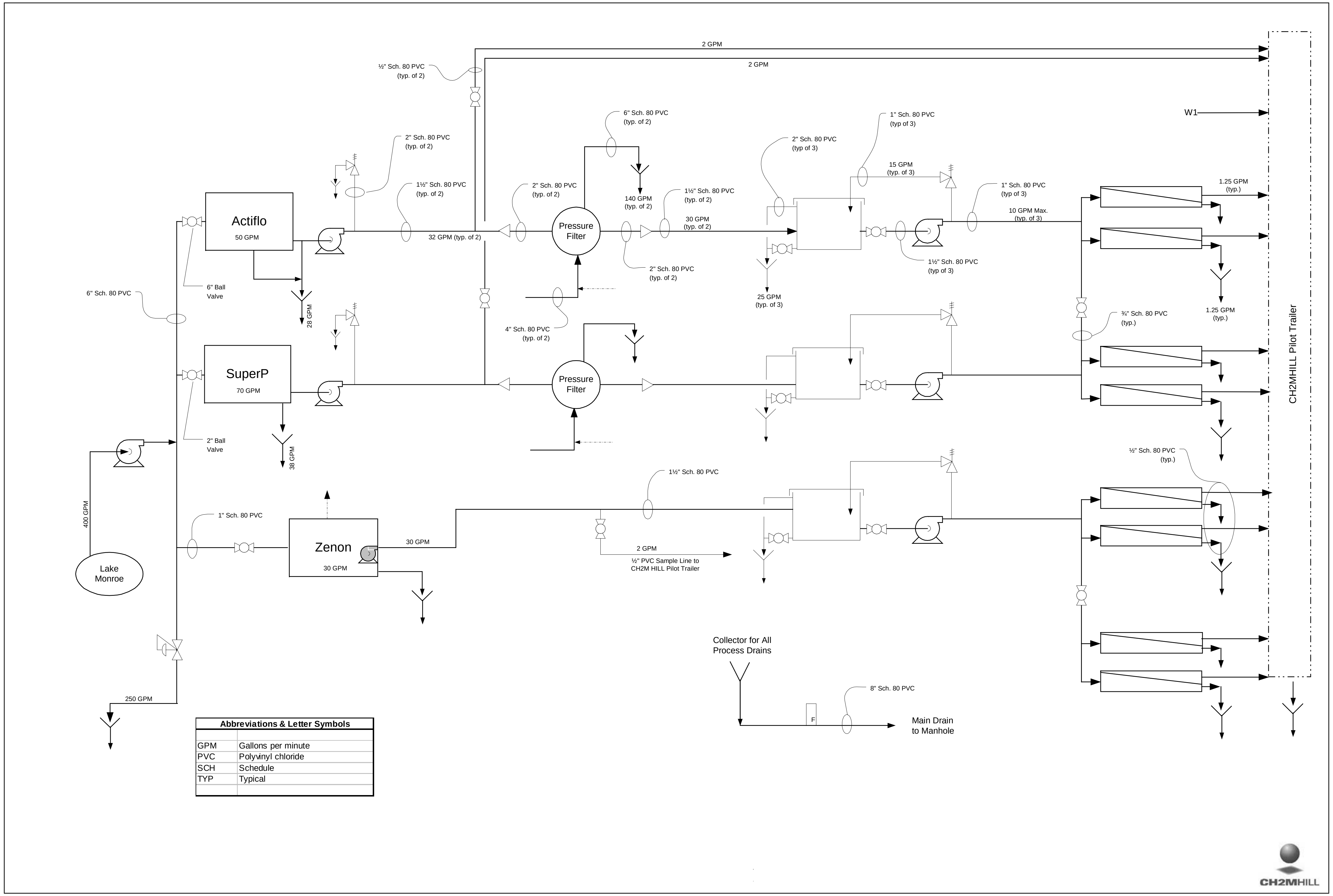
# Figure 1. Pilot Plant Process and Instrumentation Diagram



## Figure 2. Single Element RO Skid Detail



## Figure 3. Phase 1A Pilot Plant Pipe Sizes and Maximum Flows



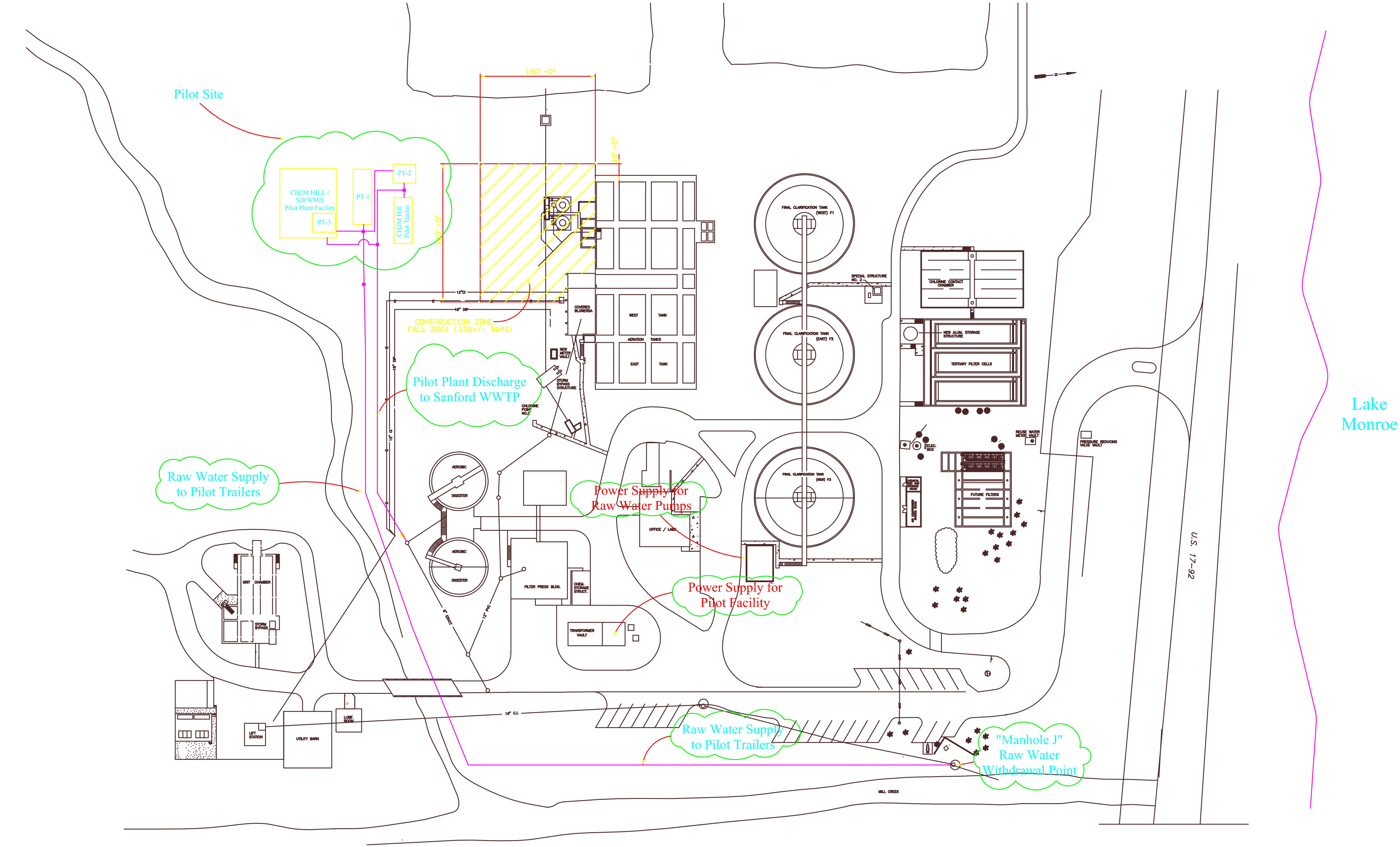



**Figure 4 Overall Site Plan**

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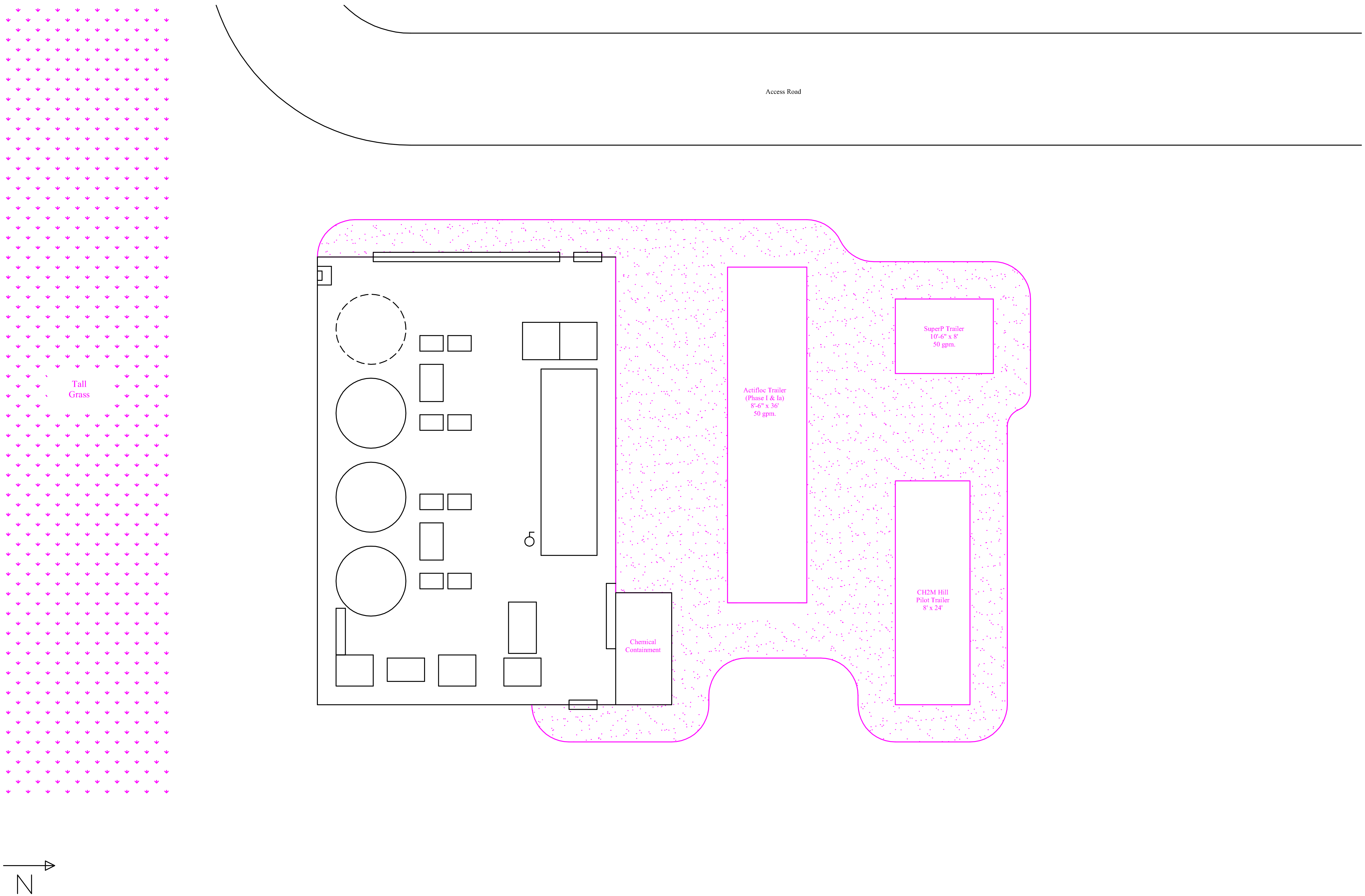


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**Figure 5 Pilot Plant Site Plan**

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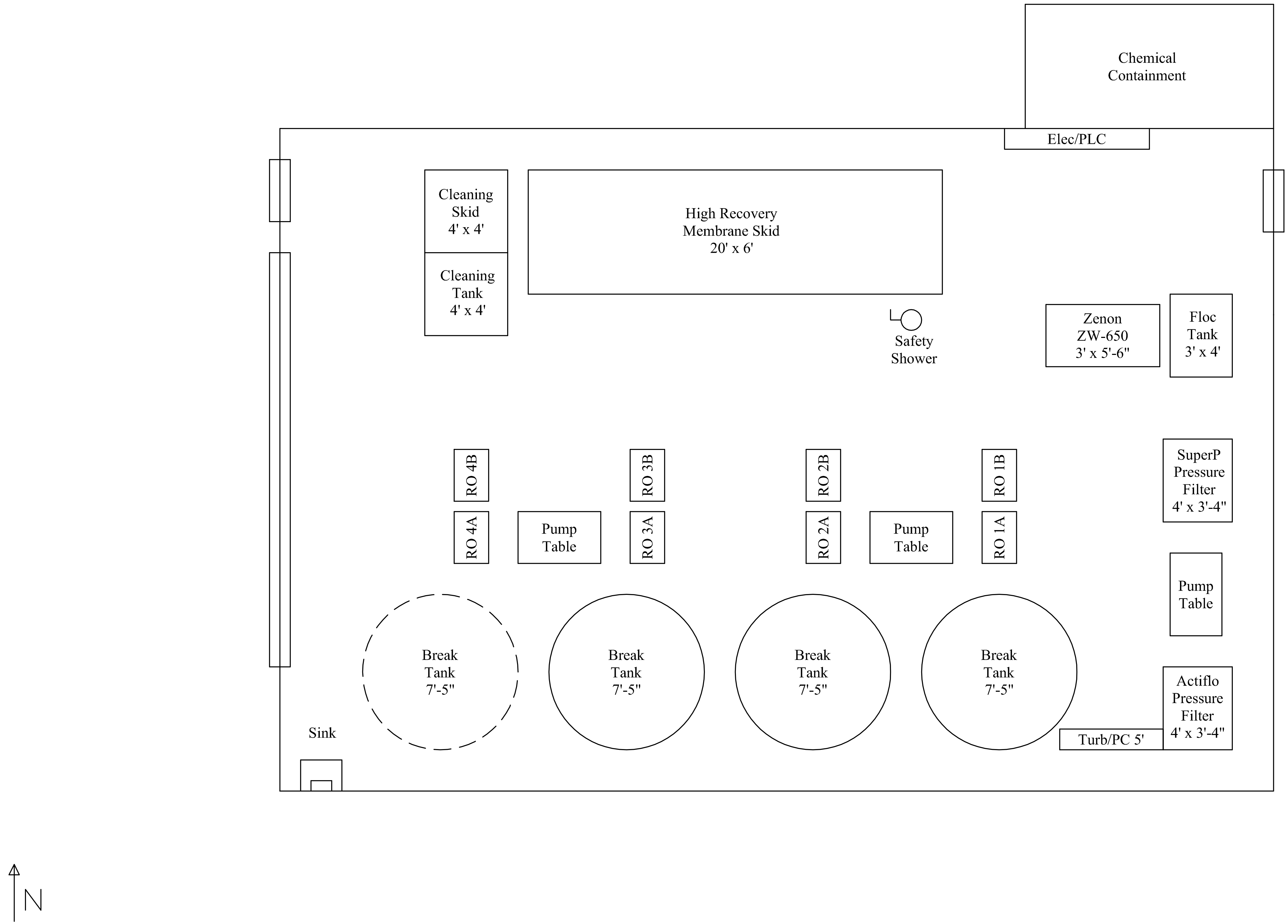


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Figure 6 Pilot Plant Building Plan

CH2MHILL

# PRELIMINARY BENCH SCALE STUDIES

Before pilot testing began, preliminary bench-scale work was conducted to select appropriate coagulant and the RO membranes used in this study. Coagulant jar testing was conducted to determine the best coagulant for water coagulation / clarification by evaluating four different types of coagulant. Membrane flat sheet testing was conducted due to the multitude of desalting membranes available on the market. Four membranes were selected for pilot testing from a field of 20 membranes.

## COAGULANT SCREENING AND SELECTION

UCF evaluated four coagulants at varying dose and pH levels for use in this study. The goal of jar testing was to determine the optimum coagulant for TOC and $UV_{254}$ removal at the optimum dose and pH. The coagulants included ferric chloride ($FeCl_3$), ferric sulfate ($Fe_2(SO_4)_3$), aluminum sulfate or alum ($Al_2(SO_4)_3$), and PAX-XL19, an aluminum chlorohydrate. The coagulant, manufacturer, specific gravity, solution strength, and dosing concentration for jar testing are provided in Table 4.

**Table 4. Coagulant Physical Parameters**

| Coagulant | Manufacturer | Specific Gravity | Solution Strength (%) | Dosing Concentration (meq/L) |
|---|---|---|---|---|
| Ferric Chloride ($FeCl_3$) | Kemiron North America | 1.474 | 43.2% $FeCl_3$ | 1 meq/mL Fe |
| Ferric Sulfate ($Fe_2(SO_4)_3$) | Kemiron North America | 1.44 | 10.1% Fe | 1 meq/mL Fe |
| Aluminum Sulfate ($Al_2(SO_4)_3$) | Kemiron North America | 1.33 | 8.27% $Al_2O_3$ | 1 meq/mL Al |
| Aluminum Chlorohydrate PAX-XL19 | Kemiron North America | 1.34 | 23.5% $Al_2O_3$ | 1 meq/mL Al |

The coagulation testing process follows:

- Determine the acid strength of the four coagulants
- Conduct jar testing on each coagulant to determine $UV_{254}$ removal as a function of pH and dose
- Correlate $UV_{254}$ and TOC

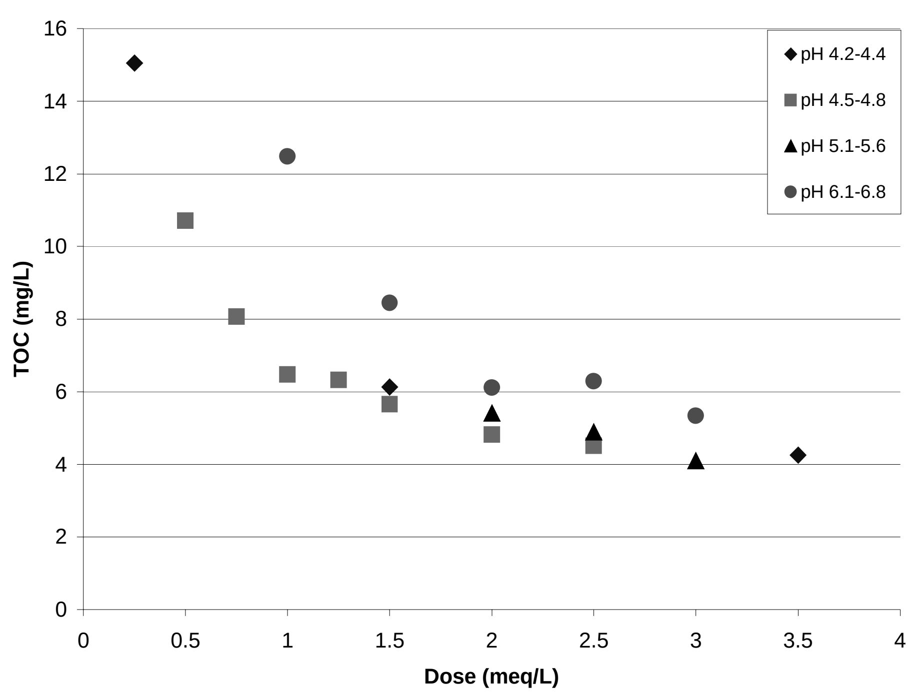
- Retest $UV_{254}$ correlation for optimum $UV_{254}$ removal at selected dose and pH
- Select recommended coagulant

The coagulants were evaluated for $UV_{254}$, TOCl, color, and turbidity removal. Ferric chloride and ferric sulfate, widely used for TOC removal in Florida, outperformed the aluminum coagulants for removal of $UV_{254}$, TOC, color, and turbidity. Both iron coagulants achieved approximately 90 percent removal of $UV_{254}$ at a dose of 1.5 to 2.5 meq/L and a pH of 4.5. For an equivalent dosage, aluminum sulfate and aluminum chlorohydrate were not as efficient in TOC and $UV_{254}$.

Figure 7 illustrates the TOC removals at varying ferric sulfate doses and pHs. The vertical axis is TOC concentration (mg/L) and the horizontal axis is coagulant dose (meq/L). The data is grouped by coagulation pH range.

As the figure suggests, a dose of 1.5 to 2.0 meq/L at a pH of 4.5 to 4.8 achieved the optimum removal of organics. This dose is considered optimal since doses above 2 meq/L only achieve minimal increases in TOC removal with a significant increase in coagulant dose.

**Figure 7. TOC Removal Results of Ferric Sulfate Jar Tests**



Ferric sulfate was chosen as the coagulant for this pilot study due to its ability to remove TOC, as illustrated in Figure 7. Further, this coagulant was selected due to its common use at most central Florida surface water plants and the additional benefit of sludge usage as a fertilizer.

Based on the jar tests, a ferric sulfate dosage of 120 to 150 mg/L and coagulation pH of pH of 4.0 to 4.5 achieved the most efficient removal of dissolved organics from the water. As a side note, dosages during field testing were much higher due to higher raw water TOC levels. The raw water TOC concentration for jar testing was 18.74 mg/L, while average TOC levels during field testing were approximately 25 mg/L, subsequently requiring much higher dosages.

## FLAT SHEET MEMBRANE SCREENING AND SELECTION

There are a variety of commercially-available NF and RO membranes. Therefore, a selection and screening process was conducted to select the appropriate membranes for this source water. Testing was conducted by UCF on 25 different membrane types, selected based on manufacturer provided data. The membranes evaluated included RO as well as NF membranes. NF membranes were tested to assess if there were any "tight enough" to remove chloride and bromide ions. If a "tight" NF membrane were identified, energy cost savings could be realized due to lower NF membrane feed pressure requirements.

To produce water for the flat sheet tests, Lake Monroe water was coagulated with ferric sulfate at the dose determined above and filtered prior to application to the flat sheets. For the purposes of this discussion, this water is referred to as CSF water. Membranes were selected using the following criteria:

- Non-purgable dissolved organic carbon (NPDOC) removal
- Inorganics rejection
- Surface characterization

The membranes were accepted or rejected based on NPDOC rejection. Membranes with permeate NPDOC levels greater than 0.5 mg/L were considered unacceptable and were subsequently eliminated. Table 5 summarizes the results of membrane selection based on NPDOC rejection. Based on this testing, 10 membrane types were eliminated from consideration, while 10 were accepted for further testing.

**Table 5. Membrane Flat Sheet NPDOC Rejection Summary**

| Membrane | Type | Category | Feed NPDOC Concentration | Permeate NPDOC Concentration | NPDOC Rejection | Acceptable Removal |
|---|---|---|---|---|---|---|
| | | | (mg/L) | (mg/L) | (%) | (Yes/No) |
| AG | TFC | LPRO | 4.81 | 0.42 | 91.3 | Yes |
| TFC-SR1 | TFC | NF | 4.69 | 0.79 | 83.1 | No |
| TFC-SR2 | TFC | NF | 5.93 | 0.96 | 83.8 | No |
| TFC-S | TFC | NF | 3.99 | 0.59 | 85.1 | No |
| DL | TFC | NF | 5.63 | 0.65 | 88.4 | No |
| ESPA2 | TFC | LPRO | 6.00 | 0.75 | 87.4 | No |
| ESNA1 | TFC | NF | 5.78 | 0.36 | 93.8 | Yes |
| NF90 | TFC | NF | 5.82 | 0.52 | 91.0 | No |
| NF270 | TFC | NF | 5.88 | 0.65 | 88.9 | No |
| HL | TFC | NF | 5.99 | 0.86 | 85.6 | No |
| BW30FR | TFC | LPRO | 6.96 | 0.26 | 96.2 | Yes |
| X-20 | TFC | LPRO | 6.73 | 0.19 | 97.2 | Yes |
| LFC-1 | TFC | LPRO | 5.84 | 0.19 | 96.8 | Yes |
| SG | TFC | LPRO | 5.09 | 0.21 | 95.9 | Yes |
| CD | CA | RO | 5.17 | 1.05 | 79.7 | No |
| TS80 | TFC | NF | 5.32 | 0.58 | 89.2 | No |
| DK | TFC | NF | 5.25 | 0.06 | 98.9 | Yes |
| BE-FR | TFC | NF | 6.64 | 0.14 | 97.9 | Yes |
| BL-FR | TFC | LPRO | 6.81 | 0.17 | 97.5 | Yes |
| CG | CA | LPRO | 7.01 | 0.46 | 93.4 | Yes |

TFC = Thin Film Composite; CA = Cellulose Acetate; LPRO = Low Pressure Reverse Osmosis; NF = Nanofilter; RO = Reverse Osmosis

Membrane inorganic compound removal was evaluated based on TDS, Ca, Mg, Na, Cl, Br, and $SO_4$ rejection from CSF treated St. Johns River. Table 6 summarizes the results of flat sheet testing for inorganic removals. Criteria for acceptance follow:

(1) 90 percent or higher rejections of TDS, Ca, Mg, Na, Cl, Br, and $SO_4$ at low recovery (i.e., flat-sheet experiments)

(2) 70 percent or higher rejections projected at 85 percent recovery and 15 gallons per square foot per day (gsfd).

Membranes with unacceptable performance are shaded gray. The feed water used in projections contains 1,400 mg/L TDS, 100 mg/L Ca, 40 mg/L Mg, 300 mg/L Na, 550 mg/L Cl, 3 mg/L Br, and 450 mg/L $SO_4$. Note that projected TDS removal for the BW30FR membrane was 69.3 percent at 85 percent recovery and 15 gsfd; however, this was very close to the acceptance criteria of 70 percent and was, therefore, included in the remaining evaluations.

**Table 6. Membrane Flat Sheet Inorganic Rejection Summary**

| Membrane Type | TDS | | Ca | | Mg | | Na | | SO4 | | Cl | | Br | | Acceptable Perfomance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $R_f$ | $R_p$ | $R_f$ | $R_p$ | $R_f$ | $R_p$ | $R_f$ | $R_p$ | $R_f$ | $R_p$ | $R_f$ | $R_p$ | $R_f$ | $R_p$ | |
| | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (Yes/No) |
| AG | 93.9 | 70.9 | 92.0 | 64.6 | 94.5 | 73.3 | 89.0 | 56.2 | 95.9 | 78.7 | 89.6 | 57.8 | 91.3 | 62.6 | No |
| ESNA1 | 80.9 | 30.7 | 86.9 | 40.9 | 88.5 | 44.7 | 73.1 | 22.1 | 96.7 | 75.5 | 70.6 | 20.1 | 56.6 | 12.0 | No |
| BW30FR | 94.1 | 69.3 | 97.6 | 85.4 | 97.4 | 84.2 | 95.0 | 72.8 | 98.5 | 90.4 | 94.8 | 71.9 | 96.8 | 81.0 | Yes |
| X20 | 93.6 | 77.2 | 100.0 | 100.0 | 99.5 | 97.7 | 97.4 | 89.7 | 99.8 | 99.0 | 98.4 | 93.2 | 97.8 | 91.2 | Yes |
| LFC-1 | 97.5 | 85.4 | 100.0 | 100.0 | 99.7 | 98.2 | 96.2 | 79.2 | 100.0 | 100.0 | 97.2 | 84.2 | 97.7 | 86.6 | Yes |
| SG | 98.1 | 92.4 | 97.9 | 91.6 | 99.1 | 96.1 | 94.9 | 80.9 | 99.4 | 97.4 | 95.0 | 81.3 | 95.6 | 83.4 | Yes |
| DK | 66.4 | 20.6 | 94.2 | 68.2 | 96.4 | 78.0 | 39.9 | 8.0 | 99.6 | 96.9 | 46.1 | 10.1 | 39.4 | 7.9 | No |
| BE-FR | 96.4 | 84.2 | 100.0 | 100.0 | 99.7 | 98.6 | 98.6 | 93.2 | 99.8 | 99.2 | 99.2 | 96.2 | 100.0 | 100.0 | Yes |
| BL-FR | 84.8 | 45.0 | 99.9 | 99.3 | 99.3 | 95.5 | 97.5 | 85.0 | 99.4 | 96.2 | 98.2 | 88.8 | 98.5 | 90.6 | No |
| CG | 77.9 | 50.9 | 93.2 | 80.3 | 93.1 | 80.0 | 67.9 | 38.4 | 99.0 | 96.8 | 70.5 | 41.4 | 55.2 | 26.7 | No |

Rf = Flat sheet experiment rejection data

Rp = Projected rejections at 85% recovery and 15 gsfd based on linear solution diffusion model.

Fouling potential was not directly determined in flat sheet experiments, but rather based on surface properties. Generally, the rate and extent of membrane fouling are greatly affected by membrane surface properties such as roughness, charge, and hydrophobicity; membranes with low surface roughness, neutral charge, and less hydrophobicity are expected to be ideal for high organic surface water treatment.

Although the relative importance of these surface properties are not fully understood and varies with source waters, for this study they were equally weighted and ranked based on the following criteria:

(1) Roughness: Relative to other flat sheets, lower is better

Score = RMS / 10

(2) Charge: Relative to other flat sheets, the least negative charge is better

Score = - ZP at pH = 8

(3) Hydrophobicity: Relative to other flat sheets, lower is better

Score = Contact Angle / 10

As Table 7 suggests, the BW30FR, LFC1, and SG membranes have surface characteristics desirable for high fouling surface water treatment (total scores of 17, 17.4, and 15, respectively), and were recommended for single element evaluation. The X-20 membrane was also included in the final list since it may perform well if the feed water primarily contains negatively charged foulants. The BE-FR membrane was not selected because of the lack of experience with this, or any of Saehan's products for drinking water in the U.S., although it showed good performance.

**Table 7. Membrane Surface Characterization Summary**

| Membrane | RMS (nm) | Score | Zeta Potential at pH 8.0 (mV) | Score | Contact Angle (°) | Score | Total Score | Acceptable Surface Characteristics (Yes/No) |
|---|---|---|---|---|---|---|---|---|
| BW30FR | 65.0 | 6.50 | -6.1 | 6.1 | 43.8 | 4.38 | 17.0 | Y |
| X-20 | 41.6 | 4.16 | -15.1 | 15.1 | 52.3 | 5.23 | 24.5 | N or Y |
| LFC1 | 67.4 | 6.74 | -5.5 | 5.5 | 51.8 | 5.18 | 17.4 | Y |
| SG | 13.1 | 1.31 | -7.6 | 7.6 | 60.9 | 6.09 | 15.0 | Y |
| BE-FR | 108.6 | 10.86 | -7.3 | 7.3 | 58.4 | 5.84 | 24.0 | N or Y |

## Recommended Membranes for Pilot Testing

### Filmtec BW30FR

This membrane is specifically designed to resist bio-film formation, one of the causes of membrane fouling during surface water treatment. The manufacturer claimed that this membrane exhibits significantly less productivity loss and better cleanability than typical thin-film composite polyamide membranes. The surface analysis revealed that the BW30FR had a relatively neutral and hydrophilic surface with medium surface roughness.

### TriSep X-20

This is a thin-film composite membrane featuring polyamide urea, specifically designed for high fouling feed waters. The manufacturer reported that the surface charge of the X-20 membrane minimizes fouling by organic substances. The charge measurement by SPA suggested a highly negatively charged surface. Thus, this membrane is expected to perform well with feed waters containing negatively charged organics and colloids. However, in general, a wide spectrum of foulants with varying degrees of surface charge exist in typical source waters. As a result, it is also possible that this membrane may suffer severe fouling, particularly through the interactions with positively charged organics.

Hydranautics LFC1: This is a low fouling composite membrane specifically designed for high fouling feed waters. According to the manufacturer, the LFC1 features neutral surface charge and hydrophilicity which significantly minimize membrane fouling. The surface analysis data suggested low negative charge and medium hydrophobicity. The surface roughness of this membrane was also estimated to be medium to high.

Osmonics SG: The SG is a thin-film composite brackish water demineralization membrane. The manufacturer claimed that the SG membrane has a smooth surface which makes it quite resistant to fouling. The AFM data suggested much smaller surface peaks compared to the other fouling resistant membranes. However, the contact angle measurements suggested this membrane was more hydrophobic than the others while it carried a low to medium surface charge.

Saehan BE-FR: This membrane is a newly developed fouling resistant membrane by a Korean manufacturer. Similar to the LFC1, neutral surface charge and enhanced hydrophilicity by new coating techniques improve fouling resistance of this membrane. The surface analysis suggested low to medium surface charge and hydrophobicity. However, its surface was much rougher than the other membranes.

Based on the results of flat sheet testing, the following four membranes were selected for field pilot evaluation:

- Filmtec BW30FR
- TriSep X-20
- Hydranautics LFC1
- Osmonics SG

# RAW WATER QUALITY

This section documents the Lake Monroe raw water quality during this study. Raw water quality in large part determines the necessary treatment requirements to process water into drinking water and to meet drinking water goals and regulations. Raw water quality characterization is the initial step in the selection, evaluation, and design of water treatment facilities.

In order to quantify the different treatment requirements, raw water characteristics and quality must be identified. For example, NOM in the raw water will generally control the coagulant dosage required to successfully treat the water. Also, TDS will generally control the level of demineralization required and the percent of water that must be processed by RO membranes.

During this study, the USGS collected grab samples biweekly and analyzed them for various general, organic, inorganic, and nutrient analytes. Further, grab samples were collected daily during pilot testing and analyzed for easily measured field parameters such as pH, turbidity, color, and alkalinity. USGS data was collected from January 2000 to August 2002, while pilot testing grab samples were collected from August 2001 to April 2003 and only when pilot testing was being conducted.

## Raw Water Characterization

The USGS conducted biweekly sampling at four points along this reach of the river. The USGS began sampling in January 2000 and continued until August 2002 (a total of 31 months). This water quality characterization defines the expected range of raw water quality parameters and correlates lab measured organic and inorganic parameters to simple field measurements.

This section is divided into four subsections — general water quality parameters, organic parameters, inorganic parameters, and nutrients. The general water quality section summarizes commonly monitored parameters such as temperature and pH. Organic parameters include organic carbon concentration, as well as organic carbon surrogates, including color and $UV_{254}$. Inorganic parameters include hardness, metals, silica, and sulfur-derived compounds such as sulfate and sulfide. The nutrients section contains information on parameters that primarily support biological activity (e.g., nitrogen, phosphorus, dissolved oxygen).

In each subsection, the averages, maximum levels, minimum levels, and standard deviations for all monitored parameters are summarized. The coefficient of variance, which illustrates the variability of the parameters, is also summarized.

During the first 18 months of sampling, east central Florida was in a severe drought. This drought was correlated to higher than average inorganic levels and lower than average organic levels. August 2001 was the start of the characteristic rainy season in east central Florida. This rainy season correlated to a sharp decrease in inorganic parameters and a sharp increase in organic parameters.

### General Water Quality Parameters

Table 8 summarizes the results of the general raw water quality parameters during the monitoring period.

The temperature ranged widely from 10.1 degrees Celsius ($^{o}$C) to 32.3$^{o}$ C with an average of 25.0$^{o}$ C. The pH ranged from 8.9 to 6.8 with an average of 7.5. Alkalinity ranged from 38 mg/L as $CaCO_3$ to 108 mg/L as $CaCO_3$. The average alkalinity was 68 mg/L as $CaCO_3$. These levels suggest that the temperature, pH, and alkalinity for the St. Johns River are considered normal compared to other central Florida surface waters.

As indicated in Table 8, the conductivity ranged from 41 Siemens per meter (S/m) to 235 S/m with an average of 124 S/m. Total dissolved solids ranged from a minimum of 278 mg/L to a maximum of 1400 mg/L. The average TDS was 753 mg/L. The standard deviation for conductivity was 49 S/m compared to a standard deviation of 281 mg/L for TDS. However, in order to make a side by side comparison of variability for these parameters, the standard deviations must be “normalized” with respect to the average. The coefficient of variance, calculated by dividing the standard deviation by the average, is a normalized standard deviation which allows this comparison. The coefficient of variance for conductivity was 0.39 compared to a coefficient of variance for TDS of 0.37, suggesting that the variability of these two parameters is similar. This is expected in that conductivity and TDS both quantify ionic concentrations in the water.

The average turbidity was 5.5 nephelometric turbidity units (NTU) and ranged from 0.9 NTU to 45.0 NTU. The total suspended solids (TSS) ranged from 1 mg/L to 140 mg/L with an average of 19 mg/L. The coefficient of variance for turbidity and TSS was 1.19 and 1.30, respectively. This suggests that the variability of these two parameters is also similar. Again, this similarity is consistent with expectations as turbidity is a surrogate measure for particles (suspended solids) in the water.

The high level of TSS and turbidity that occurs during part of the year suggests that some form of particle removal is necessary to treat the water to both drinking water standards and to RO feed water guidelines. Particle removal is required either in the form of coagulation / flocculation / sedimentation followed by media filtration or MF / UF.

**Table 8. Summary of General Raw Water Quality Parameters on the St. Johns River at Sanford**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **Temperature** | **($^oC$)** | 25.0 | 32.3 | 10.1 | 5.5 | 0.22 |
| **pH** | | 7.5 | 8.9 | 6.8 | 0.4 | 0.05 |
| **Alkalinity** | **(mg/L as $CaCO_3$)** | 68 | 108 | 38 | 17 | 0.24 |
| **Conductivity** | **(S/m)** | 124 | 235 | 41 | 49 | 0.39 |
| **Total Dissolved Solids** | **(mg/L)** | 753 | 1400 | 278 | 281 | 0.37 |
| **Turbidity** | **(NTU)** | 5.5 | 45.0 | 0.9 | 6.6 | 1.19 |
| **Total Suspended Solids** | **(mg/L)** | 19 | 140 | 1 | 24 | 1.30 |

Figure 8 shows the sampling period trend for temperature. Generally, the maximum temperature occurred between June and July and the minimum temperature occurred in January.

**Figure 8. Historical Temperature for the St. Johns River at Sanford**

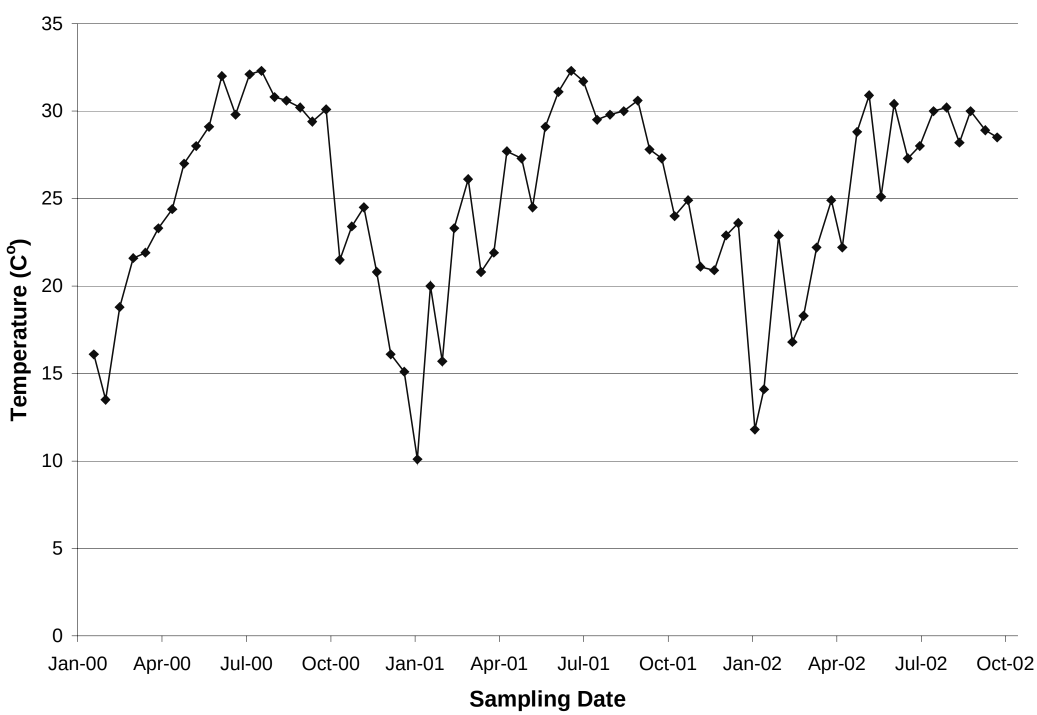


Figure 9 presents the sampling period trend for pH and alkalinity. The data suggest a positive correlation between alkalinity and pH in that both tend to increase and decrease at similar times. However, pH changes are more pronounced than those for alkalinity. As might be expected, linear regression analysis of the data indicated a poor correlation between the two parameters. Generally, maximum alkalinities occurred from May to June while minimum alkalinities occurred from September to October. Also, peaks in alkalinity correspond with high TDS. However, as with alkalinity and pH, a linear regression between alkalinity and TDS suggested a poor correlation.

**Figure 9. Historical pH and Alkalinity for the St. Johns River at Sanford**

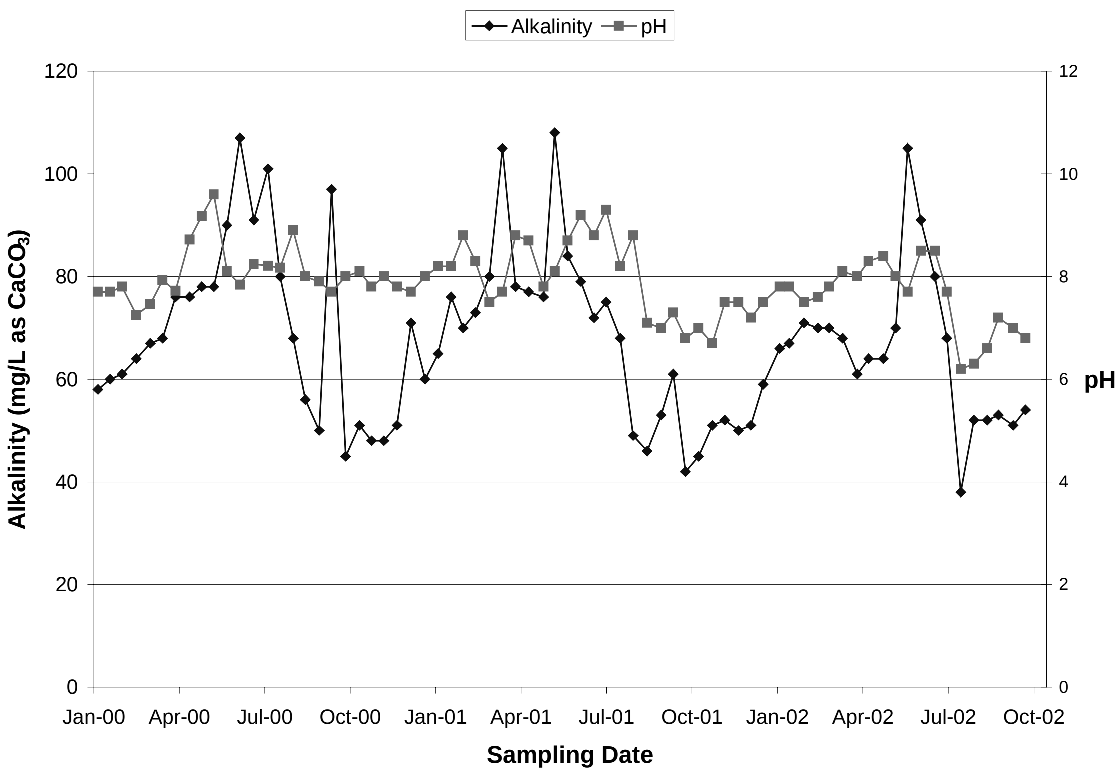
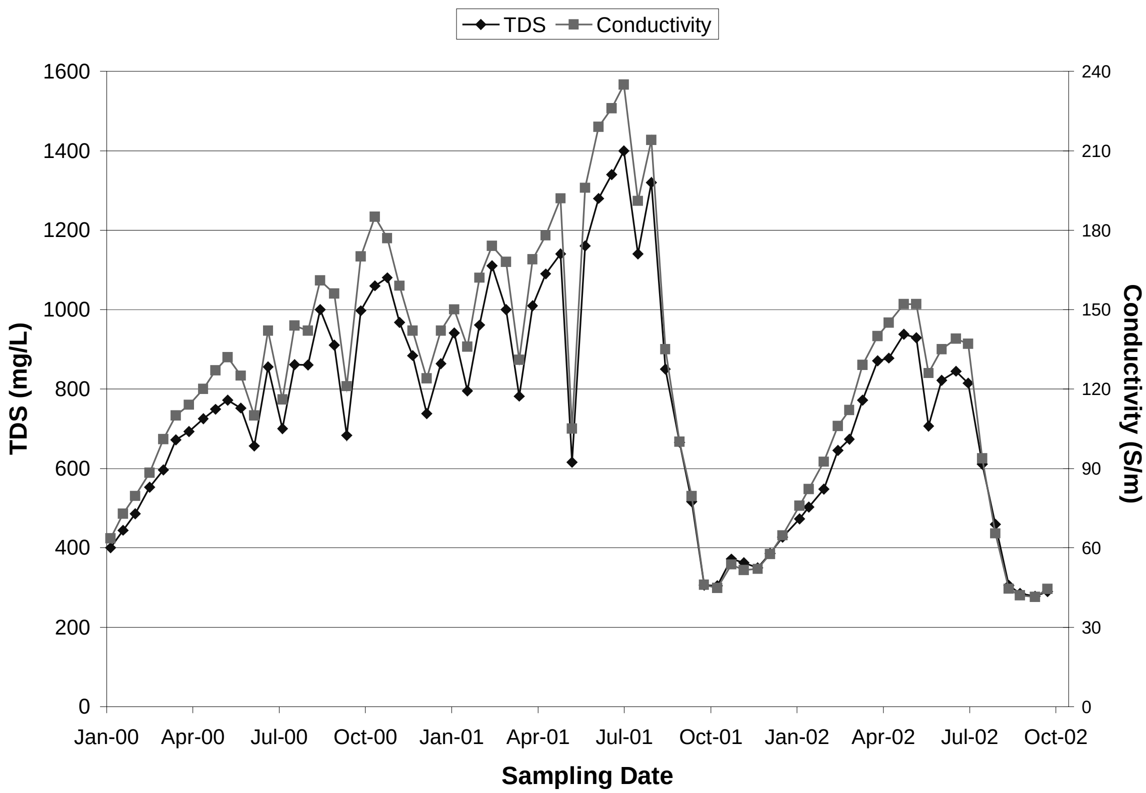



Figure 10 illustrates temporal trends for TDS and conductivity. This figure shows a pronounced increase in conductivity and TDS from January 2000 to August 2001 during the drought period on the St. Johns River. However, once the typical wet weather season began in August 2001, the conductivity decreased to normal wet weather levels. As discussed previously Figure 10 indicates a very strong correlation between TDS and conductivity for the sampling period. This is particularly true when considering how well these parameters correlated during the seasonal change in water quality shown in Figure 10.

The greater difference between the two parameters at higher levels suggests that the level of lower conductance salts (monovalent ions) increases disproportionately when TDS levels are highest.

**Figure 10. Historical Total Dissolved Solids and Conductivity for the St. Johns River at Sanford**



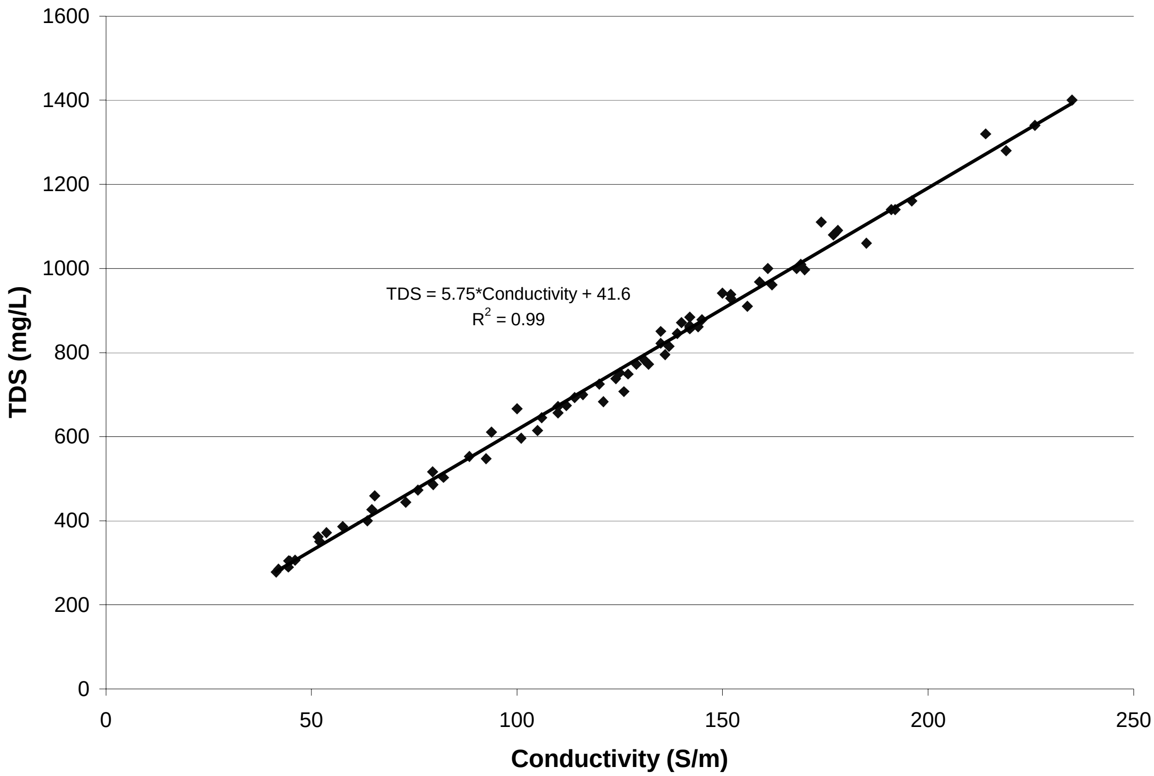

The strong correlation between TDS and conductivity was mathematically confirmed by linear regression and is illustrated in Figure 11 and Equation 1.

**Equation 1. Estimation of TDS (mg/L) based on Conductivity (S/m)**

$$TDS = 5.75 * Conductivity + 41.6$$

The R2 value of 0.99 confirms the nearly perfect correlation between these two parameters and suggests that conductivity could be used as a very accurate predictor of TDS.

**Figure 11. Approximate Total Dissolved Solids/Conductivity Relationship for the St. Johns River at Sanford**




The data presented in Figure 12 shows the temporal trend of, and relation between, TSS and turbidity at Lake Monroe. Maximum turbidity and TSS occurred during August corresponding to the start of the wet season. Generally, there was a consistent correlation between TSS and turbidity during the sampling period.

This correlation was confirmed by linear regression illustrated in Figure 13 and Equation 2.

**Equation 2. Estimation of TSS (mg/L) based on Turbidity (NTU)**

$$TSS = 3.38 * Turbidity + 0.045$$

Although the correlation between these parameters is not as strong as between TDS and conductivity, it does indicate that TSS levels can be well predicted by turbidity.

**Figure 12. Historical Total Suspended Solids and Turbidity for the St. Johns River at Sanford**

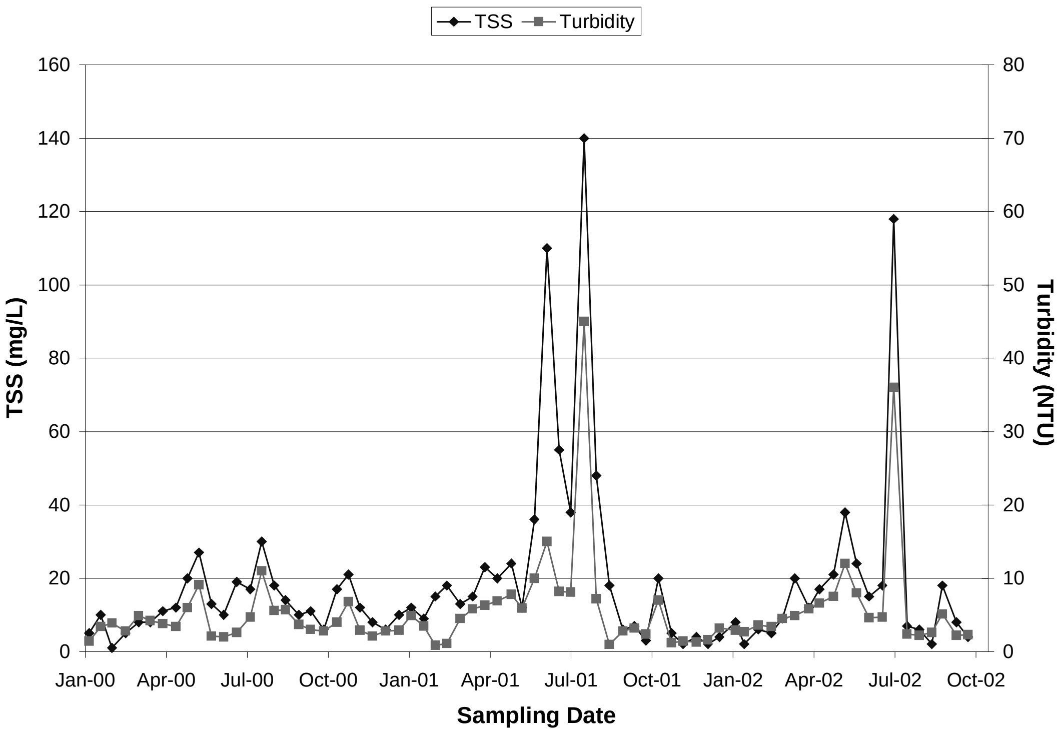
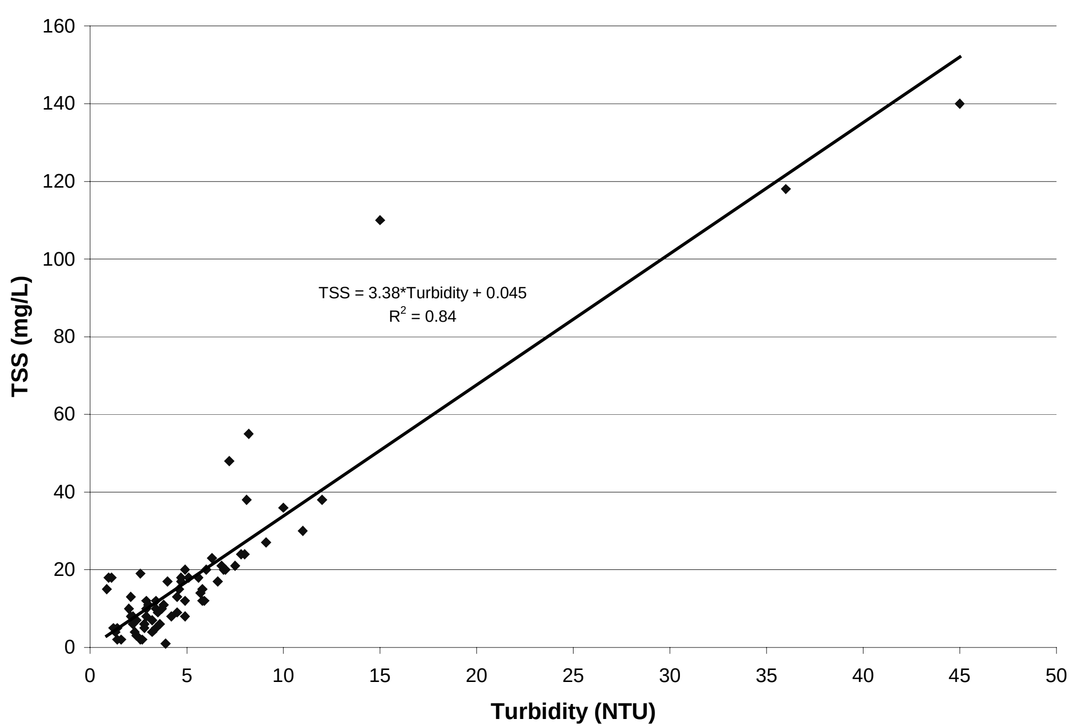



**Figure 13. Approximate Total Suspended Solids/Turbidity Relationship for the St. Johns River at Sanford**



### Organic Parameters

Table 9 summarizes the results of organic parameter monitoring at Lake Monroe. Average dissolved organic carbon (DOC) concentration during the sampling period was 20 mg/L with a range from 4 mg/L to 33 mg/L. True color ranged from 10 Pt-Co to 320 Pt-Co with an average of 119 Pt-Co. Average $UV_{254}$ absorbance was 0.81 abs/cm and ranged from 0.15 abs/cm to 1.69 abs/cm.

These data illustrate the large variations in organic levels that occur throughout the year. These characteristics required that enhanced coagulation be practiced to achieve substantial DOC and color reductions in order to meet finished water DBP and color regulations.

**Table 9. Summary of Organic Raw Water Quality Parameters on the St. Johns River at Sanford**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| DOC | (mg/L) | 20 | 33 | 4 | 7 | 0.34 |
| Color | (Pt-Co) | 119 | 320 | 10 | 84 | 0.71 |
| UV254 | (abs/cm) | 0.81 | 1.69 | 0.15 | 0.38 | 0.47 |

Temporal DOC and true color trends for Lake Monroe are presented in Figure 14. The DOC and color increased in July and August, the beginning of the wet season due to a flush of terrestrial organic matter into the St. Johns River. These increases were particularly high in August 2001 at the end of the drought and beginning of the rainy season. As data in Figure 14 suggests, DOC and true color appear to correlate for the sampling period.

This correlation was confirmed by linear regression illustrated in Figure 15 and Equation 3.

**Equation 3. Estimation of DOC (mg/L) based on True Color (Pt-Co)**

$$DOC = 0.0665 * TrueColor + 11.9$$

Although there is a correlation between these parameters, the $R^2$ factor is only 0.69, likely due to the low precision of the color readings exemplified by the grouping of the color data.

**Figure 14. Historical Dissolved Organic Carbon and True Color for the St. Johns River at Sanford**

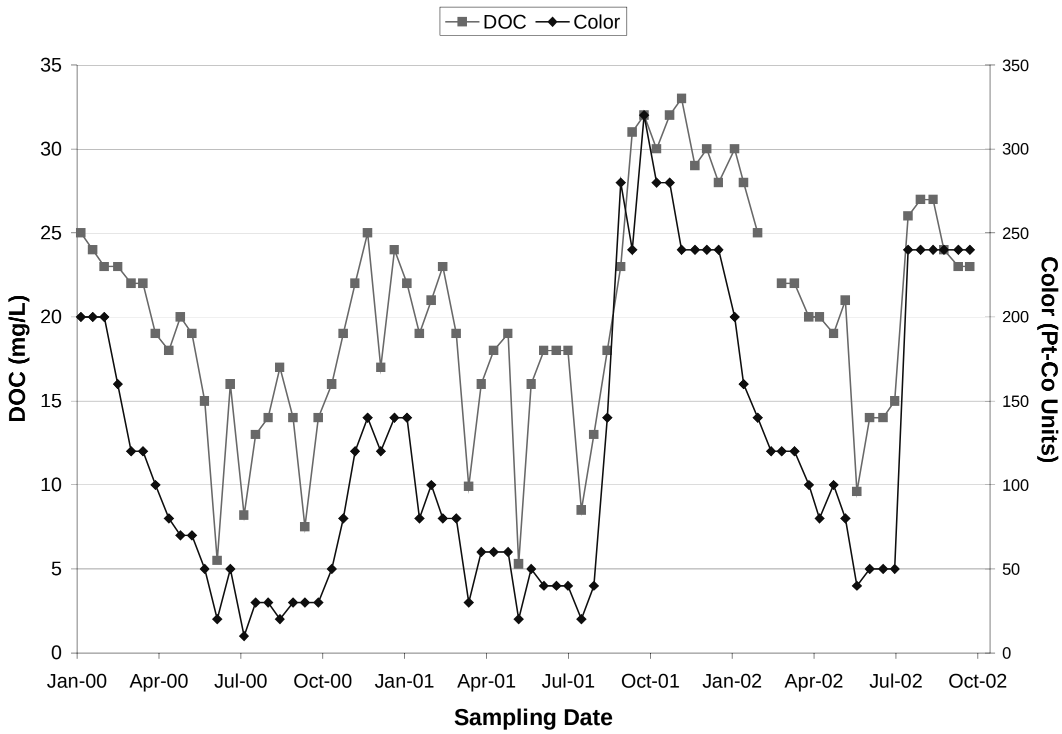
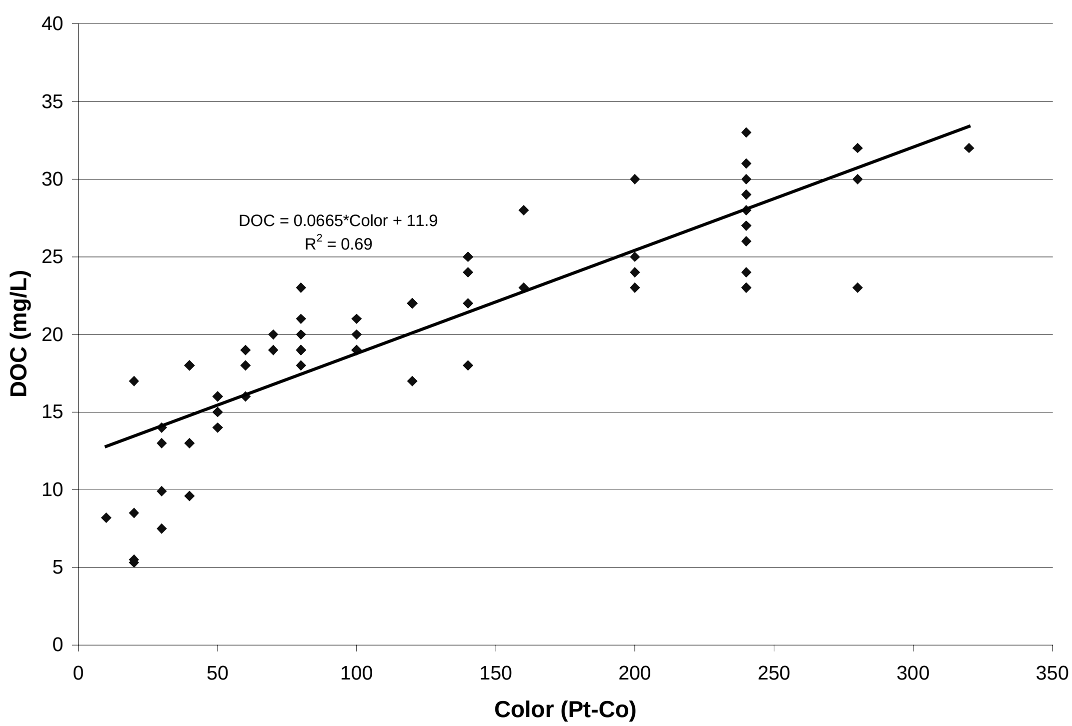
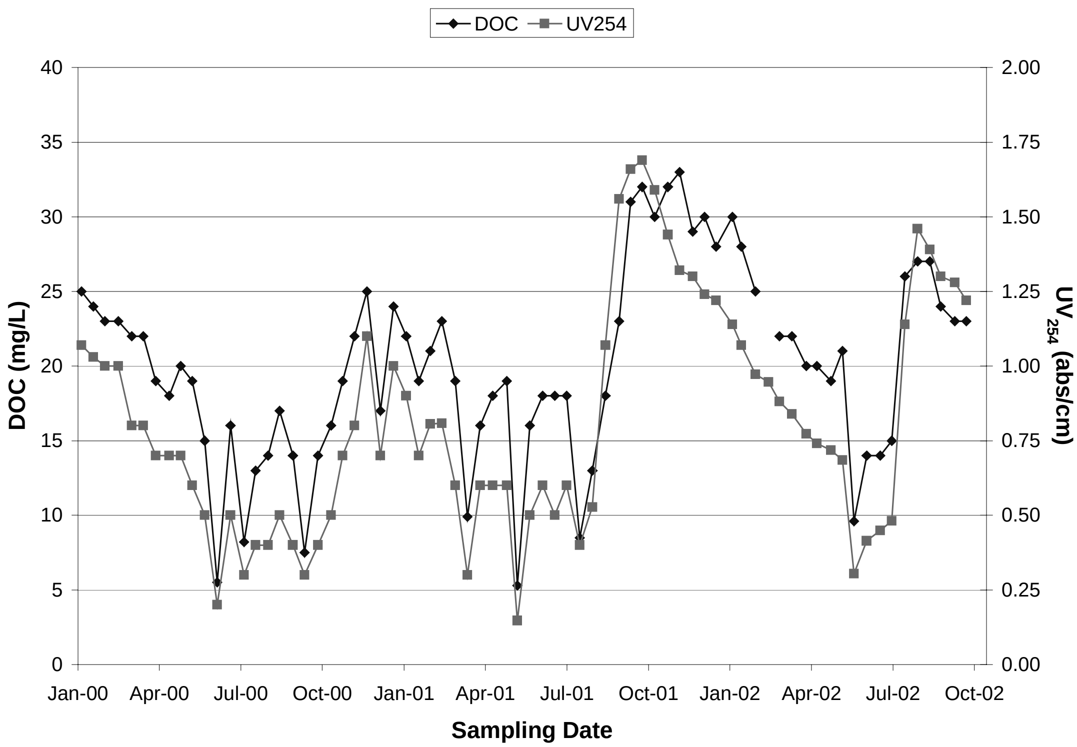



**Figure 15. Approximate Dissolved Organic Carbon/True Color Relationship for the St. Johns River at Sanford**



Temporal trends for DOC and $UV_{254}$ for Lake Monroe are shown in Figure 16. As with color and DOC, $UV_{254}$ increases in July and August, the beginning of the wet season based upon a flush of terrestrial organic matter into the St. Johns River. These increases were particularly high in August 2001 at the end of the drought and beginning of the rainy season. As Figure 16 suggests, DOC and $UV_{254}$ appear to correlate for the sampling period.

**Figure 16. Historical Dissolved Organic Carbon and $UV_{254}$ for the St. Johns River at Sanford**



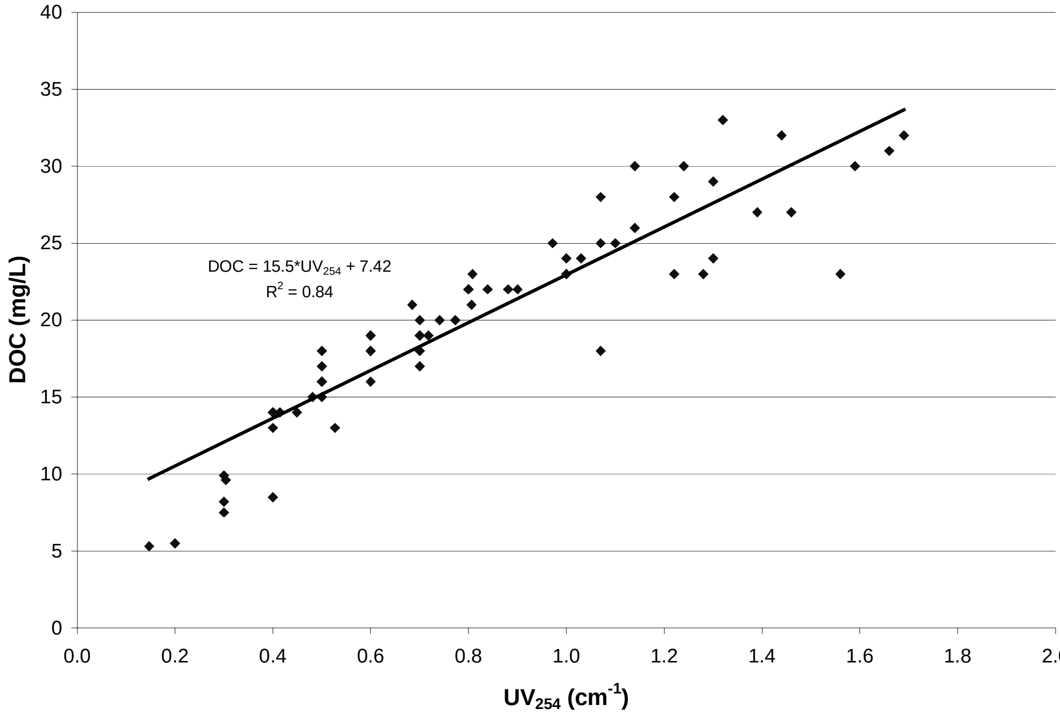

This correlation was confirmed by linear regression illustrated in Figure 17 and Equation 4.

**Equation 4. Estimation of DOC (mg/L) based on $UV_{254}$ (abs/cm)**

$$DOC = 15.5 * UV_{254} + 7.42$$

The $R^2$ for the DOC / $UV_{254}$ correlation was 0.84, while the $R^2$ for the DOC / true color correlation previously discussed was 0.69, suggesting the DOC / $UV_{254}$ correlation is more appropriate for the St. Johns River at Lake Monroe. This weaker correlation between DOC and true color again reflects the lower color measurement precision compared to $UV_{254}$ measurement precision.

**Figure 17. Approximate Dissolved Organic Carbon/$UV_{254}$ Relationship for the St. Johns River at Sanford**




## Inorganic Parameters

Table 10 summarizes the results of inorganic parameter monitoring in Lake Monroe. Several of the parameters—total barium, total calcium, total magnesium, and total strontium—were only sampled until August 12, 2001 and, therefore, only include a few samples taken after the end of the drought.

As Table 10 shows, total bromide levels ranged from 0.4 mg/L to 2.0 mg/L with an average of 1.0 mg/L. These bromide levels suggest that effective ozonation may not be possible without exceeding the regulatory bromate level of 10 micrograms per liter (µg/L).

Average total hardness was 230 mg/L as $CaCO_3$ and ranged from 390 mg/L as $CaCO_3$ to 89 mg/L as $CaCO_3$. These levels of hardness suggest that softening would be necessary. This could be done through the use of RO membranes.

Linear regression analyses were performed to develop relationships between the conductivity and the parameters listed in Table 10. Conductivity is a simple, inexpensive field analysis, and could be used to estimate the raw water quality.

**Table 10. Summary of Inorganic Raw Water Quality Parameters on the St. Johns River at Sanford**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance | Number |
|---|---|---|---|---|---|---|---|
| Barium (Dissolved) | (μg/L) | 29 | 45 | 16 | 8 | 0.28 | 72 |
| Barium (Total)* | (μg/L) | 33 | 51 | 18 | 9 | 0.27 | 46 |
| Bromide (Dissolved)** | (mg/L) | 1.0 | 2.0 | 0.4 | 0.4 | 0.38 | 66 |
| Calcium (Dissolved) | (mg/L) | 53 | 89 | 24 | 17 | 0.32 | 72 |
| Calcium (Total)* | (mg/L) | 61 | 87 | 31 | 14 | 0.23 | 45 |
| Chloride (Dissolved) | (mg/L) | 285 | 560 | 81 | 122 | 0.43 | 72 |
| Hardness (Total) | (mg/L as $CaCO_3$) | 230 | 390 | 89 | 76 | 0.33 | 65 |
| Iron (Dissolved) | (μg/L) | 140 | 518 | 3 | 158 | 1.13 | 72 |
| Iron (Total) | (μg/L) | 306 | 1400 | 55 | 257 | 0.84 | 72 |
| Magnesium (Dissolved) | (mg/L) | 22.3 | 40.0 | 6.9 | 8.4 | 0.38 | 65 |
| Magnesium (Total)* | (mg/L) | 27 | 39 | 14 | 6 | 0.23 | 39 |
| Potassium (Dissolved) | (mg/L) | 7.1 | 12.0 | 3.8 | 2.2 | 0.31 | 61 |
| Silica (Dissolved) | (mg/L) | 5.0 | 12.0 | 0.1 | 3.1 | 0.62 | 72 |
| Sodium (Dissolved) | (mg/L) | 158 | 300 | 44 | 71 | 0.45 | 60 |
| Strontium (Dissolved) | (μg/L) | 1300 | 2400 | 550 | 479 | 0.37 | 72 |
| Strontium (Total)* | (μg/L) | 1495 | 2300 | 690 | 444 | 0.30 | 45 |
| Sulfate (Dissolved) | (mg/L) | 90 | 200 | 8 | 51 | 0.56 | 72 |
| Sulfide (Total) | (mg/L as S) | 1 | 3 | < 1 | 1 | 0.39 | 49 |

*** Only sampled until August 12, 2001 (one year less than other listed parameters)**

**** Several suspect bromide data points were omitted**

Table 11 summarizes the linear regression results for each of the listed parameters. Table 11 also presents the regression coefficients for the analyses. Regression coefficients less than 0.8 are shaded dark gray and suggest a poor correlation exists between conductivity and the parameter, while coefficients between 0.80 and 0.90 are shaded a lighter gray and suggest a questionable correlation. Parameters that are not shaded have a coefficient above 0.90 and suggest a good correlation between conductivity and the parameter.

As Table 11 suggests, dissolved chloride, dissolved magnesium, and dissolved sodium all had regression coefficients of 0.99 suggesting a good correlation for estimating these parameters based on conductivity. Dissolved calcium, total hardness, total magnesium, total and dissolved strontium, and sulfate had regression coefficients higher than 0.90 suggesting a good correlation with conductivity. Total barium, dissolved barium, bromide, total calcium, and potassium had regression coefficients between 0.8 and 0.9 suggesting a questionable correlation. Silica, dissolved iron, and total iron had regression coefficients less than 0.8 suggesting poor or no linear correlation exists between these parameters and conductivity.

**Table 11. Summary of Linear Regression Analyses for Estimating Raw Water Inorganic Parameters Based on Raw Water Conductivity on the St. Johns River at Sanford**

| Parameter | Units | Equation* | $R^2$ |
|---|---|---|---|
| Barium (Dissolved) | (µg/L) | 0.16*Conductivity + 9.3 | 0.87 |
| Barium (Total) | (µg/L) | 0.20*Conductivity + 4.7 | 0.88 |
| Bromide (Dissolved)** | (mg/L) | 0.0071*Conductivity + 0.16 | 0.82 |
| Calcium (Dissolved) | (mg/L) | 0.33*Conductivity + 12 | 0.91 |
| Calcium (Total) | (mg/L) | 0.30*Conductivity + 17 | 0.81 |
| Chloride (Dissolved) | (mg/L) | 2.5*Conductivity - 23 | 0.99 |
| Hardness (Total) | (mg/L as $CaCO_3$) | 1.5*Conductivity + 35 | 0.95 |
| Iron (Dissolved) | (mg/L) | -2.7*Conductivity + 471 | 0.68 |
| Iron (Total) | (mg/L) | -2.0*Conductivity + 548 | 0.14 |
| Magnesium (Dissolved) | (mg/L) | 0.17*Conductivity + 0.27 | 0.99 |
| Magnesium (Total) | (mg/L) | 0.17*Conductivity + 1.6 | 0.96 |
| Potassium (Dissolved) | (mg/L) | 0.040*Conductivity + 2.0 | 0.89 |
| Silica (Dissolved) | (mg/L) | -0.019*Conductivity + 7.4 | 0.09 |
| Sodium (Dissolved) | (mg/L) | 1.4*Conductivity - 17 | 0.99 |
| Strontium (Dissolved) | (µg/L) | 9.5*Conductivity + 122 | 0.94 |
| Strontium (Total) | (µg/L) | 10*Conductivity + 24 | 0.90 |
| Sulfate (Dissolved) | (mg/L) | 1.0*Conductivity - 35 | 0.94 |
| Sulfide (Total) | (mg/L as S) | NA*** | NA |

*** Conductivity is in S/m**

**** Several suspect bromide data points were ommitted**

***** 49% of total sulfide results were below detection limits**

## Nutrients

Table 12 summarizes results of nutrient level monitoring for Lake Monroe water, including ammonia, chlorophyll a, nitrate and nitrite, orthophosphate and phosphate, and dissolved oxygen.

As Table 12 illustrates, total ammonia levels ranged between 0.81 mg/L as N to < 0.01 mg/L as N (BDL) with an average concentration of 0.09 mg/L as N. Chlorophyll a ranged from 120.0 µg/L to < 0.1 µg/L with an average of 28.2 µg/L. Dissolved oxygen ranged from a minimum of 1.7 mg/L to a maximum of 13.8 mg/L with an average of 7.4 mg/L. Average total phosphorus was 0.09 and ranged from < 0.03 mg/L to 0.38 mg/L. These levels suggest sufficient inorganic nutrients exist to promote biological activity and membrane biofouling, with ammonia serving as the limiting of the two nutrients. However, when chloramination is practiced, the ammonia and free chlorine would react and be biologically unavailable.

**Table 12. Summary of Nutrient Raw Water Quality Parameters on the St. Johns River at Sanford**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| Ammonia (Dissolved) | (mg/L as N) | 0.05 | 0.33 | < 0.01 | 0.07 | 1.27 |
| Ammonia (Total) | (mg/L as N) | 0.09 | 0.81 | < 0.01 | 0.12 | 1.30 |
| Ammonia plus Organic (Total) | (mg/L as N) | 1.7 | 2.5 | 1.1 | 0.3 | 0.20 |
| Chlorophyll a (μg/L) | (μg/L) | 28.2 | 120.0 | < 0.1 | 27.9 | 0.99 |
| Nitrite (Dissolved) | (mg/L as N) | 0.02 | 0.20 | < 0.01 | 0.03 | 1.60 |
| Nitrite (Total) | (mg/L as N) | 0.02 | 0.21 | < 0.01 | 0.04 | 2.11 |
| $NO_2^- + NO_3^-$ (Dissolved) | (mg/L as N) | 0.08 | 0.28 | < 0.02 | 0.08 | 0.99 |
| $NO_2^- + NO_3^-$ (Total) | (mg/L as N) | 0.07 | 0.28 | < 0.02 | 0.09 | 1.23 |
| Orthophosphate (Dissolved) | (mg/L as P) | 0.03 | 0.21 | < 0.01 | 0.05 | 1.59 |
| Orthophosphate (Total) | (mg/L as P) | 0.04 | 0.22 | < 0.01 | 0.05 | 1.18 |
| Oxygen (Dissolved) | (mg/L) | 7.4 | 13.8 | 1.7 | 2.5 | 0.34 |
| Phosphorus (Total) | (mg/L) | 0.09 | 0.38 | < 0.03 | 0.06 | 0.67 |

## Raw Water Pilot Data Summary

Raw water samples were collected daily at the pilot plant site to provide additional characterization of the raw water quality during the study period (August 2001 to April 2003). Raw water samples taken at the pilot site were only taken when testing was being conducted.

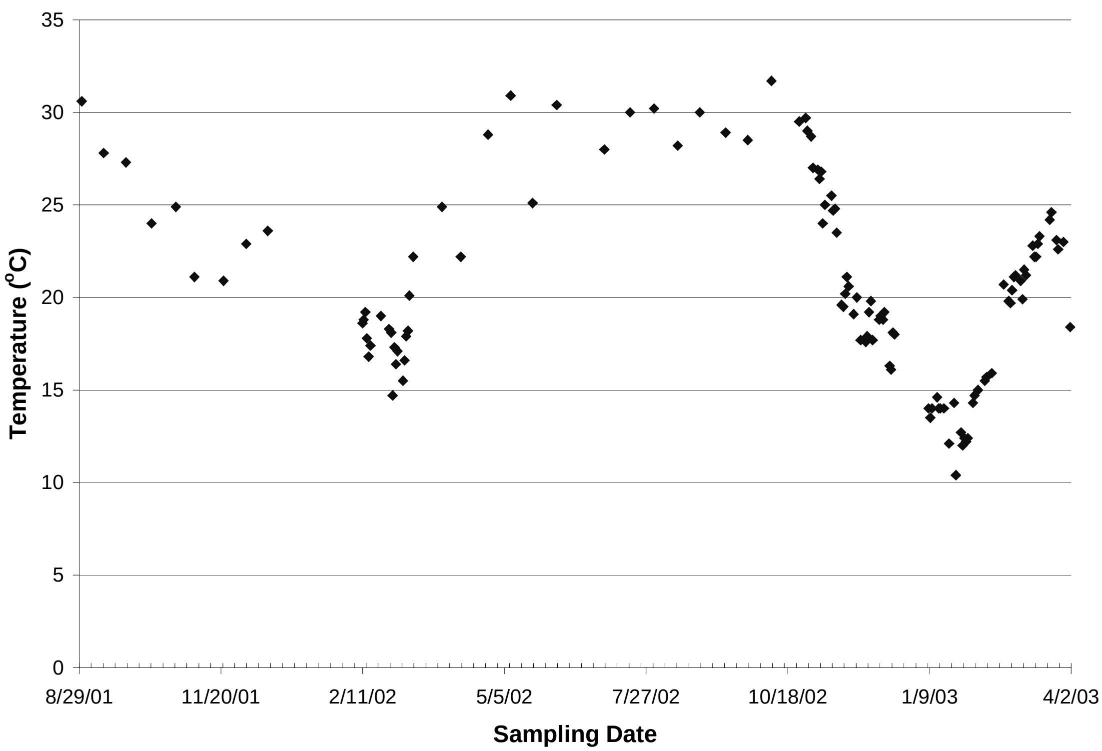
Table 13 summarizes the average, maximum, and minimum levels for temperature, pH, alkalinity, turbidity, conductivity, apparent color, and $UV_{254}$ for the duration of field testing. Table 13 also presents the standard deviation and coefficient of variance for each parameter to illustrate the water quality variability.

**Table 13. Summary of Raw Water Field Analysis on the St. Johns River at Sanford**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| Temperature | ($^oC$) | 24.3 | 31.7 | 10.4 | 5.1 | 0.21 |
| pH | | 7.1 | 8.7 | 5.8 | 0.3 | 0.05 |
| Alkalinity | (mg/L as $CaCO_3$) | 59 | 115 | 19 | 14 | 0.24 |
| Turbidity | (NTU) | 4.88 | 58.60 | 0.82 | 2.05 | 0.42 |
| Conductivity | (S/m) | 78.5 | 185.9 | 31.3 | 38.3 | 0.49 |
| Apparent Color | (Pt-Co) | 284 | > 520 | 115 | 91 | 0.32 |
| $UV_{254}$ | (abs/cm) | 1.006 | 1.715 | 0.205 | 0.347 | 0.35 |

Figure 18 illustrates the field testing grab sample data collected during pilot testing. As the figure suggests, minimum temperatures occurred during February 2002 and January 2003. As Table 13 suggests, the average temperature during field testing was 24.3° C with a maximum of 31.7° C and a minimum of 10.4° C. This wide swing (>20° C) has implications for RO system design and operation as both the feed pressure and salt rejection of the RO membranes are affected by temperature.

**Figure 18. Raw Water Temperature Daily Grab Sample Data**




As shown in Table 13, during field testing, the average pH was 7.1 with a maximum of 8.7 and a minimum of 5.8. The alkalinity ranged from 115 mg/L as $CaCO_3$ to 19 mg/L as $CaCO_3$ with an average of 59 mg/L as a $CaCO_3$. Figure 19 illustrates the field testing alkalinity and pH. As the figure suggests, alkalinity was lowest during January 2003.

Figure 20 illustrates the raw water turbidity during field testing from August 29, 2001 to April 4, 2003. As Table 13 suggests, the average raw water turbidity was 4.88 NTU with a maximum turbidity of 58.6 NTU, occurring during a heavy rain event. Generally, during testing, most raw water turbidity readings were below 10 NTU.

**Figure 19. Raw Water Alkalinity and pH Daily Grab Sample Data**

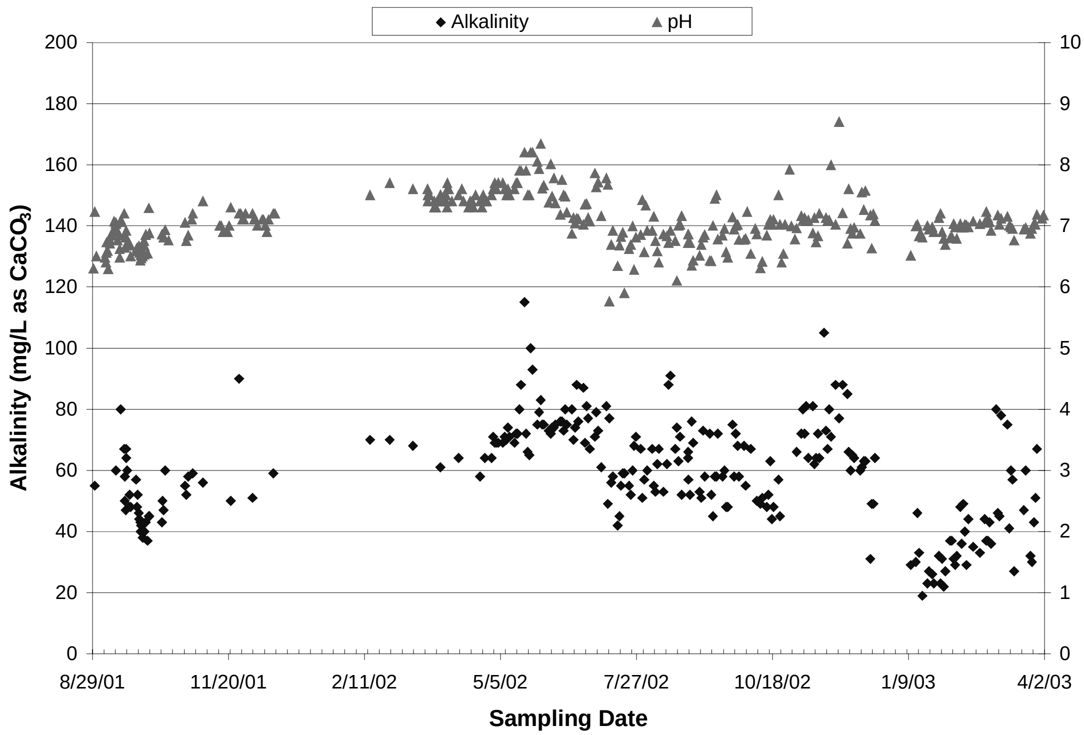
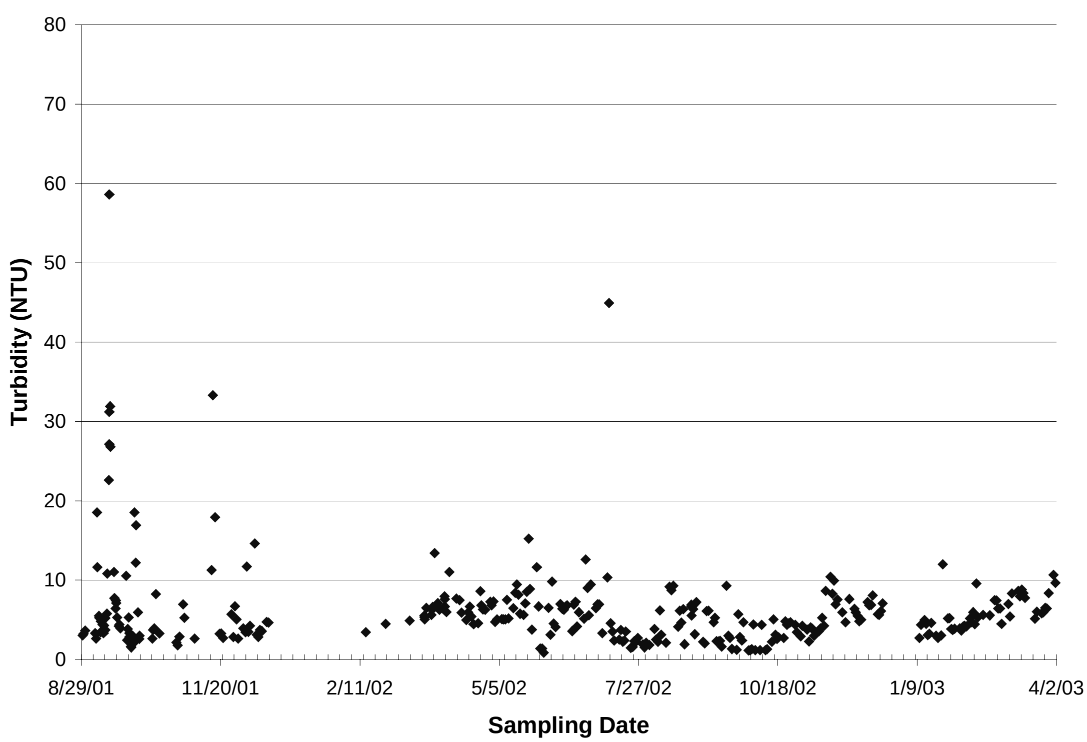



**Figure 20. Raw Water Turbidity Daily Grab Sample Data**



Conductivity, a surrogate for TDS (and other inorganic parameters illustrated in Table 11), was monitored throughout the study. Figure 21 summarizes the raw water conductivity data collected during pilot field analysis. As Table 13 suggests, the average conductivity for the duration of the study 78.5 S/m and ranged from 185.9 S/m to 31.3 S/m. Based on Equation 1, these conductivity values suggest an average raw water TDS of 479 mg/L, maximum of 1077 mg/L and minimum of 216 mg/L.

**Figure 21. Raw Water Conductivity Daily Grab Sample Data**

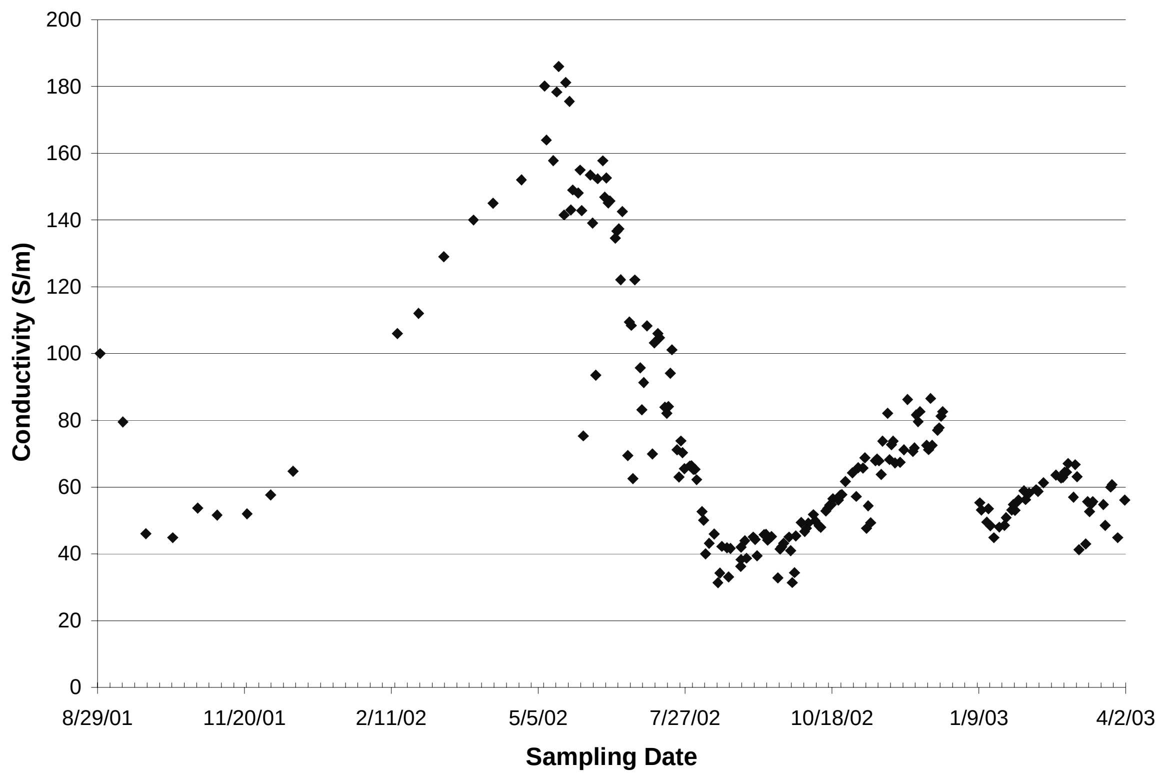
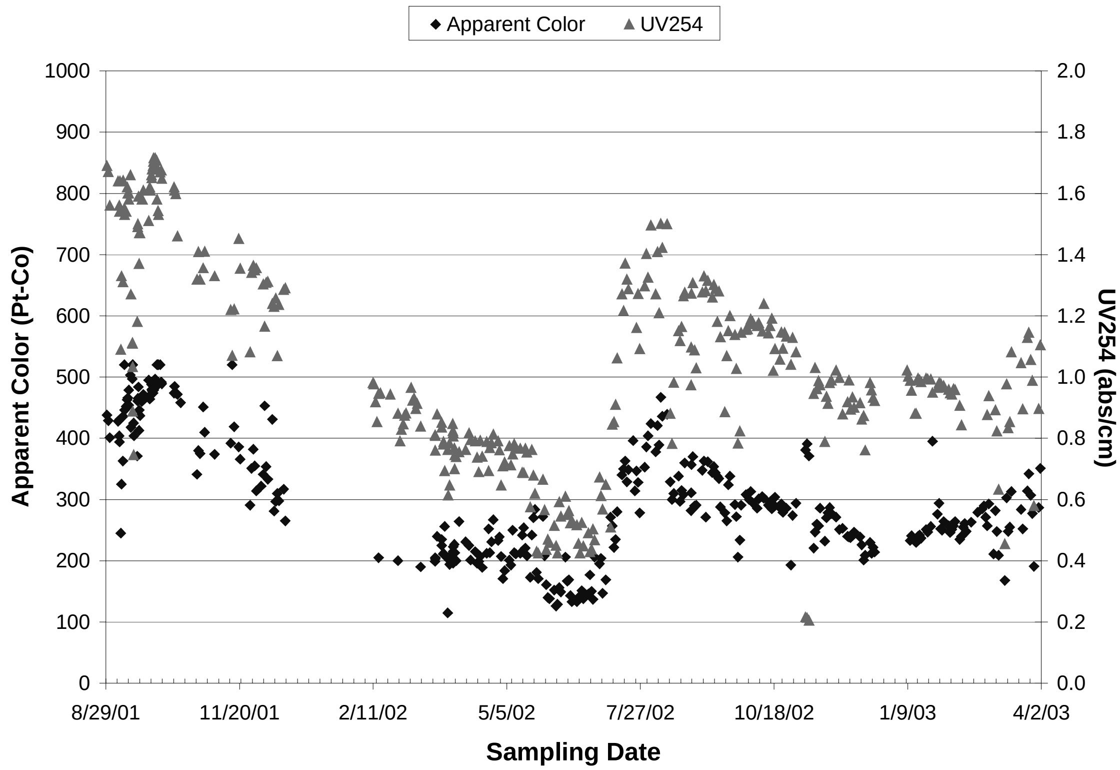



Figure 22 summarizes apparent color and $UV_{254}$, monitored as surrogates for natural organic levels or DOC. As Table 13 suggests, the average raw water apparent color was 284 Pt-Co during the study with a maximum of greater than 520 Pt-Co which occurred several times due to rain events. The minimum color was 115 Pt-Co.

Average $UV_{254}$ absorbance levels during field testing were 1.006 abs/cm with a maximum of 1.715 abs/cm and a minimum of 0.205 abs/cm.

**Figure 22. Raw Water Apparent Color Daily Grab Sample Data**



# PILOT TESTING

After completing the pilot design and construction in August 2001, the pilot testing program began. The pilot testing program was conducted over a 19 month period, beginning in September 2001 and continuing through April 2003. During pilot testing, a number of treatment combinations—pretreatment systems followed by RO membranes—were tested.

As discussed previously, water from the St. Johns River is seasonally brackish with TDS levels that can exceed 1,200 mg/L. Therefore, desalting with RO membranes is required to achieve potable water standards. However, for the RO membranes to perform properly, the high levels of raw water organics and particles must be removed prior to membrane treatment.

The pretreatment alternatives tested in this study were selected by the project stakeholders. The three pretreatments selected included high-rate clarification with dual media filtration, Actiflo and SuperP, and membrane ultrafiltration.

The different pretreatment system configurations included the following:

- Actiflo ballasted sand clarifier followed by dual media filtration
- SuperP blanket clarifier followed by dual media filtration
- Zenon ultrafilter operating in direct filtration mode (coagulation in tank)
- Zenon ultrafilter operating as a filter after clarification (following Actiflo)
- Memcor microfilter operating as a filter after clarification (following Actiflo)

Each pretreatment alternative used ferric sulfate for coagulation of turbidity and NOM.

Pretreatment testing with these technologies was conducted throughout the entire pilot testing program. The testing was divided into these phases: Phase 1A, 1B, 2A, 2B, and 3. The pretreatment systems were evaluated based on their ability to remove organics, turbidity, and pathogens. In addition, the pretreatment systems were evaluated based on process stability and operability.

It is important to note that in each phase, these pretreatments provided treated water to RO membranes for desalting. Therefore, these pretreatments were also evaluated on their ability to provide a suitable feed water to the RO desalting membranes. The pretreatments were evaluated based on changes in RO performance parameters, including normalized product flow (NPF), differential pressure coefficient (DPC) and normalized salt passage (NSP).[4]

The NPF, DPC, and NSP were also used to evaluate the suitability of the membranes in desalting this pretreated surface water. The RO membrane evaluation was conducted using single element, low recovery, and high recovery testing systems. The single element RO units were tested to evaluate different membrane operating conditions. The high recovery membrane unit was used as a final step in testing to gather membrane system design data.

The RO membranes tested included the following:

- Osmonics SG Brackish Water Membrane
- Hydranautics Low Fouling Composite (LFC1) Membrane
- TriSep X-20 Membrane
- Filmtec BW30FR Membrane
- Filmtec BW30LE Membrane[5]

The first four of the above membranes were selected from flat sheet testing conducted by UCF. The fifth membrane was a conventional, low energy, non-fouling resistant membrane. This membrane was tested to determine if such a membrane type could be cost effectively operated on the pretreated Lake Monroe water.

The membrane systems were operated to evaluate recovery, flux, cleaning types and frequencies, as well as characterize the permeate and concentrate water qualities. Due to the high organic levels in this water, different biofouling control methods had to be assessed. Biological fouling control was evaluated using chloramines as well as a bioinhibitor, BioGuard. BioGuard is the only National Sanitation Foundation (NSF)-approved product

[4] Each of these parameters will be defined in a subsequent section of the report.

[5] The BW30LE membrane is a conventional (non-fouling resistant membrane) having lower cost and energy consumption compared to the other fouling resistant membranes. This membrane was not selected during the *Flat Sheet Membrane Screening and Selection* previously discussed. Testing was performed on this membrane to determine if such a membrane type could be cost effectively operated on the pretreated Lake Monroe water.

currently available for use with drinking water systems to inhibit RO membrane biofouling.

The following sections present the pilot data collected during this study. The first section reviews the pilot timeline and phases and summarizes the pilot process and combinations used in these testing phases. The next two sections review and summarize the pretreatment and RO membrane results, respectively.

# PILOT TESTING TIMELINE

The pilot testing program began in September 2001 and was completed in April 2003. The program consisted of pretreatment evaluation, single element RO membrane evaluation, and high recovery RO membrane evaluation.

Pilot testing was separated into five phases each with specific goals, purposes, and testing plans.

**Phase 1A**

Phase 1A testing began in August 2001 and ended in December 2001. This phase, the initial pretreatment evaluation, tested three technologies to assess:

- the effectiveness of each technology to provide potable water after filtration (i.e., if membranes were not used when the source water is fresh, not brackish); and
- the effectiveness of each technology to sufficiently pretreat the water for further treatment by RO for dissolved organics and salt removal (i.e., when the source water is brackish).

The Phase 1A testing was the only phase in which all three pretreatment technologies were tested side-by-side.

The Phase 1A intent was to select the best pretreatment which would then be used for the remaining testing phases with the RO membranes. However, all three pretreatment processes worked well in Phase 1A. Therefore, based on this result, all three pretreatment processes were used in subsequent phases.

Pretreatment testing began August 2001. The three pretreatment processes tested concurrently were:

- Actiflo ballasted sand clarification followed by dual media filtration

- SuperP floc blanket clarification followed by dual media filtration
- Zenon UF operating in direct filtration mode (coagulation and filtration occurring in a single tank)

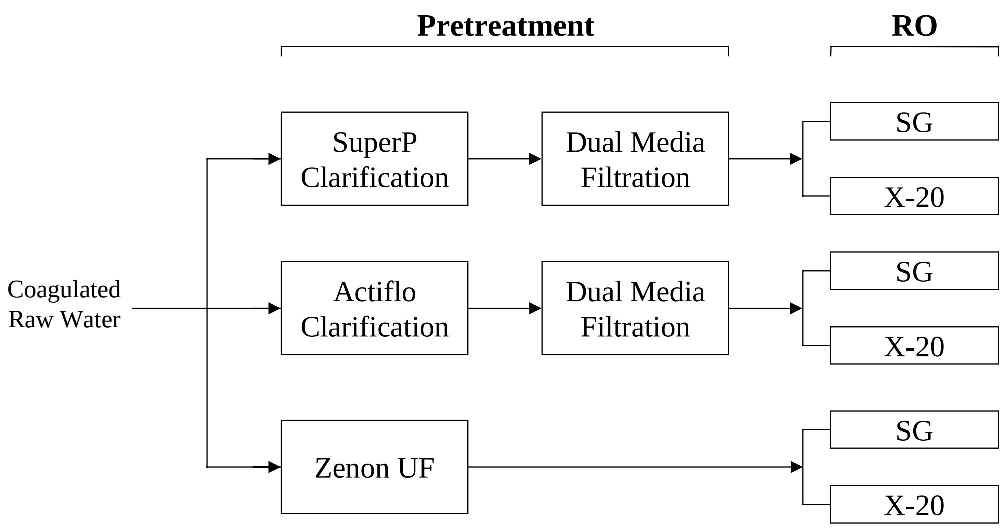
Each of these pretreatment alternatives utilized ferric sulfate for coagulation of turbidity and NOM.

RO testing began November 9, 2001, once pretreatment system operation was optimized and the pretreatment systems had been evaluated based on their ability to produce potable water without membrane polishing. The following two membrane types[6] were operated as single elements on effluent from each pretreatment train:

- Osmonics SG
- TriSep X-20

Figure 23 illustrates the process layout for the Phase 1A testing.

**Figure 23. Phase 1A Process Block Diagram**




## Phase 1B

Phase 1B testing began February 2002 and ended in July 2002. Based on Phase 1A results, SuperP / granular media filtration and Zenon UF were selected for Phase 1B testing. Actiflo was not evaluated during Phase 1B but was selected for Phase 2 testing.

[6] These types represented two of the four types selected from prior flat sheet testing

This was done based on equipment availability. RO testing began April 10, 2002, once each pretreatment system was optimized.

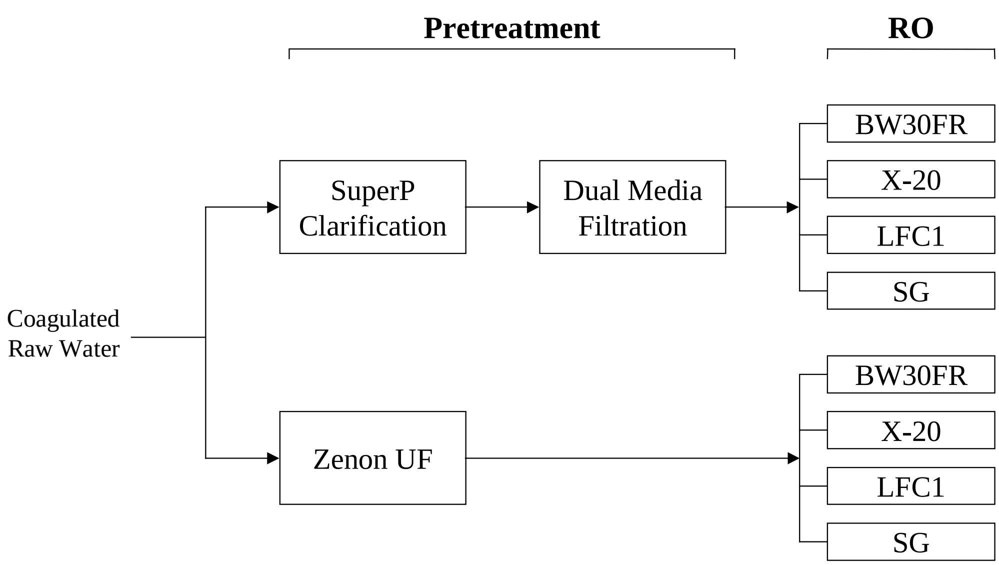
Pretreatment performance was evaluated using the same criteria as in Phase 1A. During this phase, pretreatment effluent fed each of the following four membrane types:

- Osmonics SG
- Filmtec BW30FR
- TriSep X-20
- Hydranautics LFC1

The primary goal of Phase 1B testing was to compare performance of each RO membrane type to select the best performing RO membrane for Phase 2A and 2B. An additional Phase 1B goal was to assess two methods of biological fouling control, chloramines and BioGuard.

Figure 24 illustrates the Phase 1B testing layout.

**Figure 24. Phase 1B Process Block Diagram**




## Phase 2A

Phase 2A began in July 2002 and ended in September 2002. This phase continued single element testing and included operation of the large RO unit, consisting of a high and three low recovery systems. Based on Phase 1B results, the Filmtec BW30FR was selected for high recovery system testing, while the TriSep X-20, Osmonics SG, and Filmtec BW30LE were selected for low recovery system testing.

Phase 2A began at the end of the dry season, characterized by lower than average NOM levels and higher than average TDS levels. However, the bulk of Phase 2A testing was conducted during the rainy season, characterized by higher than average NOM levels and lower than average TDS.

As with the previous phases, the pretreatment systems were evaluated based on both pretreatment and RO performance. During this phase, the SuperP / granular media filter and Zenon UF operated continuously, and effluent from each pretreatment fed the following four fouling resistant membranes operated as single elements:

- Osmonics SG
- Filmtec BW30FR
- TriSep X-20
- Hydranautics LFC1

Further, effluent from the SuperP / dual media filter pretreatment fed the high recovery RO pilot unit. The Filmtec BW30FR was operated in the high recovery system in a 2-1 array, with each stage containing six elements per vessel. Also, low recovery membrane testing was conducted. The following membranes were tested in the low recovery system:

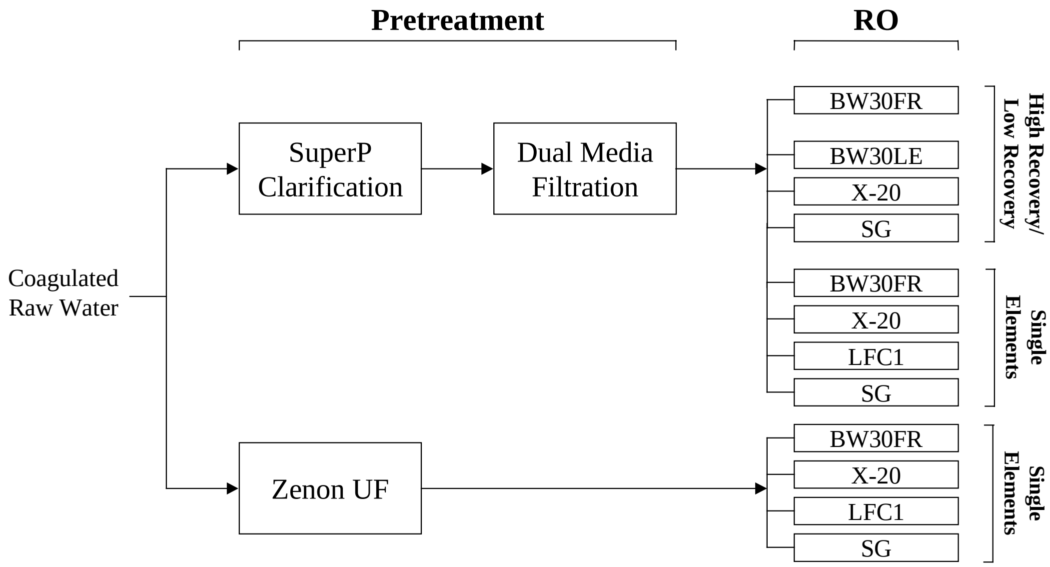
- Osmonics SG
- TriSep X-20
- Filmtec BW30LE

Low recovery system testing involved evaluating each element type using single pass three element vessels, which could then be compared to the lead vessel performance in the high recovery system. The Hydranautics LFC1 was excluded from testing due to the poor performance observed during the previous phases.

The Filmtec BW30LE, a conventional (non-fouling resistant) membrane having lower cost and energy consumption, was evaluated instead, to determine if such a membrane type could be cost effectively operated on the pretreated Lake Monroe water.

Figure 25 illustrates the layout for the Phase 2A testing.

**Figure 25. Phase 2A Process Block Diagram**




## Phase 2B

Phase 2B began in September 2002 and ended in December 2002. During this phase, Actiflo clarification was replaced by SuperP clarification (both followed by dual media filtration) as the pretreatment for the high recovery RO unit. The Zenon UF operation was evaluated in place of the dual media filters treating clarified water from the Actiflo as well.

Phase 2B was conducted exclusively during the rainy season characterized by higher than average NOM, color, and $UV_{254}$ levels and lower than average TDS and conductivity levels.

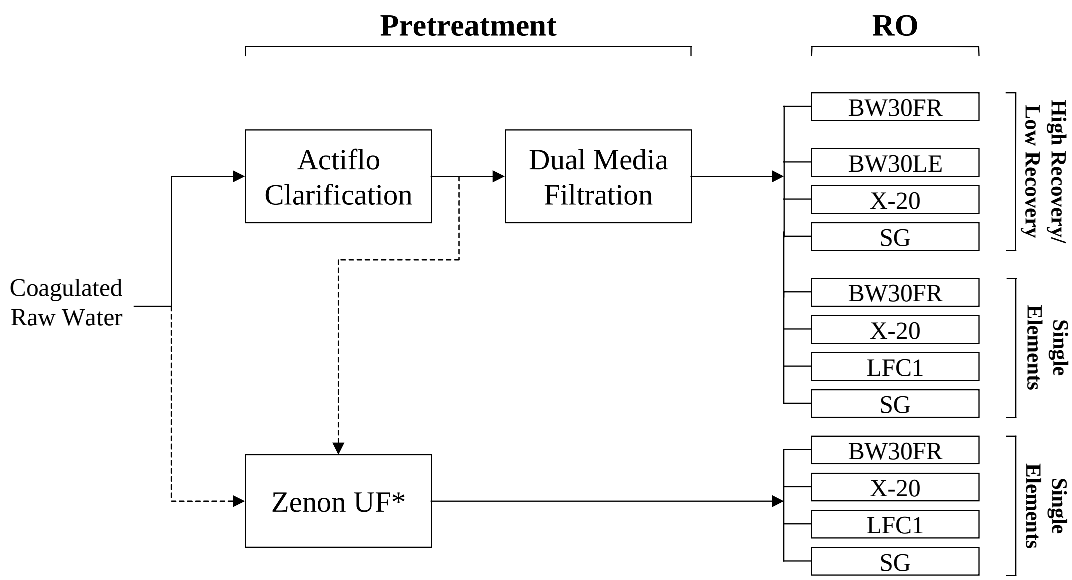
As with the previous phases, the pretreatment systems were evaluated based on both pretreatment and RO performance. During this phase, the Actiflo dual media filter and Zenon ultrafilter continued to feed the following single element membranes:

- Osmonics SG
- Filmtec BW30FR
- TriSep X-20
- Hydranautics LFC1

Phase 2B testing included further operation of the large RO unit using Actiflo clarified / filtered water. Operation of the Filmtec BW30FR element was continued in the high recovery system, with Osmonics SG, TriSep X-20, and Filmtec BW30LE elements in the low recovery system. The X-20 was replaced once during Phase 2B to evaluate fouling mechanisms in the system. Further, SG testing was discontinued based on poor membrane performance.

Figure 26 illustrates the layout for the Phase 2B testing.

**Figure 26. Phase 2B Process Block Diagram**




*In this phase, Zenon UF was tested as a direct filter pretreatment and as an alternative for dual media filtration

## Phase 3

Phase 3, conducted as a follow up to Phase 2B, began in January 2003 and ended in April 2003. During Phases 2A and 2B, the high and low recovery membrane systems fouled rapidly and to a much greater degree than the single elements. The rapid fouling was not considered characteristic of performance on properly pretreated water and was attributed to the following two factors:

(1) Lack of biofouling control by BioGuard

(2) Poor chemical clean efficiency

Phase 3 was therefore conducted to determine RO performance at high recovery on properly pretreated feed water using chloramines rather than BioGuard for biofouling control. Further, chemical clean efficiency was evaluated based on different chemicals and pH ranges. Finally, this phase was intended to develop full scale design and cost data.

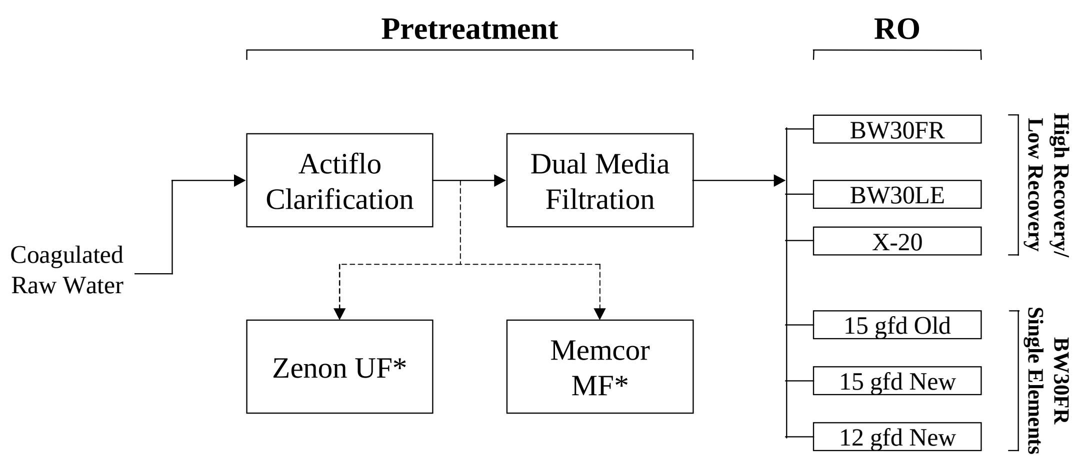
Additionally, verification testing was conducted with the Zenon UF system operating on Actiflo clarified water. During this testing, this Zenon permeate did not feed the RO system.

The Actiflo-dual media filter pretreatment continued to feed the high recovery RO unit. High and low recovery system testing continued using the Filmtec BW30FR, TriSep X-20, and Filmtec BW30LE elements. Further, Actiflo-dual media filter pretreatment system fed the single elements. However, two single elements were replaced with new BW30FR elements to evaluate RO performance at higher fluxes.

Phase 3 was conducted exclusively during what should have been the dry season. However, due to heavy rains throughout this phase, Lake Monroe had higher than average NOM levels and lower than average TDS.

Figure 27 illustrates the Phase 3 testing layout.

**Figure 27. Phase 3 Process Block Diagram**




*In this phase, the Zenon UF and Memcor MF were tested as an alternative to dual media filtration

# PRETREATMENT TESTING

As discussed earlier, the raw for the St. Johns River at Lake Monroe is seasonally brackish with TDS exceeding 1,200 mg/L. This TDS can only be removed by RO membranes. However, the organic and turbidity levels in raw water should be significantly reduced for proper RO membrane performance. Therefore, pretreatment before the RO membranes is an important step for treating this water and was a large focus for this pilot study. As discussed previously, the pretreatment technologies selected were the Actiflo high-rate clarifier, the SuperP high-rate clarifier, and the Zenon Ultrafilter membrane.

Pretreatment testing with these technologies was conducted throughout the entire pilot testing program. The testing, as described earlier, was divided into 4 phases—Phase 1A, 1B, 2A, 2B, and 3. The Phase 1A testing was the only phase in which all three pretreatment technologies were tested side-by-side.

The intent of Phase 1A was to select the best pretreatment which would then be used for the remaining phases of RO membrane testing. However, all three pretreatment processes worked well in Phase 1A. Therefore, based on this result, all three pretreatment processes were used in the subsequent phases. The pretreatment technologies used in Phases 1B, 2 and 3 depended on availability and schedule. The pretreatments used in the different phases are as follows:

| | |
|---|---|
| Phase 1A | SuperP, Actiflo, and Zenon Ultrafilter |
| Phase 1B | Super P and Zenon Ultrafilter |
| Phase 2A | Super P and Zenon Ultrafilter |
| Phase 2B | Actiflo and Zenon Ultrafilter |
| Phase 3 | Actiflo, Zenon Ultrafilter, and Memcor Microfilter |

It is important to note that in each phase, these pretreatments were providing treated water to RO membranes for desalting. The following subsections highlight the pretreatment system performance and pretreatment system water quality. Membrane performance for desalting using water from these pretreatments is discussed in the *Membrane Testing* section of this report.

### Phase 1A Pretreatment Evaluation — High Rate Clarification and Ultrafiltration Testing

Phase 1A testing consisted of the initial pretreatment evaluation, beginning in August 2001 and ending in December 2001. The Phase 1A purpose was to test each of the pretreatment technologies, side-by-side with respect to:

- the effectiveness of each technology to provide potable water after filtration (i.e., if membranes were not used when the source water is fresh, not brackish); and
- the effectiveness of each technology to sufficiently pretreat the water for further treatment and salt removal with RO membranes (i.e., when the source water is brackish).

This section provides a brief summary of each pretreatment system's ability to provide potable water after filtration. For further information on the initial pretreatment evaluation, see Appendix B, *Technical Memorandum: Interim Pilot Report Phase 1A Pilot Protocol Phases 1B & 2.*

The three pretreatment processes tested during Phase 1A were:

- Actiflo ballasted sand clarifier followed by dual media filtration
- SuperP blanket clarifier followed by dual media filtration
- Zenon ZeeWeed ultrafiltration

The simultaneous pretreatment testing began in late August 2001 and concluded on December 20, 2001. Pretreatment system effectiveness on treating Lake Monroe water was based on operability, treated water quality, and process stability. Pretreatment process operating parameters were determined by the pretreatment manufacturers and CH2M HILL.

Each of these pretreatments was evaluated by feeding the following two (of the four single element membranes selected) membranes:

- Osmonics SG Brackish Water Membrane
- TriSep X-20 Membrane

The RO membrane testing began November 9, 2001 and ended December 20, 2001, when the pretreatment testing ended. Regarding membrane performance, the three pretreatments were evaluated with respect to feed pressure change, trans-membrane pressure change, and water quality change. For further information on the membrane testing, see the *Reverse Osmosis Membrane Testing* section of this report.

**Water Quality**

Daily raw water quality samples were taken to characterize the raw water quality during pilot testing. Table 14 summarizes average, maximum, and minimum pH, turbidity, $UV_{254}$, apparent color, and alkalinity levels for this initial testing. The table also summarizes the standard deviation and coefficient of variance (CV) for each parameter to illustrate the variable water quality in this water source. The CV, calculated by dividing the standard deviation by the average, quantifies the magnitude the standard deviation varies from the average.

During Phase 1A, the average raw water turbidity was 7.5 NTU with a maximum of 58.6 NTU which occurred during a heavy rain event. Apparent color and $UV_{254}$ were monitored as natural organic surrogates. Average raw water apparent color was 429 Pt-Co during Phase 1A with maximums greater than 520 Pt-Co, occurring several times due to rain and wind events.

**Table 14. Raw Water Quality Field Analyses; Initial Pretreatment Evaluation**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **pH** | | 7.1 | 9.2 | 6.3 | 0.7 | 0.10 |
| **Alkalinity** | **(mg/L as $CaCO_3$)** | 51 | 90 | 37 | 11 | 0.23 |
| **Turbidity** | **(NTU)** | 7.5 | 58.6 | 1.5 | 8.9 | 1.19 |
| **$UV_{254}$** | **(abs/cm)** | 1.448 | 1.715 | 0.746 | 0.215 | 0.15 |
| **Color (App)** | **(Pt-Co)** | 429 | >520 | 245 | 70 | 0.16 |

Table 15 summarizes several general water quality parameters monitored by UCF in the laboratory including NPDOC, TSS, TDS, and conductivity.

As Table 15 illustrates, average NPDOC levels were 32.9 mg/L during this initial evaluation. The maximum was 47.1 mg/L compared to the minimum of 22.9 mg/L, which was nearly half the maximum concentration. This illustrates the broad range in NPDOC between the rainy and dry season.

The maximum TDS during Phase 1A was 988 mg/L compared to a minimum TDS concentration of 294 mg/L, less than a third of the maximum. As should be expected, the minimum TDS occurred during the rainy season when fresh water run off was at a maximum. As the rainy season ended, the TDS began to increase.

**Table 15. Raw Water Quality Laboratory Analyses; Initial Pretreatment Evaluation**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **NPDOC** | **(mg/L)** | 32.9 | 47.1 | 22.9 | 5.2 | 0.16 |
| **TSS** | **(mg/L)** | 49 | 120 | 16 | 48 | 0.98 |
| **TDS** | **(mg/L)** | 631.2 | 988.0 | 294.0 | 213.7 | 0.34 |
| **Conductivity** | **(S/m)** | 67.3 | 92.0 | 43.8 | 18.5 | 0.27 |

### Pretreatment Performance

During this study, all pretreatments utilized ferric sulfate coagulant (Fe2(SO4)3) for coagulation, selected during the coagulant evaluation. Average coagulant dosages for Actiflo, SuperP, and Zenon were 166, 157, and 174 mg/L, respectively. Coagulation pHs for Actiflo, SuperP, and Zenon were 4.3, 4.6, and 5.7, respectively.

Coagulation pHs were 4.3 and 4.6 for Actiflo and SuperP, with adjustment after coagulation to a pH of 6.5 to maximize iron removal in the filters. Because Zenon is a one-step UF system and was operated at a pH of 5.7. This pH level maximized organic removal while minimizing the filtered iron concentration.

To aid in clarification, a cationic polymer was used by SuperP and Actiflo treatment trains; however, no polymer was necessary for Zenon treatment. PAC was also added to the SuperP sludge blanket for taste and odor control and additional TOC removal.

### Clarified Water Quality

The Actiflo and SuperP clarified water quality is summarized in Table 16. This table summarizes the average, maximum, minimum, standard deviation, and CV for the clarification systems. Since Zenon is a membrane filter, not a clarifier, its performance is compared to Actiflo and SuperP filtration, later in this section.

Both processes achieved good organic removal as illustrated in Table 16. This table summarizes $UV_{254}$ and color, surrogate measures of natural organic matter. Average clarified $UV_{254}$ was 0.106 abs/cm for Actiflo compared to 0.123 abs/cm for SuperP. Both processes were also able to achieve low color levels.

The table also summarizes the low clarified turbidity achieved by both processes. Actiflo achieved an average clarified turbidity of 0.62 NTU compared to 0.57 NTU for SuperP during Phase 1A, well below 1 NTU. The CV for both processes were 0.61 and 0.47 for Actiflo and SuperP, respectively. These low CV values indicate stable process operations.

**Table 16. Clarified Water Quality Comparison; Pretreatment Evaluation**

| Analyte | Units | Process | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|---|
| $UV_{254}$ | (abs/cm) | Actiflo | 0.106 | 0.163 | 0.069 | 0.019 | 0.18 |
| | | SuperP | 0.123 | 0.760 | 0.050 | 0.082 | 0.67 |
| Apparent Color | (Pt-Co) | Actiflo | 15 | 42 | 6 | 8 | 0.53 |
| | | SuperP | 17 | 61 | 7 | 10 | 0.59 |
| Turbidity | (NTU) | Actiflo | 0.62 | 1.73 | 0.24 | 0.38 | 0.61 |
| | | SuperP | 0.57 | 1.60 | 0.27 | 0.98 | 0.47 |

### Filtered Water Quality

Filtered water quality samples were collected daily for pH, turbidity, $UV_{254}$, and color with weekly samples for NPDOC. Table 17 summarizes the filtered water quality samples for the duration of Phase 1A. All pretreatments were able to achieve an average turbidity lower than 0.1 NTU during Phase 1A.

The SuperP, Actiflo, and Zenon NPDOC levels are also summarized in Table 17. All three processes achieved much higher than the 50 percent NPDOC removal required by the regulations. Actiflo had an average NPDOC level of 4.7 mg/L. SuperP had an average NPDOC level of 5.2 mg/L without PAC addition and 2.8 mg/L with PAC addition. These data show that SuperP with PAC addition can achieve much higher removals of NPDOC than can be achieved with coagulation alone. Further, Actiflo and SuperP achieved average filtered water color of 4 Pt-Co and 5 Pt-Co, respectively.

The average Zenon ultrafiltered water had an NPDOC value of 8.1 mg/L with an average color of 21 Pt-Co. The difference in the Zenon organic levels is attributed to the higher coagulation pH required for that process. Actiflo and SuperP coagulation occurred at pHs of 4.3 and 4.9 where optimum removal of organics occur. The pH of the clarified water was then increased to 6.5 for filtration. At this pH, soluble (dissolved) iron becomes insoluble (solid) and can be removed during the filtration step. Since Zenon is a one-step process, the coagulation in the Zenon system occurred at a pH of 5.7 to control iron passage through the ultrafilter. The pH of the Zenon water increased to approximately 6.4 at the end of the process due to air stripping of carbon dioxide. The coagulation pH of 5.7 is the pH at which soluble iron can be minimized and NPDOC removal can be maximized. At this high pH, coagulation is not as efficient for the Zenon process, however, it does meet the regulatory requirements for NPDOC removal. In addition, using Zenon as a one step process is a constraint for testing in this phase as a pretreatment, which requires the subsequent higher coagulation pH values as mentioned above. In later phases of the study, Zenon was tested after clarification as a filter. This will allow the organics to be removed in the clarification process and further tested its ability as a filter, and as an absolute barrier for particles and turbidity.

**Table 17. Average Filtered Water Quality; Pretreatment Evaluation**

| Process | pH | Turbidity (NTU) | NPDOC (mg/L) | $UV_{254}$ (abs/cm) | $Color_{App}$ (Pt-co) | Total $Cl_2$ (mg/L as $Cl_2$) |
|---|---|---|---|---|---|---|
| AF/GF | 6.4 | 0.07 | 4.7 | 0.094 | 4 | 6.95 |
| SP/GF | 6.2 | 0.10 | 5.2/2.8* | 0.090 | 5 | 3.17 |
| ZW-UF | 6.4 | 0.08 | 8.1 | 0.225 | 21 | 5.93 |

*Indicates with/without PAC addition, respectively

### Filtration Performance

#### *High Rate Clarification with Granular Media Filtration*

The SuperP and Actiflo units were each followed by a dual media filter. The filterability of SuperP and Actiflo treated water was evaluated based on headloss, turbidity, particle counts, and unit filter run volume (UFRV). The evaluation was performed at a filter loading rate of 4 gpm/ft$^2$ (higher loading rates were evaluated in subsequent phases of testing). Continuous data for headloss, particle counts, and turbidity were collected in the CH2M HILL trailer using the 4 inch pilot scale filters and a PLC data logger.

Pretreatment optimization was conducted during September and October of 2001. The goal of pretreatment optimization was to evaluate the ability of the pretreatments to achieve potable water standards without using membranes. During pretreatment optimization, chloramination of the raw water, for biological fouling control on the RO membranes, had not begun. Prior to starting raw water chloramination, the pretreatment systems were unable to consistently produce a filtered water which achieved the minimum filtered water total particle goal of less than 30 to 50 counts per ml for the duration of the filter run. Further, Actiflo was unable to meet the UFRV minimum level goal of 7,200 gal/ft$^2$ due to high headloss. Both pretreatments were, however, able to achieve the turbidity goal of less than 0.1 NTU with each having average turbidities of 0.053 NTU.

Filter run data suggested that particle levels and headloss were high without preoxidation with chloramines. This may be due to the high levels of organics that may have prevented complete particle destabilization with the coagulant alone. The addition of chloramines to the raw water, however, may have provided particle conditioning, which significantly improved filterability.

Figure 28 and Table 18 summarize a typical filter run that occurred once the pretreatments were optimized and chloramines were being applied to the raw water. During this run, both pretreatments were able to meet and exceed all goals for turbidity, particle counts, and UFRV. As the Actiflo and SuperP filtration parameters summary in Table 18 illustrates, both pretreatments had nearly equal particle count levels and equal turbidity levels. SuperP had a slightly lower rate of headloss increase, resulting in a longer run duration, and subsequently a higher UFRV. This run is typical of the filtered water quality that was produced for RO membrane treatment during the Phase 1A testing.

**Figure 28. Typical Granular Media Filter Headloss, Turbidity, and Particle Counts; Initial Pretreatment Evaluation**

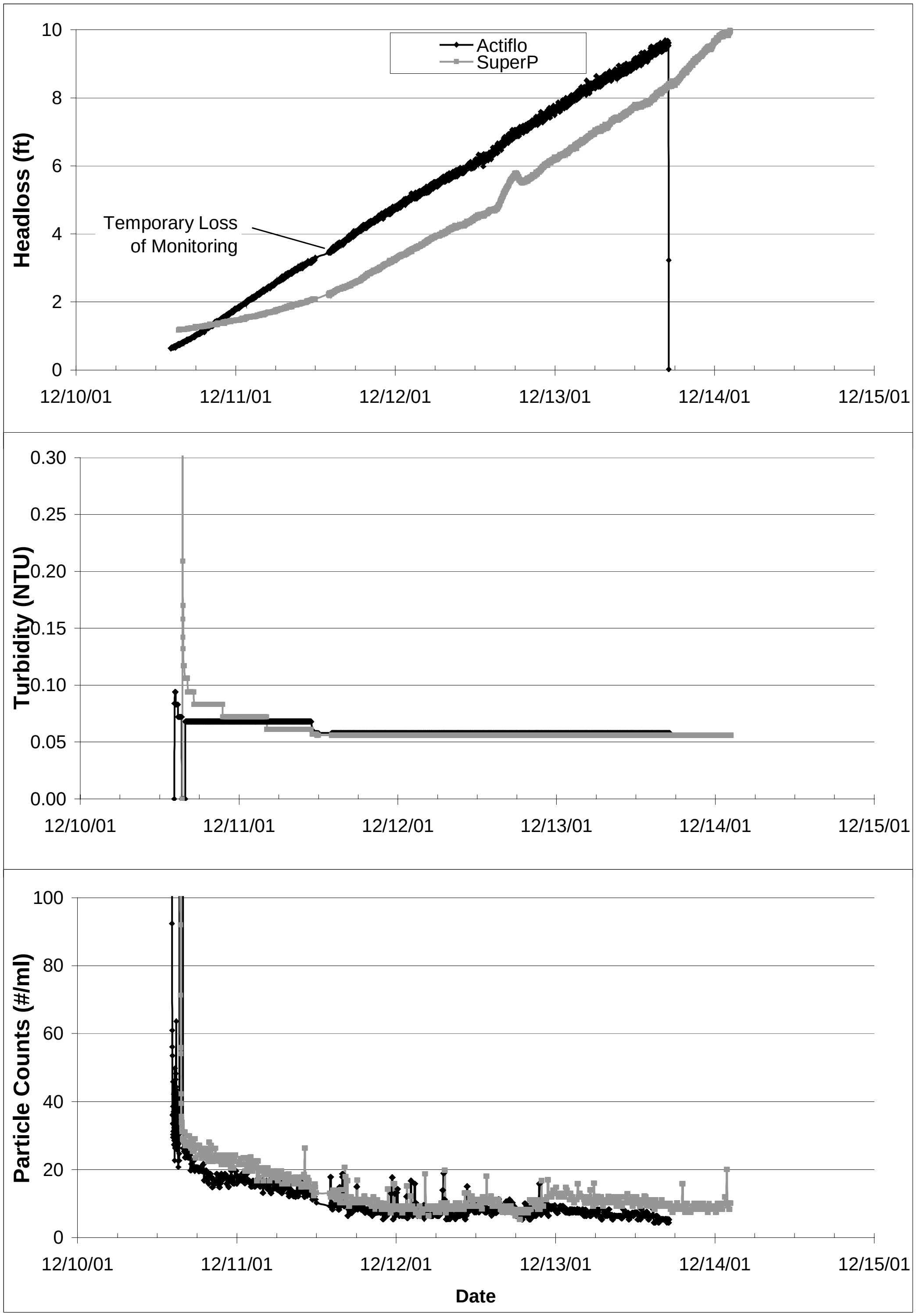


**Table 18. Typical Filter Run Performance; Initial Pretreatment Evaluation**

| Parameter | Units | Actiflo | SuperP |
|---|---|---|---|
| Filter Run Duration | (hrs) | 74.9 | 89.6 |
| Unit Filter Run Volume | (gal/ft$^2$) | 17972 | 21504 |
| Total Headloss | (ft) | 9.0 | 8.8 |
| Rate of Headloss | (in/hr) | 1.4 | 1.3 |
| Average Turbidity$_{Online}$ | (NTU) | 0.061 | 0.061 |
| Average Particle Counts$_{Online}$ | (#/ml) | 11.9 | 13.3 |

### *Zenon Ultrafiltration*

During Phase 1A, the Zenon pilot unit was operated at a flux of 20 gfd (gal/ft$^2$/day) and a recovery of 90 percent. Online turbidity and particle count data were collected every 15 minutes during testing and are summarized in Figure 29. The Zenon unit was able to achieve an average turbidity of less than 0.046 NTU and average particle counts of 2.2 counts/ml for the duration of testing. This illustrates the higher level of treatment that can be achieved using membrane technology which is a nearly absolute barrier. [7]

Although the Actiflo and SuperP filters had relatively low levels of turbidity and particles, as expected, the Zenon ultrafilter membrane was clearly able to achieve much lower levels than the conventional media filtration.

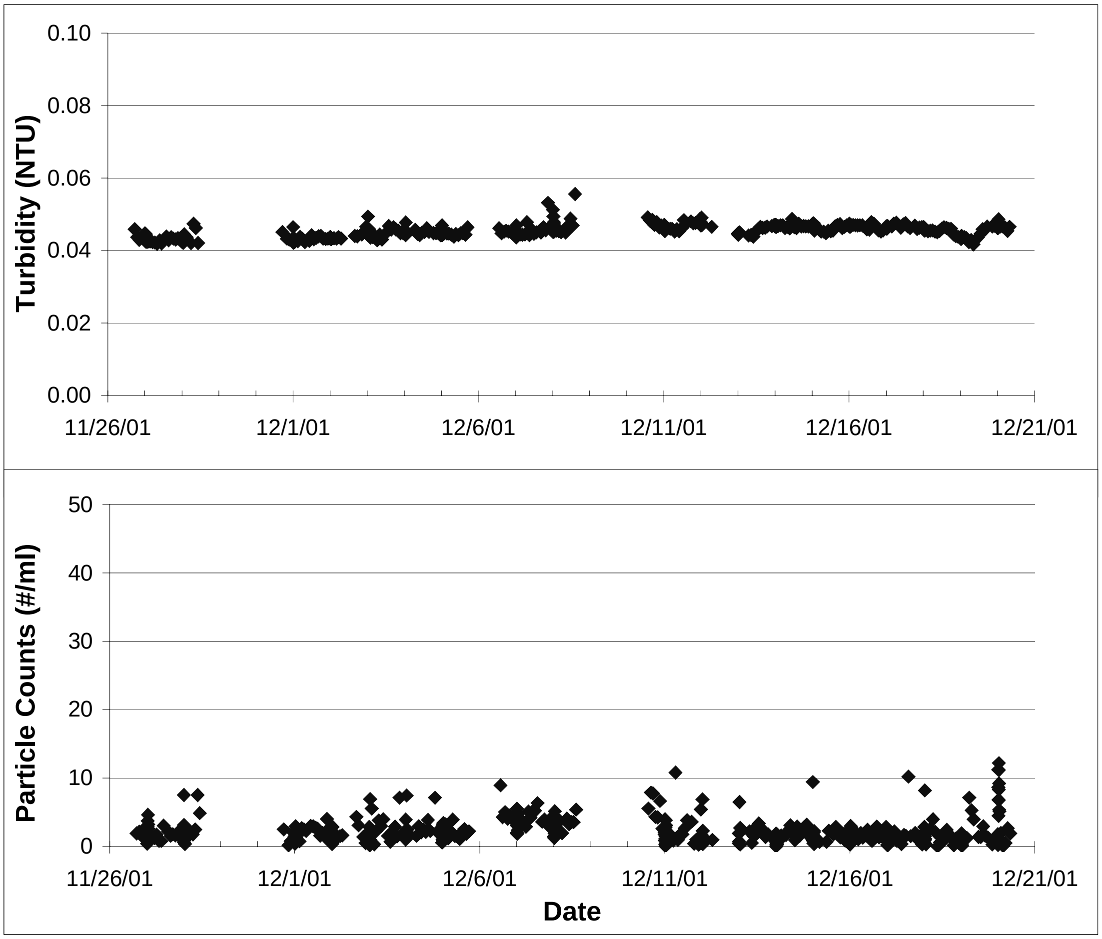
## Conclusions

The goal of Phase 1A was to simultaneously test each of the three pretreatments for their ability to produce potable water without membrane treatment during the rainy season; and to also test their ability to feed low pressure RO membranes during the dry season when higher raw water salt concentrations occurred.

All three pretreatments were able to produce potable water quality without RO membrane treatment. Namely, Actiflo followed by dual media filtration, SuperP followed by dual media filtration, and Zenon ultrafiltration achieved this result. Organics removal by each pretreatment exceeded regulatory requirements. The filtered water turbidity from each process was significantly below the potential future standard of 0.1 NTU, and each process demonstrated a stable operation throughout this phase.

[7] For more information on Zenon performance, see the “Microfiltration/Ultrafiltration” section in this document.

**Figure 29. Typical Zenon Filtered Water Quality; Initial Pretreatment Evaluation**




For further information on the initial pretreatment evaluation, see Appendix B, *Technical Memorandum: Interim Pilot Report Phase 1A Pilot Protocol Phases 1B & 2.*

Throughout Phase 1A and the remainder of this pilot study, levels of residual iron were evaluated and monitored throughout the unit processes. Iron levels after coagulation, in the clarified water, ranged from 0.5 to 1.5 mg/L. These high levels would be unacceptable in the distribution system as well as adversely impact the RO membranes.

Iron levels were controlled after clarification by adjusting the filtration (media filters and MF/UF membranes) pH to 6.5 to 7.5, which further lowers the solubility of iron. Iron levels through the filters, i.e. RO feed water, typically ranged below 0.1 mg/L. These low iron feed values are referenced throughout the membrane sections of this report. Iron precipitation did not adversely affect either the granular media filters or the MF/UF membrane filters, with each performing within acceptable ranges.

### Phase 1B, 2, and 3 Testing

Based on these results, the protocol and testing plan for the remaining phases of testing was developed. Since all three of the pretreatments performed well, the remaining phases of testing included SuperP, Zenon, and Actiflo providing water to the low and high recovery membranes at different times. This allowed for additional data collection on the three processes since they all demonstrated good performance. The membrane testing was expanded from two to four membranes. Given the pretreatments evaluated in Phase 1A, the subsequent phases focused more on membrane performance and development of design data.

An important element of the subsequent phases of testing was the continued evaluation of chloramine addition. Due to the potential degradation of the membranes during Phase 1A, significantly lower chloramine levels were added in subsequent phases to control biological fouling. Chloramine addition was lowered from dosages of 3 to 7 mg/L during the initial pretreatment evaluation testing down to 1 to 2 mg/L.

### Phase 1B, 2, and 3 High Rate Clarification Testing

SuperP and Actiflo were tested as clarification technologies for organics and turbidity removal with further particle removal by granular media filtration. The systems fed RO membranes to demonstrate that SuperP with SP/GF and Actiflo with AF/GF could produce treated water that meets drinking water goals. These two processes were evaluated in side-by-side comparison studies during phase 1A and, individually, during the remainder of the testing.

Both technologies are alternatives to conventional clarification. However, the two processes have different approaches. Actiflo is a sand-ballasted clarifier and uses the attachment of floc particles to microsand to ballast the floc particle. Subsequently, the floc particles are quickly removed due to the increased density and settling velocity of the floc particle. SuperP is an upflow blanket clarifier and uses cohesion of a sludge blanket with a polymer to capture floc particles as the coagulated stream flows up through the blanket.

Both of these are clarification technologies that require some form of filtration to polish the effluent prior to RO treatment. SuperP and Actiflo were both evaluated using granular media filters for particle removal[8]. The filters were anthracite/sand dual media filters.

### SuperP Clarification with Granular Media Filtration

The objective of this testing was to evaluate the SP/GF process as a pretreatment system for RO membranes. The goal of testing was to gather the necessary data to develop full scale design recommendations for Actiflo clarification and granular media filtration.

#### SuperP Process Equipment Description

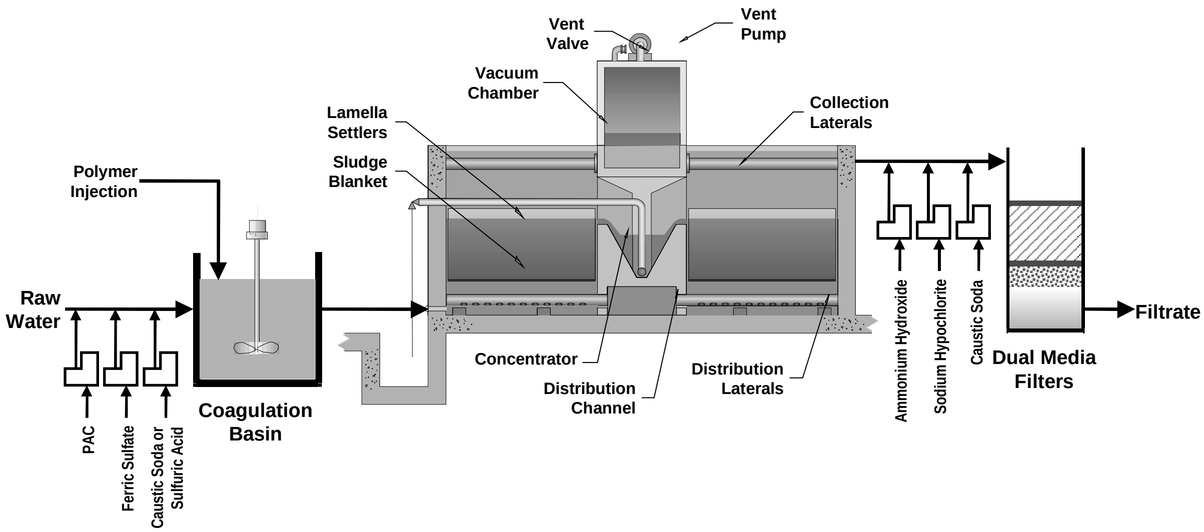
The SuperPulsator®, manufactured by Infilco Degremont, Inc., was evaluated during this study. The SuperP upflow blanket clarifier, also known as the solids contact units, combines rapid mixing, flocculation, and sedimentation in one unit. These clarifiers are designed to maintain a large volume of flocculated solids within the unit, which enhances flocculation by encouraging interparticle collisions. The SuperP units are popular because of their high loading rate, which occupies less land space, and produces more water per unit area than conventional sedimentation.

Figure 30 shows the SuperP process used during this pilot study. As the figure suggests, rapid mixing occurs upstream of the unit where ferric sulfate coagulant is added to begin the formation of floc. After rapid mixing, a polymer is added which promotes sludge blanket cohesion. The coagulated water then enters the unit. The SuperP uses a vacuum pump and chamber to produce a pulsing effect within the flocculation zone. The pulsing of the solids blanket expands the blanket and increases the rate of interparticle collisions. Solids are maintained in the unit at a set height through the use of a solids overflow weir. Solids overflow into a hopper and are removed at a set intervals. For this study, solids were discharged from the unit every 20 minutes.

Clarification occurs with the use of inclined plates above the sludge blanket that settle the remaining floc. The clarified effluent is discharged at the top of the unit and flows to granular media (anthracite/sand) filters for further particle removal and polishing prior to RO treatment.

[8] The Actiflo clarification technology was further evaluated with both microfiltration and ultrafiltration membranes. For further information on this testing see the *Microfiltration/Ultrafiltration* section.

**Figure 30. Process Flow Schematic for SuperP Clarifier with Granular Media Filtration**




## Testing Summary

SuperP testing began in August 2001 and continued until October 2002. During this time, granular media filtration testing was done, with subsequent RO testing also conducted on the filtrate. Granular media filtration testing included evaluation of high filter loading rates to maximize the production from the filters.

SuperP testing from August 2001 to December 2001 was previously summarized. This section discusses SuperP testing from March 2002 to October 2002. For further information on the initial pretreatment evaluation testing, see the Phase 1A Report in Appendix B.

SuperP testing resumed following the initial pretreatment evaluation, starting in March 2001. The system was restarted and optimized with respect to coagulation and filtration.

Membrane testing resumed following SP/GF optimization. Table 19 summarizes the single element membrane testing conducted on the SP/GF water. This testing was conducted on the RO membrane types selected during flat sheet testing previously discussed. The first phase of testing, Phase 1A, was the initial pretreatment evaluation. This phase included a side-by-side comparison of the SP/GF to AF/GF and ZW-UF.

The next phase of testing, from April 2002 to June 2002, was the lead element selection process, with the goal of selecting the best performing membrane for further evaluation in the high recovery system. Continued evaluation of the single elements lasted until September 2002, at which point, the SuperP clarifier was replaced by the Actiflo clarifier as the pretreatment to the membranes.

**Table 19. Single Element Membrane Testing Summary for SP/GF Evaluation**

| Task | Dates | Hours of Testing | Filmtec BW30FR | TriSep X-20 | Osmonics SG | Hydranautics LFC1 |
|---|---|---|---|---|---|---|
| Pretreatment Evaluation | 11/09/01-12/19/01 | 850 | | XX | XX | |
| Lead Element Selection | 04/08/02-06/30/02 | 1700 | XX | XX | XX | XX |
| Continued Single Element Eval. | 07/01/02-09/23/02 | 1500 | XX | XX | XX | XX |

Table 20 summarizes the high recovery membrane testing conducted on the SP/GF water. High recovery membrane testing began in August 2001 and ended in September 2002, when the SuperP clarifier was replaced by the Actiflo clarifier as the pretreatment to the RO membranes.

**Table 20. High Recovery Membrane Testing Summary for SP/GF Evaluation**

| Task | Dates | Hours of Testing | Filmtec BW30FR | Filmtec BW30LE | TriSep X-20 | Osmonics SG |
|---|---|---|---|---|---|---|
| High Recovery Evaluation | 07/16/02-09/23/02 | 1350 | XX | XX | XX | XX |

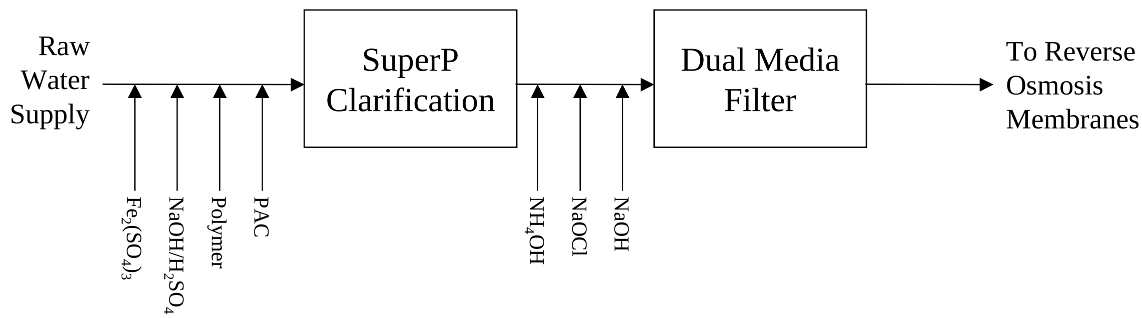
Figure 31 is a basic process schematic for the SuperP clarifier and granular media filter pretreatment. Ferric sulfate and either sodium hydroxide or sulfuric acid (depending on the raw water alkalinity and coagulant dosage) were applied to the raw water prior to the clarifier. Further, polymer addition was necessary for sludge blanket cohesion. PAC was also applied to the blanket for further blanket stabilization and for taste and odor removal from the raw water. The SuperP loading rate for these studies was 3.00 to 3.75 gpm/ft$^2$ and sludge was discharged from the system every 20 minutes.

Following coagulation/flocculation the water flowed to the dual media filters. The clarified effluent was then chloraminated with sodium hypochlorite and ammonium hydroxide. Further, prior to filtration, the pH was adjusted to between 6.5 and 7.0 to remove soluble iron in the clarified effluent. Granular media filters were 42 inches of anthracite over 12 inches of sand. Pilot filters in the CH2M HILL trailer[9] were operated to collect detailed filtration design data, while larger filters in the pilot building were

[9] The CH2M HILL trailer housed three 4 inch diameter pilot filters which were monitored online by a common turbidimeter and particle counter.

operated to produce larger quantities of filtered water for testing on the RO membranes.

**Figure 31. Basic Process Flow Diagram for the SP/GF Pretreatment Testing**




### Pretreatment Performance Testing

#### *Water Quality*

Tables 21, 22, and 23 summarize the results of daily sampling and analyses of raw, SuperP clarified, and granular media filtrate streams, respectively. The data is for the period March 21, 2002 to October 9, 2002, and includes average, maximum, minimum, standard deviation, and CV for each water quality parameter. In addition, Table 22 summarizes the coagulation dosage, polymer dosage, PAC dosage and coagulation pH data for the SuperP process while Table 23 summarizes the filtration pH and total chlorine concentration.

During the SP/GF testing, average raw water $UV_{254}$ was 0.803 abs/cm and ranged from 0.424 to 1.501 abs/cm, while average conductivity was 103.9 S/m and ranged from 33.1 to 185.9 S/m. This evaluation began in the dry season and lasted up to the rainy season, which would explain the large difference between the maximum and minimum for these parameters.

**Table 21. Raw Water Quality for SP/GF Testing on Lake Monroe Water**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| pH | | 7.3 | 8.3 | 5.8 | 0.5 | 0.06 |
| Alkalinity | (mg/L as $CaCO_3$) | 70 | 115 | 42 | 12 | 0.17 |
| Turbidity | (NTU) | 6.2 | 44.9 | 0.8 | 4.7 | 0.76 |
| Conductivity | (S/m) | 103.9 | 185.9 | 33.1 | 44.7 | 0.43 |
| Apparent Color | (Pt-Co) | 237 | 467 | 129 | 79 | 0.33 |
| $UV_{254}$ | (abs/cm) | 0.803 | 1.501 | 0.424 | 0.283 | 0.35 |

Table 22 summarizes the ferric sulfate dosages for the SuperP process during testing. All ferric sulfate dosages are reported as pure (100 percent) ferric sulfate. As the table illustrates, the average ferric sulfate dosages for the SuperP process were 155 mg/L and ranged from 230 mg/L to 75 mg/L.

The average polymer dosages during testing were 0.65 mg/L and ranged from 0.98 mg/L to 0.47 mg/L. Ciba® Magnafloc® LT22S, a medium charge density cationic polymer, was used for treatment. Note that cationic polymer can potentially cause membrane fouling. The potential impact of polymer carryover on membrane performance was not directly evaluated during this testing.

The average coagulation pH was 4.3 during testing, resulting in an average soluble iron concentration of 1.22 mg/L.

The average apparent color and $UV_{254}$ after clarification were 14 Pt-Co and 0.073 absorbance per centimeter (abs/cm), respectively. Turbidity ranged from 1.45 NTU to 0.09 NTU with an average of 0.55 NTU.

**Table 22. SP Clarified Water Quality for SP/GF Testing on Lake Monroe Water**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **Ferric Dosage (pure)** | **(mg/L)** | 155 | 230 | 75 | 43 | 0.28 |
| **Polymer** | **(mg/L)** | 0.65 | 0.98 | 0.47 | 0.13 | 0.20 |
| **Coagulation pH** | | 4.3 | 5.6 | 3.4 | 0.5 | 0.12 |
| **Powdered Activated Carbon** | **(mg/L)** | 21.4 | 34.4 | 9.8 | 4.8 | 0.22 |
| **Turbidity** | **(NTU)** | 0.55 | 1.45 | 0.09 | 0.27 | 0.49 |
| **Iron** | **(mg/L)** | 1.22 | 2.99 | 0.09 | 0.46 | 0.38 |
| **Apparent Color** | **(Pt-Co)** | 14 | 29 | 1 | 5 | 0.36 |
| **$UV_{254}$** | **(abs/cm)** | 0.073 | 0.137 | 0.023 | 0.026 | 0.36 |

As Table 23 demonstrates, filtered water turbidity was 0.056 NTU and ranged from a maximum of 0.084 NTU to 0.032 NTU. Turbidity readings were taken from the online turbidimeter and were only taken during steady state filtration conditions. Therefore, this average turbidity does not account for the turbidity during ripening and breakthrough. Average particle counts ranged from 7.5 counts/mL to 100.3 counts/mL with an average of 28.3 counts/mL. Again, as with the turbidity, readings were taken from online particle counters and were only taken during steady state filtration.

**Table 23. Filtered Water Quality for SP/GF Testing on Lake Monroe Water**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| pH | | 6.6 | 7.6 | 5.8 | 0.4 | 0.06 |
| Alkalinity | (mg/L as $CaCO_3$) | 24 | 42 | 11 | 6 | 0.25 |
| Turbidity | (NTU) | 0.056 | 0.084 | 0.032 | 0.009 | 0.16 |
| Particle Counts | (#/ml) | 28.3 | 100.3 | 7.5 | 27.4 | 0.97 |
| Apparent Color | (Pt-Co) | 1 | 10 | 0 | 2 | 1.29 |
| $UV_{254}$ | (abs/cm) | 0.055 | 0.108 | 0.013 | 0.022 | 0.40 |
| Iron | (mg/L) | 0.053 | 0.259 | 0.000 | 0.047 | 0.88 |
| Total $Cl_2$ | (mg/L as $Cl_2$) | 0.64 | 2.67 | 0.00 | 0.74 | 1.15 |

Table 24 and Figure 32 summarize the average removal of turbidity, apparent color, and $UV_{254}$ by clarification, granular media filtration, and the combined clarification / GF process. As Table 24 and Figure 32 illustrate, the cumulative turbidity removal was 99.1 percent, the cumulative apparent color removal was 99.4 percent, and the cumulative $UV_{254}$ removal was 93.1 percent.

**Table 24. Average Turbidity, Apparent Color, and $UV_{254}$ Removals for SP/GF Testing on Lake Monroe Water**

| Parameter | Units | Averages | | | Removals | | |
|---|---|---|---|---|---|---|---|
| | | Raw | Clarified | Filtered | Raw to Clarified | Clarified to Filtered | Cumulative Removal |
| Turbidity | (NTU) | 6.2 | 0.55 | 0.056 | 91.1% | 89.7% | 99.1% |
| Apparent Color | (Pt-Co) | 237 | 14 | 1 | 94.2% | 89.4% | 99.4% |
| $UV_{254}$ | (abs/cm) | 0.803 | 0.073 | 0.055 | 90.9% | 24.0% | 93.1% |

### *Filterability*

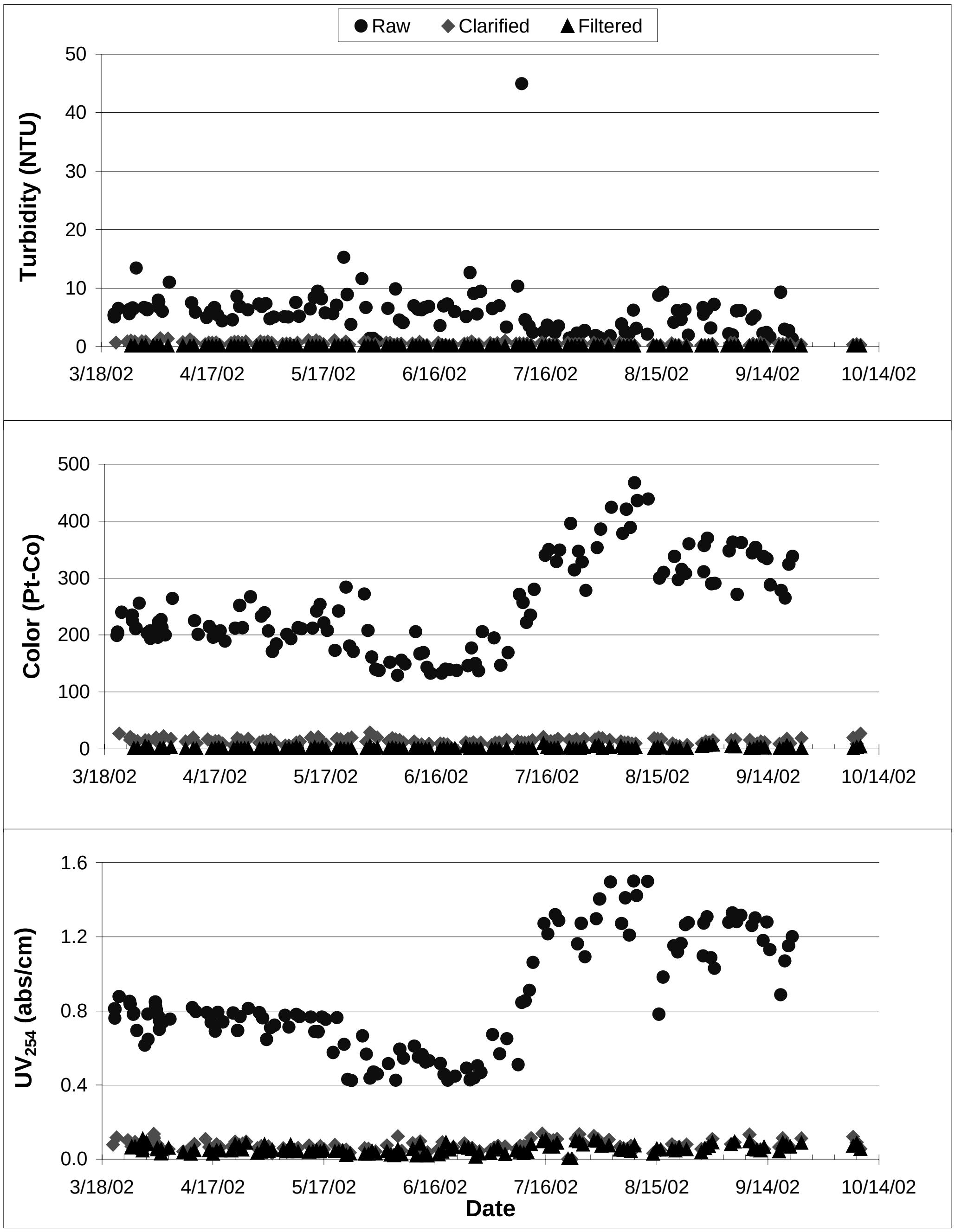
The SuperP unit was followed by a dual media filter. The filterability of the SuperP clarified effluent was quantified by headloss, turbidity, particle counts, and UFRV. Continuous data for headloss, particle counts, and turbidity were collected in the CH2M HILL trailer using the 4 inch pilot scale filters and a PLC data logger.

The data presented represents a properly operated SP / GF process and is representative of typical filter runs observed during testing. The following data collected during non-representative periods is not included:

- Interruptions in chemical feed to the clarified effluent
- SuperP operational upsets
- System pressure changes resulting in particle breakthrough
- Feed pump problems resulting in loss of flow or reduced flow

Figure 33 and Table 25 summarize the filtration data for the filter runs starting on July 26, 2002 which evaluated different filter loading rates. Three filter runs were conducted simultaneously. Filters 1, 2, and 3 were operated at 4, 7, and 10 gpm/ft$^2$, respectively, to evaluate the effect of higher filter loading rates on water quality.

**Figure 32. Raw, Clarified, and Filtered Water Quality Levels for SP/GF Testing on Lake Monroe Water**



# Figure 33. SP/GF Headloss, Turbidity, and Particle Counts; Run SP1

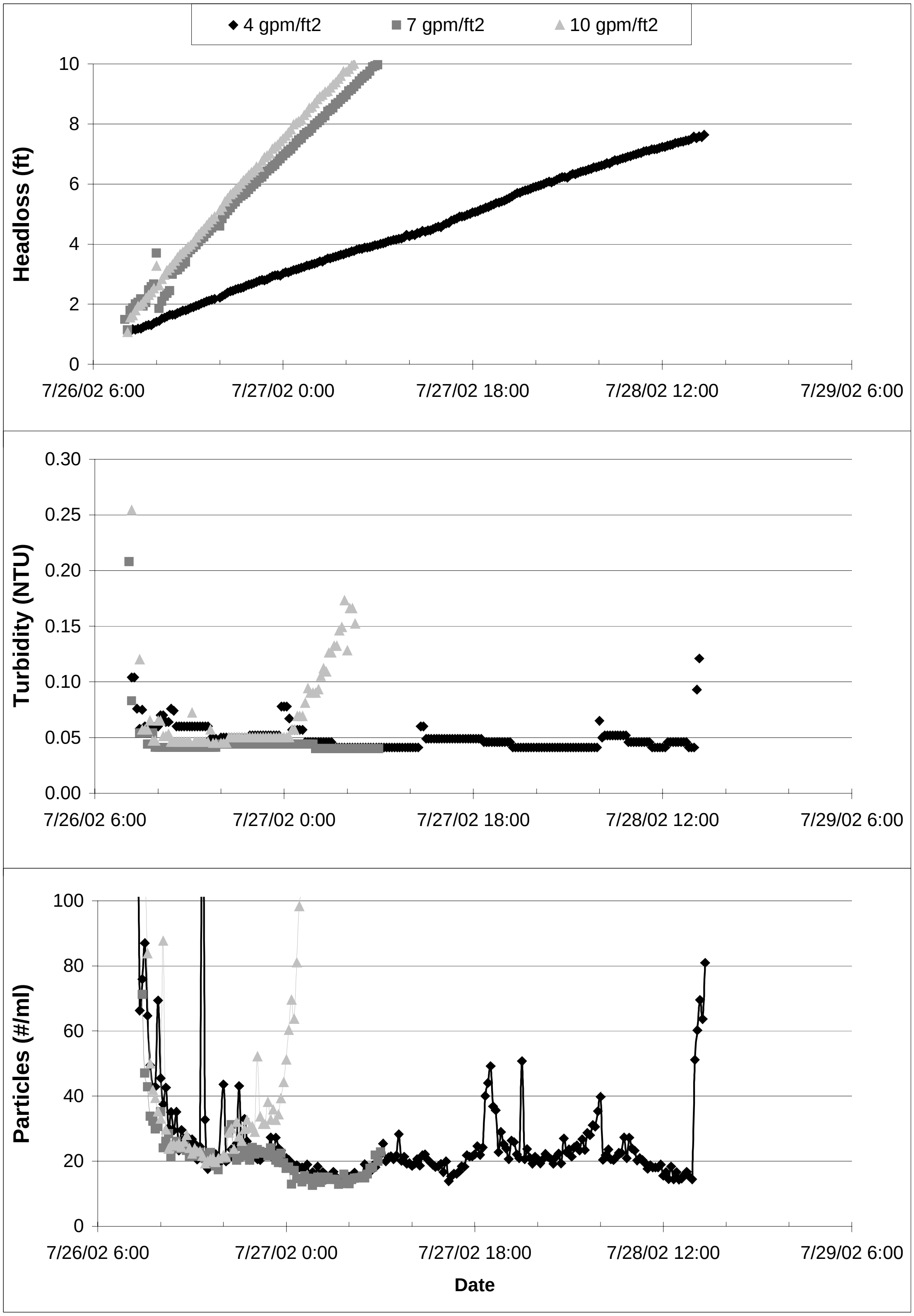


**Table 25. SP/GF Performance; Run SP1**

| Parameter | Units | Filter 1 | Filter 2 | Filter 3 |
|---|---|---|---|---|
| Filter Loading Rate | ($gpm/ft^2$) | 4 | 7 | 10 |
| Filter Run Duration | (hrs) | 54.5 | 24.0 | 15.0 |
| Unit Filter Run Volume | ($gal/ft^2$) | 13080 | 10080 | 9000 |
| Total Headloss | (ft) | 6.5 | 8.5 | 6.5 |
| Rate of Headloss | (in/hr) | 1.4 | 4.2 | 5.2 |
| Average $Turbidity_{Online}$ | (NTU) | 0.048 | 0.042 | 0.050 |
| Average Particle $Counts_{Online}$ | (#/ml) | 23.9 | 19.9 | 29.9 |

All of the filter runs had acceptable UFRV's. However, Filter 3 (10 $gpm/ft^2$) was terminated based on particle breakthrough, whereas, the other two filters were terminated based on terminal headloss.

Filtered water turbidity and particle levels were comparable among the three filters. However, Filter 3 (10 $gpm/ft^2$) had higher particle counts and higher turbidity than the other two filters. Turbidity for Filter 1 (4 $gpm/ft^2$) was higher than Filter 2 (7 $gpm/ft^2$); however, the duration of the run in Filter 1 was nearly twice as long, and the pretreated water quality may have been worse, later in the filter run.

Figure 34 and Table 26 summarize filtration data filter runs with different loading rates starting on October 5, 2002. Again, three filters were operated simultaneously. Filters 1, 2, and 3 were operated at 4, 7, and 10 $gpm/ft^2$, respectively.

Performance during this set of runs was better than the previous set. All of the filter runs had UFRV's that were nearly double those of the previous set of runs. However, during this trial, the run on Filter 3 (10 $gpm/ft^2$) was terminated based on headloss rather than particle breakthrough.

Turbidity and particle levels were comparable for Filter 1 (4 $gpm/ft^2$) and Filter 2 (7 $gpm/ft^2$). Filter 3 (10 $gpm/ft^2$) again had significantly higher particle counts and higher turbidity than the other two filters.

**Figure 34. SP/GF Headloss, Turbidity, and Particle Counts; Run SP2**

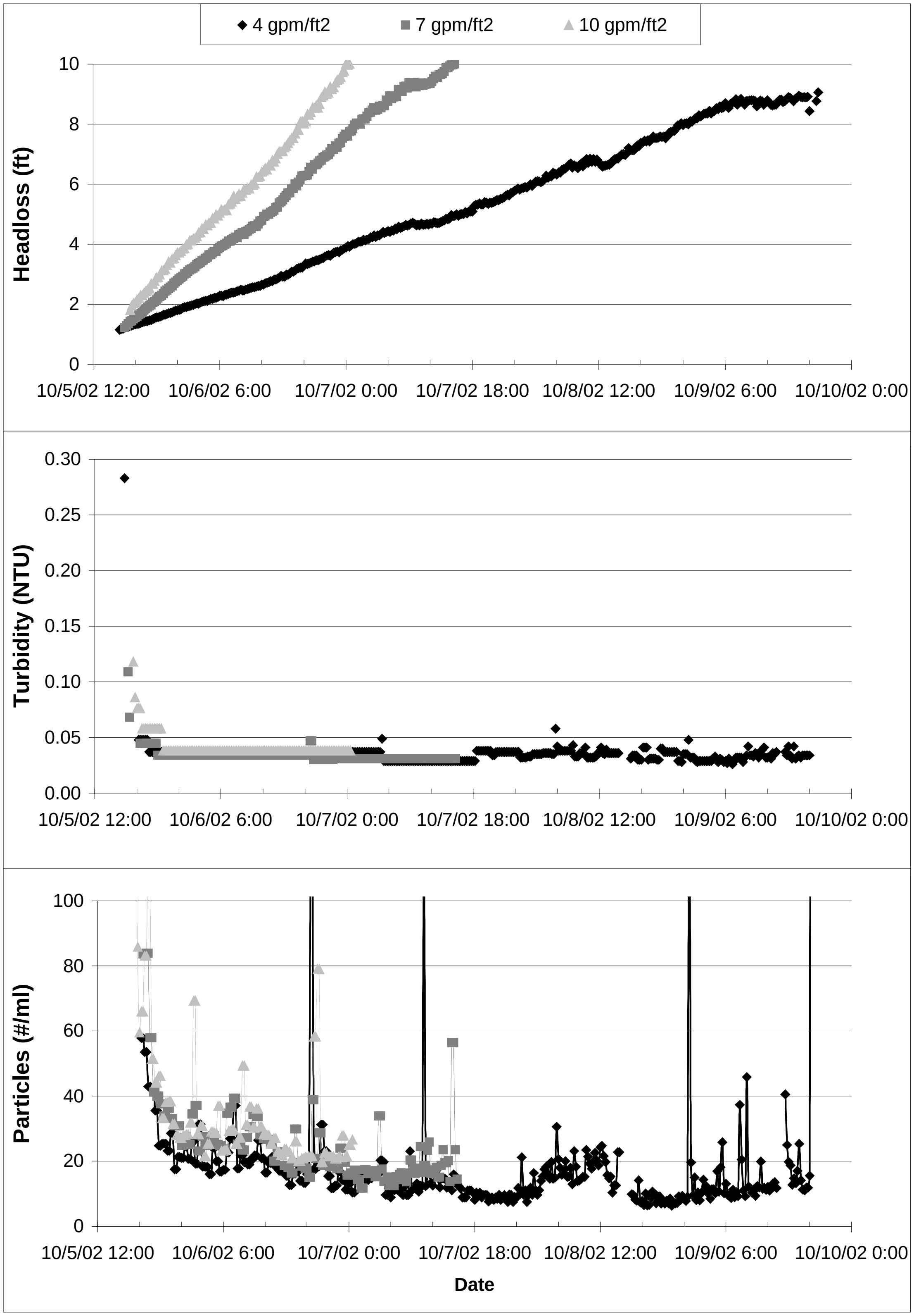


**Table 26. SP/GF Performance; Run SP2**

| Parameter | Units | Filter 1 | Filter 2 | Filter 3 |
|---|---|---|---|---|
| Filter Loading Rate | (gpm/ft$^2$) | 4 | 7 | 10 |
| Filter Run Duration | (hrs) | 99.5 | 47.0 | 31.3 |
| Unit Filter Run Volume | (gal/ft$^2$) | 23880 | 19740 | 18750 |
| Total Headloss | (ft) | 7.9 | 8.8 | 8.2 |
| Rate of Headloss | (in/hr) | 1.0 | 2.2 | 3.1 |
| Average Turbidity$_{Online}$ | (NTU) | 0.035 | 0.037 | 0.046 |
| Average Particle Counts$_{Online}$ | (#/ml) | 17.1 | 25.9 | 33.7 |

### Conclusions

The goal of this testing program was to evaluate the filterability of SuperP clarified water and assess the production of potable water meeting the drinking water regulations at various filtration rates.

The Super-P clarified water is filterable. The tests indicated that average turbidities were less than 0.05 NTU at all filtration rates (4, 7, and 10 gpm/ft$^2$) and average particle counts were less than 33.7 counts/ml. The water production measured by UFRV was also acceptable ranging from 9,000 gal/ft$^2$ to over 20,000 gal/ft$^2$ depending on the loading rate Loading rates from 4 to 7 gpm/ft$^2$ resulted in filter runs from 30 to 99 hours. Loading rates of 10 gpm/ft$^2$ were not as reproducible and may require additional optimization.

## Actiflo Clarification with Granular Media Filtration

The objective of AF/GF testing was to evaluate this process as a pretreatment system for RO membranes. The goal of testing was to gather the necessary data to develop full scale design recommendations for Actiflo clarification and granular media filtration.

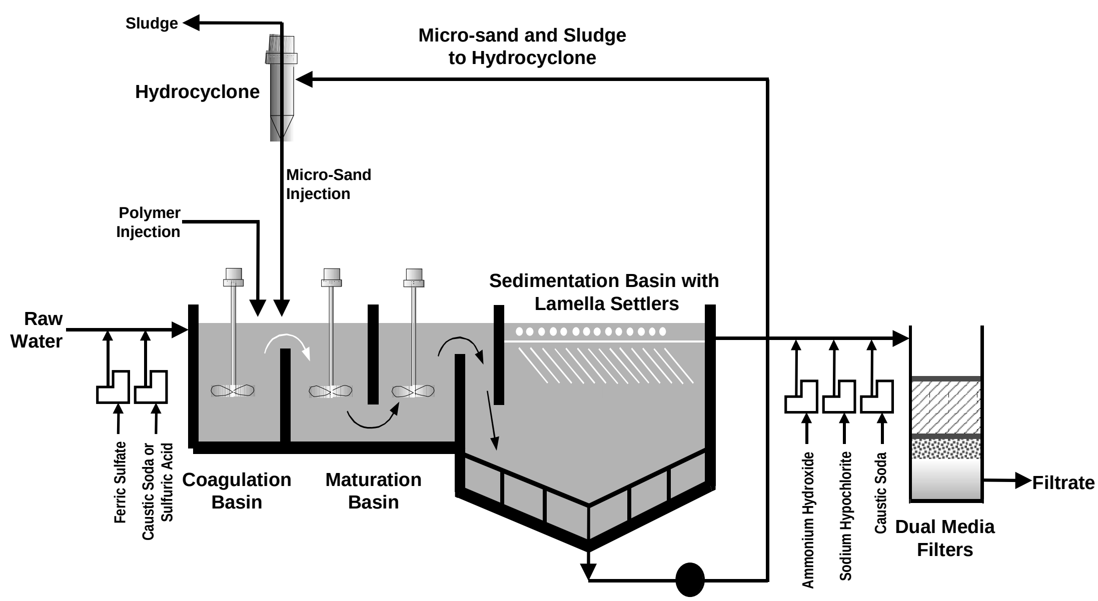
### Actiflo Process Equipment Description

Actiflo® is a high rate clarification process that uses microsand-enhanced flocculation and tube settling to produce a clarified effluent. For this treatment, sand is introduced to the coagulated water along with polymer to form the microsand ballasted floc. The sand increases the floc particle density, subsequently causing a higher floc settling velocity. Advantages of this process include enhanced treatment for colored waters and very high loading rates that can significantly reduce surface area requirements.

Figure 35 illustrates the Actiflo process used during this pilot study. The process consists of a rapid mix in which a coagulant is added, followed by an injection tank, where microsand and a polymer are added in a high energy mixing environment. A maturation zone follows, where lower energy mixing takes place to build the floc. The water then enters the settling tank, where the microsand flocs settle out quickly, with further clarification by tube settling. The clarified effluent is discharged at the top of the unit and flows to granular media (anthracite / sand) filters for further particle removal and polishing prior to RO treatment.

The microsand sludge at the bottom of the settling tank is pumped to a hydrocyclone, where the sand is separated from the sludge by centrifugal force. The separated sand is returned to the head of the process for reintroduction in the injection tank, while the sludge is removed for further processing.

**Figure 35. Process Flow Schematic for Actiflo Clarifier with Granular Media Filtration**



### Testing Summary

Actiflo testing began in August 2001 during the initial pretreatment evaluation. Piloting continued until December 2001, when testing stopped to evaluate the results of this initial testing and develop the testing protocol for the remaining phases.

In March 2002, the SuperP produced water for the RO membranes. The Actiflo process was not brought back for testing until August 2002. At this time, coagulation and filtration optimization was conducted for approximately one month. After this time, the SuperP was replaced by the Actiflo as the treatment system for the RO membranes. During this time, granular media filtration testing was performed, with subsequent RO testing being conducted on the filtrate. Granular media filtration testing included evaluation of high filter loading rates to maximize production from the filters.

Actiflo testing conducted from August 2001 to December 2001 was previously summarized. This section addresses Actiflo testing from August 2002 to April 2003. For further information on the initial pretreatment evaluation testing, see the Phase 1A Report located in Appendix B.

Membrane testing resumed once the AF/GF pretreatment was optimized. Table 27 summarizes the single element membrane testing conducted on the AF/GF water. The first phase of testing, Phase 1A, was the initial pretreatment evaluation. This phase included a side-by-side comparison of the AF/GF to SP/GF and ZW-UF pretreatment trains.

The next phase of testing, from September 2002 to November 2002 was the continued single element evaluation. The goal of this phase was to collect long term performance data on the single element membranes. From January 2003 to April 2003, the water from the AF/GF process was used for a flux evaluation with the RO membranes.

**Table 27. Single Element Membrane Testing Summary for AF/GF Evaluation**

| Task and Pretreatment | Dates | Hours of Testing | Filmtec BW30FR | TriSep X-20 | Osmonics SG | Hydranautics LFC1 |
|---|---|---|---|---|---|---|
| Pretreatment Evaluation | 11/09/01-12/19/01 | 850 | | XX | XX | |
| Continued Single Element Eval. | 09/23/02-11/08/02 | 800 | XX | XX | XX | XX |
| Flux Evaluation | 01/28/03-04/02/03 | 1250 | XX | | | |

Table 28 summarizes the high recovery membrane testing conducted on the AF/GF water. High recovery membrane testing with Actiflo treated water began in September 2002 and ended in April 2003.

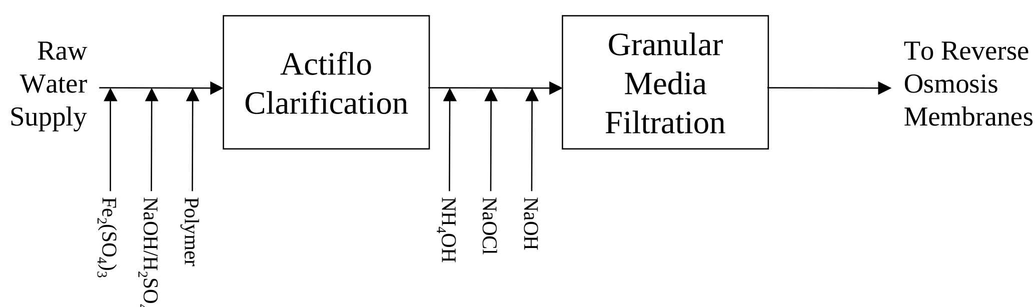
**Table 28. High Recovery Membrane Testing Summary for AF/GF Evaluation**

| Task and Pretreatment | Dates | Hours of Testing | Filmtec BW30FR | Filmtec BW30LE | TriSep X-20 | Osmonics SG |
|---|---|---|---|---|---|---|
| High Recovery Evaluation | 09/23/02-12/19/02 | 1470 | XX | XX | XX | XX |
| Continued Evaluation | 01/17/03-04/02/03 | 1270 | XX | XX | XX | |

Figure 36 is a simplified process schematic for the Actiflo clarifier and granular media filter pretreatment. Ferric sulfate and either sodium hydroxide or sulfuric acid (depending on raw water alkalinity and coagulant dosage) were applied to the raw water prior to the clarifier. Further, polymer was necessary for attachment of the floc to the microsand. The AF loading rate for these studies was approximately 20 gpm/ft$^2$.

Following coagulation/flocculation the water flowed to the dual media filters. The clarified effluent was then chloraminated with sodium hypochlorite and ammonium hydroxide. Further, prior to filtration, the pH was adjusted to between 6.5 and 7.0 to remove soluble iron in the clarified effluent. Granular media filters were 42 inches of anthracite over 12 inches of sand. Pilot filters in the CH2M HILL trailer[10] were operated to collect detailed filtration design data, while larger filters in the pilot building were operated to produce larger quantities of filtered water for testing on the RO membranes.

**Figure 36. Simplified Process Flow Diagram for the AF/GF Pretreatment Testing**




[10] The CH2M HILL trailer housed three 4 inch diameter pilot filters which were monitored online by a common turbidimeter and particle counter.

## Performance Summary

### *Water Quality*

Tables 29, 30, and 31, summarize the results for the daily sampling and analyses of raw, Actiflo clarified, and granular media filtrate streams, respectively. The data is for the period August 13, 2002 to April 2, 2003, and includes average, maximum, minimum, standard deviation, and coefficient of variance for each water quality parameter. In addition, Table 30 summarizes the coagulation dosage, polymer dosage, and coagulation pH data for the Actiflo process while Table 31 summarizes the filtration pH and total chlorine concentration.

During the AF/GF testing, average raw water $UV_{254}$ was 1.018 abs/cm and ranged from 0.455 to 1.331 abs/cm, while average conductivity was 57.1 S/m and ranged from 31.4 to 86.5 S/m. This evaluation began in the rainy season. However, due to wetter than expected conditions continuing into January and February, the conductivity was lower than would normally be expected.

**Table 29. Raw Water Quality for AF/GF Testing on Lake Monroe Water**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **pH** | | 7.0 | 7.4 | 6.3 | 0.2 | 0.02 |
| **Temperature** | **($^{o}$C)** | 19.5 | 29.7 | 10.4 | 4.7 | 0.24 |
| **Alkalinity** | **(mg/L as $CaCO_3$)** | 54 | 105 | 23 | 18 | 0.33 |
| **Turbidity** | **(NTU)** | 6.0 | 36.3 | 1.8 | 2.4 | 0.40 |
| **Conductivity** | **(S/m)** | 57.1 | 86.5 | 31.4 | 12.3 | 0.22 |
| **Apparent Color** | **(Pt-Co)** | 249 | 720 | 110 | 73 | 0.29 |
| **$UV_{254}$** | **(abs/cm)** | 1.018 | 1.331 | 0.455 | 0.150 | 0.15 |

Table 30 summarizes the ferric sulfate dosages for the Actiflo process during testing. All ferric sulfate dosages are reported as pure (100 percent) ferric sulfate. As the table shows, the average ferric sulfate dosages for the Actiflo process were 144 mg/L and ranged from 289 mg/L to 69 mg/L.

The average polymer dosage during the testing was 0.38 mg/L and ranged from 0.15 mg/L to 0.75 mg/L. Two types of polymer were tested during the evaluation, Cytec® Superfloc® C-1592 PG and Ciba® Magnafloc® LT22S. Both polymers were a medium charge density cationic polymer. Note that cationic polymers can potentially cause membrane fouling. The potential impact of polymer carryover on membrane performance was not directly evaluated during this testing.

The average coagulation pH was 4.1 for testing, resulting in an average soluble iron concentration of 0.88 mg/L.

Average apparent color and $UV_{254}$ after clarification were 6 Pt-Co and 0.079 abs/cm, respectively. Turbidity ranged from 3.53 NTU to 0.16 NTU with an average of 0.43 NTU.

**Table 30. AF Clarified Water Quality for AF/GF Testing on Lake Monroe Water**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **Ferric Dosage (pure)** | **(mg/L)** | 144 | 289 | 69 | 35 | 0.25 |
| **Polymer** | **(mg/L)** | 0.38 | 0.75 | 0.15 | 0.12 | 0.32 |
| **Coagulation pH** | | 4.1 | 5.7 | 3.3 | 0.3 | 0.06 |
| **Turbidity** | **(NTU)** | 0.43 | 3.53 | 0.16 | 0.29 | 0.68 |
| **Iron** | **(mg/L)** | 0.88 | 1.25 | 0.51 | 0.18 | 0.21 |
| **Apparent Color** | **(Pt-Co)** | 6 | 31 | 0 | 4 | 0.71 |
| **$UV_{254}$** | **(abs/cm)** | 0.079 | 1.060 | 0.027 | 0.066 | 0.84 |

As Table 31 suggests, filtered water turbidity was 0.045 NTU and ranged from a maximum of 0.084 NTU to 0.026 NTU. Turbidity readings were taken from the online turbidimeter and were only taken during steady state filtration conditions. Therefore, this average turbidity does not account for the turbidity during ripening and breakthrough. Average particle counts ranged from 10.0 counts/mL to 90.9 counts/mL with an average of 31.2 counts/mL. Again, as with the turbidity, readings were taken from online particle counters and were only taken during steady state filtration.

**Table 31. Filtered Water Quality for AF/GF Testing on Lake Monroe Water**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **pH** | | 6.6 | 7.1 | 6.0 | 0.3 | 0.04 |
| **Alkalinity** | **(mg/L as $CaCO_3$)** | 25 | 38 | 10 | 6 | 0.24 |
| **Turbidity** | **(NTU)** | 0.045 | 0.084 | 0.026 | 0.011 | 0.23 |
| **Particle Counts** | **(#/ml)** | 31.2 | 90.9 | 10.0 | 19.6 | 0.63 |
| **Apparent Color** | **(Pt-Co)** | 2 | 6 | 0 | 1 | 0.86 |
| **$UV_{254}$** | **(abs/cm)** | 0.074 | 0.100 | 0.051 | 0.011 | 0.15 |
| **Iron** | **(mg/L)** | 0.030 | 0.075 | 0.000 | 0.022 | 0.71 |
| **Total $Cl_2$** | **(mg/L as $Cl_2$)** | 1.67 | 4.27 | 0.00 | 1.26 | 0.75 |

Table 32 and Figure 37 summarize the average removal of turbidity, apparent color, and $UV_{254}$ by clarification, granular media filtration, and the combined clarification/granular media filtration process. As Table 32 and Figure 37 illustrate, the cumulative turbidity removal was 99.2 percent, the cumulative apparent color removal was 99.3 percent, and the cumulative $UV_{254}$ removal was 92.8 percent.

**Table 32. Average Turbidity, Apparent Color, and UV254 Removals for AF/GF Testing on Lake Monroe Water**

| Parameter | Units | Averages | | | Removals | | |
|---|---|---|---|---|---|---|---|
| | | Raw | Clarified | Filtered | Raw to Clarified | Clarified to Filtered | Cumulative Removal |
| Turbidity | (NTU) | 6.0 | 0.43 | 0.045 | 92.8% | 89.5% | 99.2% |
| Apparent Color | (Pt-Co) | 249 | 6 | 2 | 97.7% | 70.6% | 99.3% |
| $UV_{254}$ | (abs/cm) | 1.018 | 0.079 | 0.074 | 92.3% | 6.5% | 92.8% |

### *Filterability*

The Actiflo unit was followed by a dual media filter. The filterability of the Actiflo clarified effluent was quantified by headloss, turbidity, particle counts, and UFRV. Continuous data for headloss, particle counts, and turbidity were collected in the CH2M HILL trailer using the 4 inch pilot scale filters and a PLC data logger.

The data presented represents a properly operated AF/GF process and is representative of typical filter runs observed during testing. The following data collected during non-representative periods is not included:

- Interruptions in chemical feed to the clarified effluent
- Actiflo operational upsets
- System pressure changes resulting in particle breakthrough
- Feed pump problems resulting in loss of flow or reduced flow

Figure 38 and Table 33 summarize the filtration data for the filter runs with different loading rates starting on November 26, 2002. Three filter runs were conducted simultaneously. Filters 1, 2, and 3 were operated at 4, 7, and 10 gpm/$ft^2$, respectively, to evaluate the effect of higher filter loading rates on water quality.

**Figure 37. Raw, Clarified, and Filtered Water Quality Levels for AF/GF Testing on Lake Monroe Water**

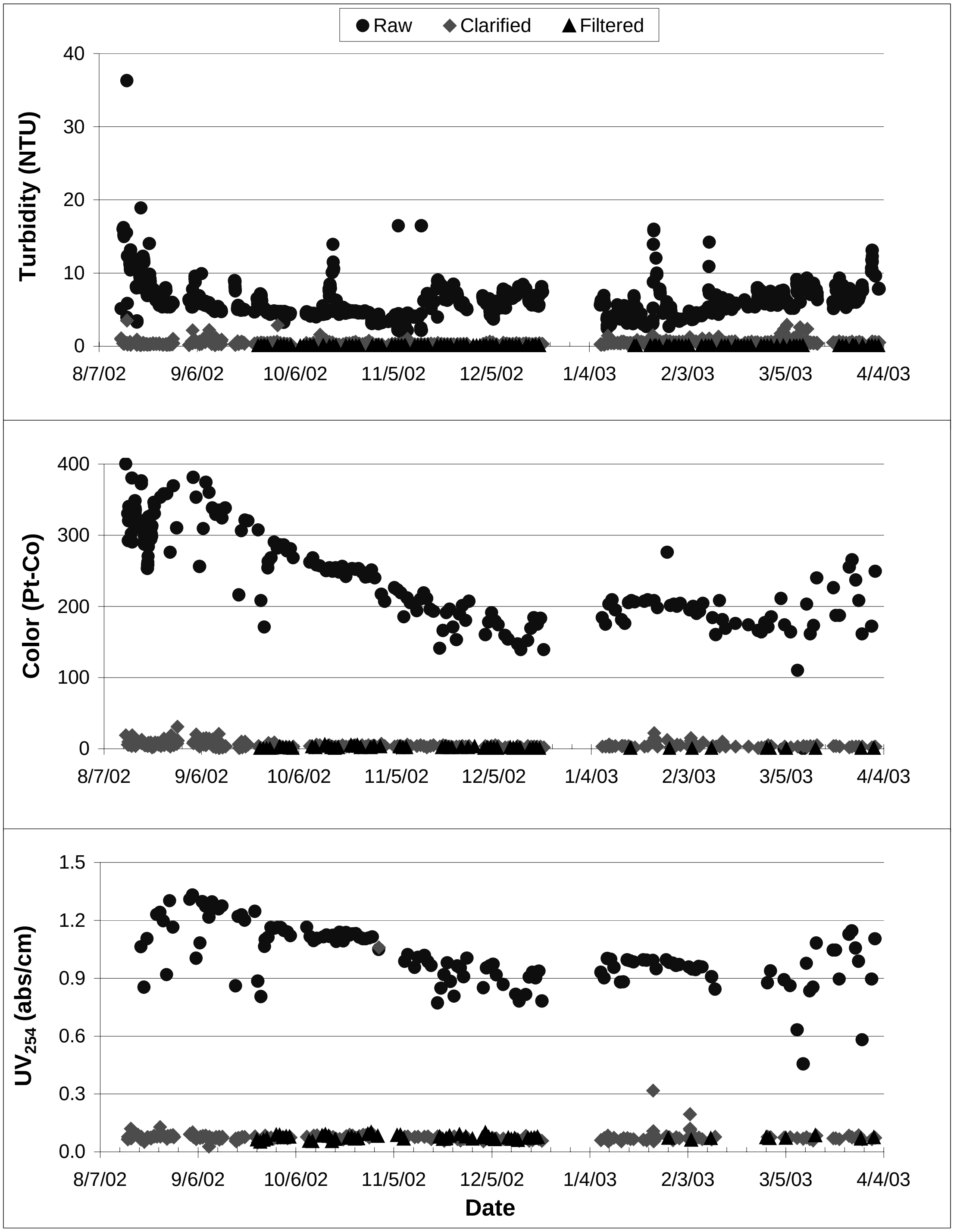
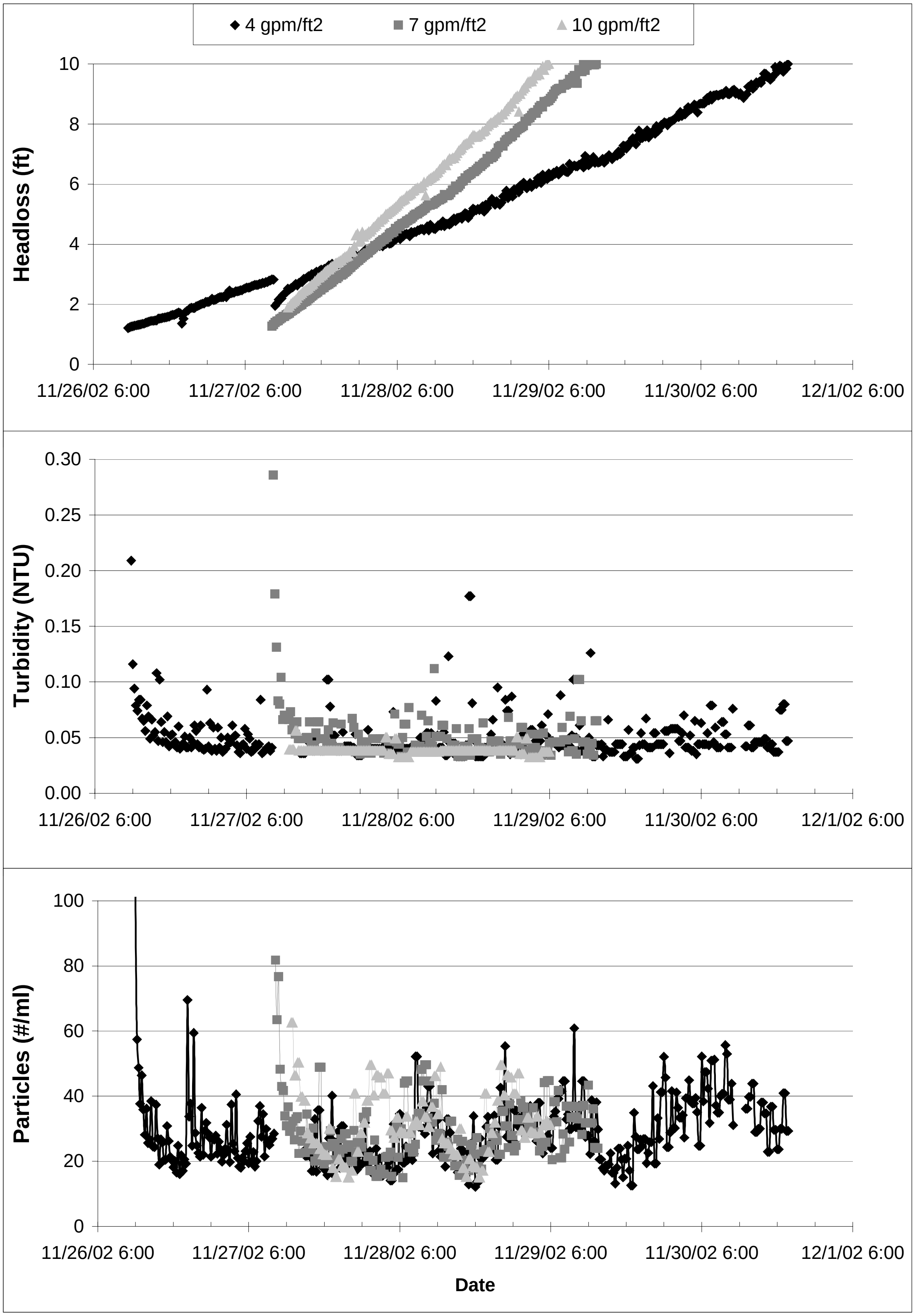


**Figure 38. AF/GF Headloss, Turbidity, and Particle Counts; Run AF1**



All of the filter runs had acceptable UFRV's with all filter runs being terminated based on terminal headloss rather than particle breakthrough.

Filtered water turbidity and particle levels were comparable among the three filters. Surprisingly, Filter 3 (10 gpm/ft$^2$) had higher particle counts and lower turbidity than the other two filters even though the differences were small. This may have been due to the shorter filter run duration for Filter 3 (10 gpm/ft$^2$) and the variability in feed water quality throughout the filter run.

**Table 33. AF/GF Performance; Run AF1**

| Parameter | Units | Filter 1 | Filter 2 | Filter 3 |
|---|---|---|---|---|
| Filter Loading Rate | (gpm/ft$^2$) | 4 | 7 | 10 |
| Filter Run Duration | (hrs) | 104.3 | 51.2 | 41.3 |
| Unit Filter Run Volume | (gal/ft$^2$) | 25020 | 21525 | 24750 |
| Total Headloss | (ft) | 8.8 | 8.7 | 8.1 |
| Rate of Headloss | (in/hr) | 1.0 | 2.0 | 2.4 |
| Average Turbidity$_{Online}$ | (NTU) | 0.048 | 0.047 | 0.038 |
| Average Particle Counts$_{Online}$ | (#/ml) | 28.0 | 28.7 | 31.0 |

Figure 39 and Table 34 summarize the filtration data for the filter runs with different loading rates starting on March 3, 2002. Again, three filter runs were conducted simultaneously on Filters 1, 2, and 3, which were operated at 4, 6, and 8 gpm/ft$^2$, respectively. Lower filter rates were evaluated due to the unpredictable filter performance at the highest loading rate, namely 10 gpm/ft$^2$.

The performance during this set of runs was worse than the previous set with respect to UFRV. The lower UFRV's were due to increased rates of headloss on the filters, likely due to excess particle carryover from the Actiflo clarifier. However, UFRV's were still at an acceptable level.

It would appear that Filter 1 (4 gpm/ft$^2$) performed better than the other filters with respect to turbidity and particle levels. However, as Figure 39 illustrates, all of the filters had improving water quality throughout the filter run. But, after Filter 2 and 3 were taken offline, the turbidity and particle counts continued to decrease for Filter 1 (4 gpm/ft$^2$). This, subsequently, resulted in lower average turbidity and particle counts for Filter 1.

**Figure 39. AF/GF Headloss, Turbidity, and Particle Counts; Run AF2**

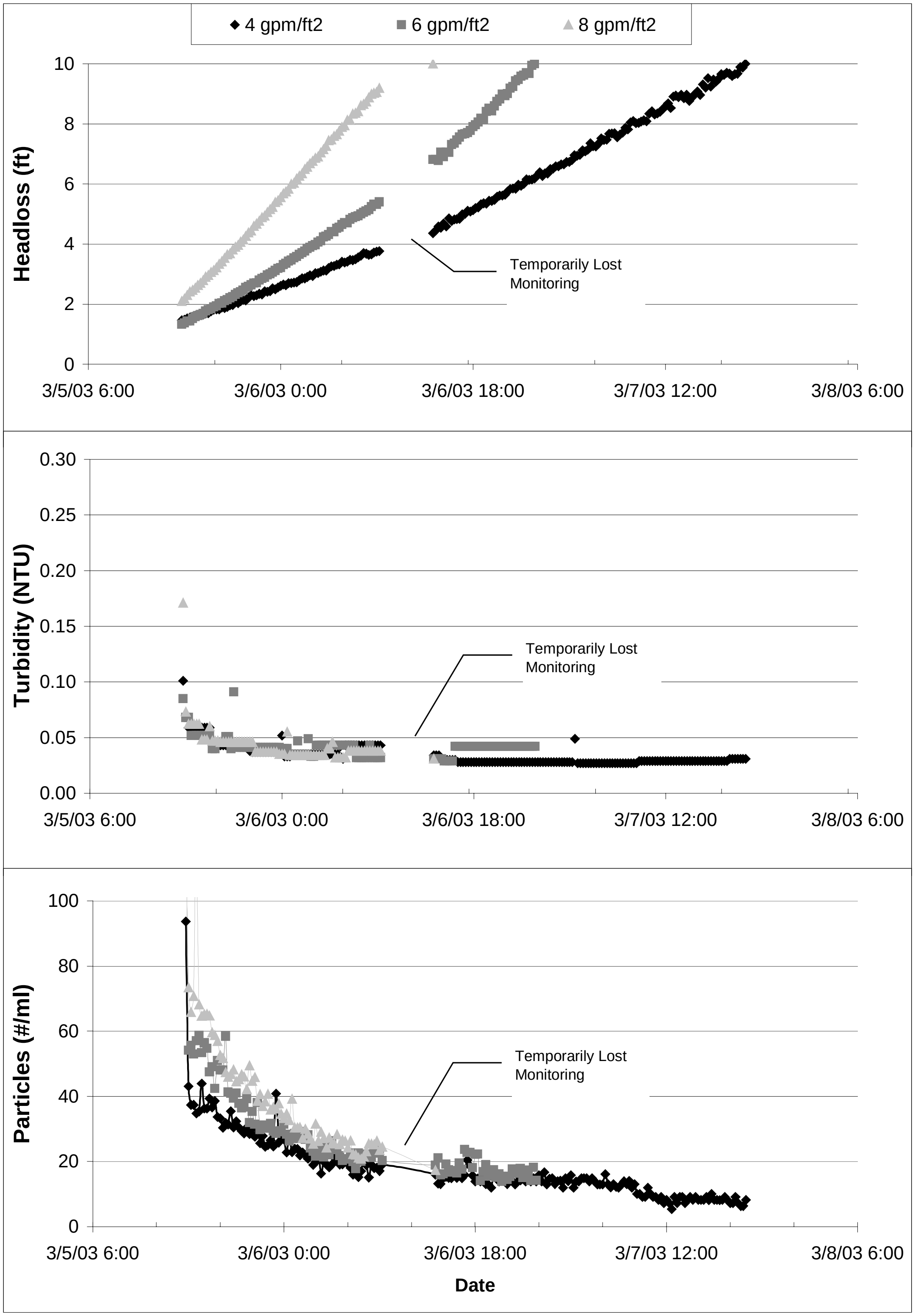


**Table 34. AF/GF Performance; Run AF2**

| Parameter | Units | Filter 1 | Filter 2 | Filter 3 |
|---|---|---|---|---|
| Filter Loading Rate | (gpm/ft$^2$) | 4 | 6 | 8 |
| Filter Run Duration | (hrs) | 52.7 | 33.0 | 23.5 |
| Unit Filter Run Volume | (gal/ft$^2$) | 12660 | 11880 | 11280 |
| Total Headloss | (ft) | 8.5 | 8.7 | 7.9 |
| Rate of Headloss | (in/hr) | 1.9 | 3.2 | 4.0 |
| Average Turbidity$_{Online}$ | (NTU) | 0.033 | 0.040 | 0.039 |
| Average Particle Counts$_{Online}$ | (#/ml) | 16.5 | 25.0 | 34.1 |

Figure 40 and Table 35 summarize filter runs in which ozone was applied to the clarified effluent/filter feed stream. The runs began on March 13, 2003 and were conducted simultaneously at 4, 6, and 8 gpm/ft$^2$ on Filters 1, 2, and 3, respectively. Ozone was applied in a contactor at a dosage of 5 mg/L, and was then passed through an off-gasser.

The performance during this set of runs was very poor with respect to UFRV when compared to other filter runs. This data set is not representative since the ozone testing was terminated before it could be optimized. The ozone testing was not continued since the bromide levels exceed 1.0 mg/L and result in significant levels of the by-product bromate that would exceed regulatory levels.

**Table 35. GF with Ozone Preoxidation; Performance Summary; Run AF1**

| Parameter | Units | Filter 1 | Filter 2 | Filter 3 |
|---|---|---|---|---|
| Filter Loading Rate | (gpm/ft$^2$) | 4 | 6 | 8 |
| Filter Run Duration | (hrs) | 31.0 | 19.5 | 9.2 |
| Unit Filter Run Volume | (gal/ft$^2$) | 7440 | 7020 | 4440 |
| Total Headloss | (ft) | 1.1 | 1.4 | 0.9 |
| Rate of Headloss | (in/hr) | 0.4 | 0.9 | 1.2 |
| Average Turbidity$_{Online}$ | (NTU) | 0.047 | 0.051 | 0.053 |
| Average Particle Counts$_{Online}$ | (#/ml) | 10.9 | 16.7 | 16.8 |

The applied ozone dosage was approximately 5 mg/L.

**Figure 40. GF with Ozone Preoxidation; Headloss, Turbidity and Particle Counts; Run GF1**

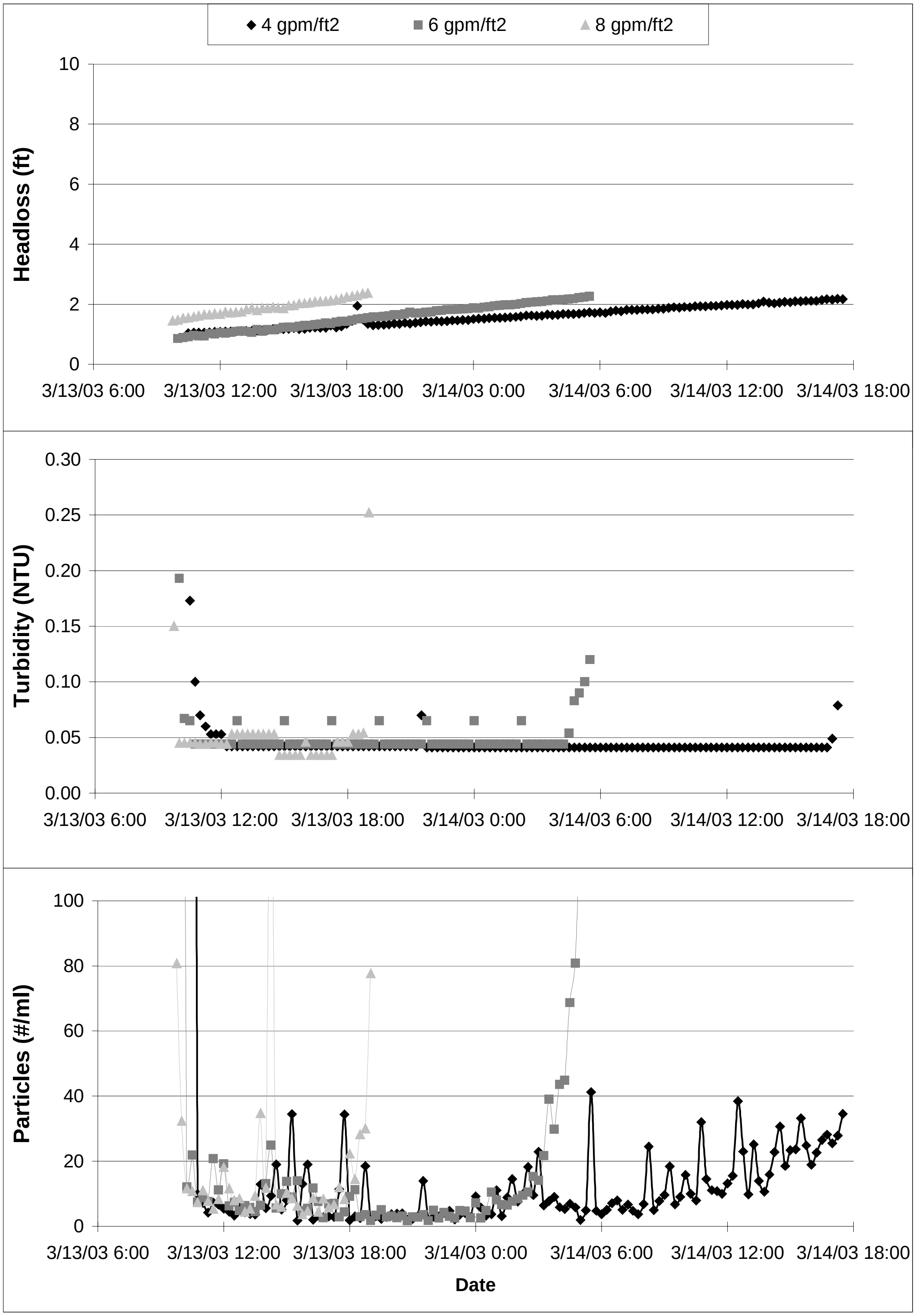


Figure 41 and Table 36 summarize filter runs starting on March 31, 2003 to assess different media configurations. Anthracite was added to two of the filters in order to have anthracite depths of 44, 48, and 52 inches to assess the effect on filtered water quality. The depth of sand was held constant at 12 inches for all of the filters. Again, three filter runs were conducted simultaneously. All of the filters were operated at 6 $gpm/ft^2$.

During this run, the higher anthracite depths resulted in slightly higher UFRV's and lower rates of headloss. With more optimization, more substantial levels of improvement could be realized using deeper media configurations. Turbidity and particle count levels were comparable for the filters.

**Table 36. GF with Varying Media Configurations; Performance Summary; Run AF1**

| Parameter | Units | 44" Anthracite | 48" Anthracite | 52" Anthracite |
|---|---|---|---|---|
| Filter Loading Rate | ($gpm/ft^2$) | 6 | 6 | 6 |
| Filter Run Duration | (hrs) | 22.3 | 23.3 | 26.0 |
| Unit Filter Run Volume | ($gal/ft^2$) | 8010 | 8370 | 9360 |
| Total Headloss | (ft) | 7.8 | 7.5 | 6.8 |
| Rate of Headloss | (in/hr) | 4.2 | 3.9 | 3.1 |
| Average $Turbidity_{Online}$ | (NTU) | 0.041 | 0.043 | 0.043 |
| Average Particle $Counts_{Online}$ | (#/ml) | 31.2 | 31.0 | 28.8 |

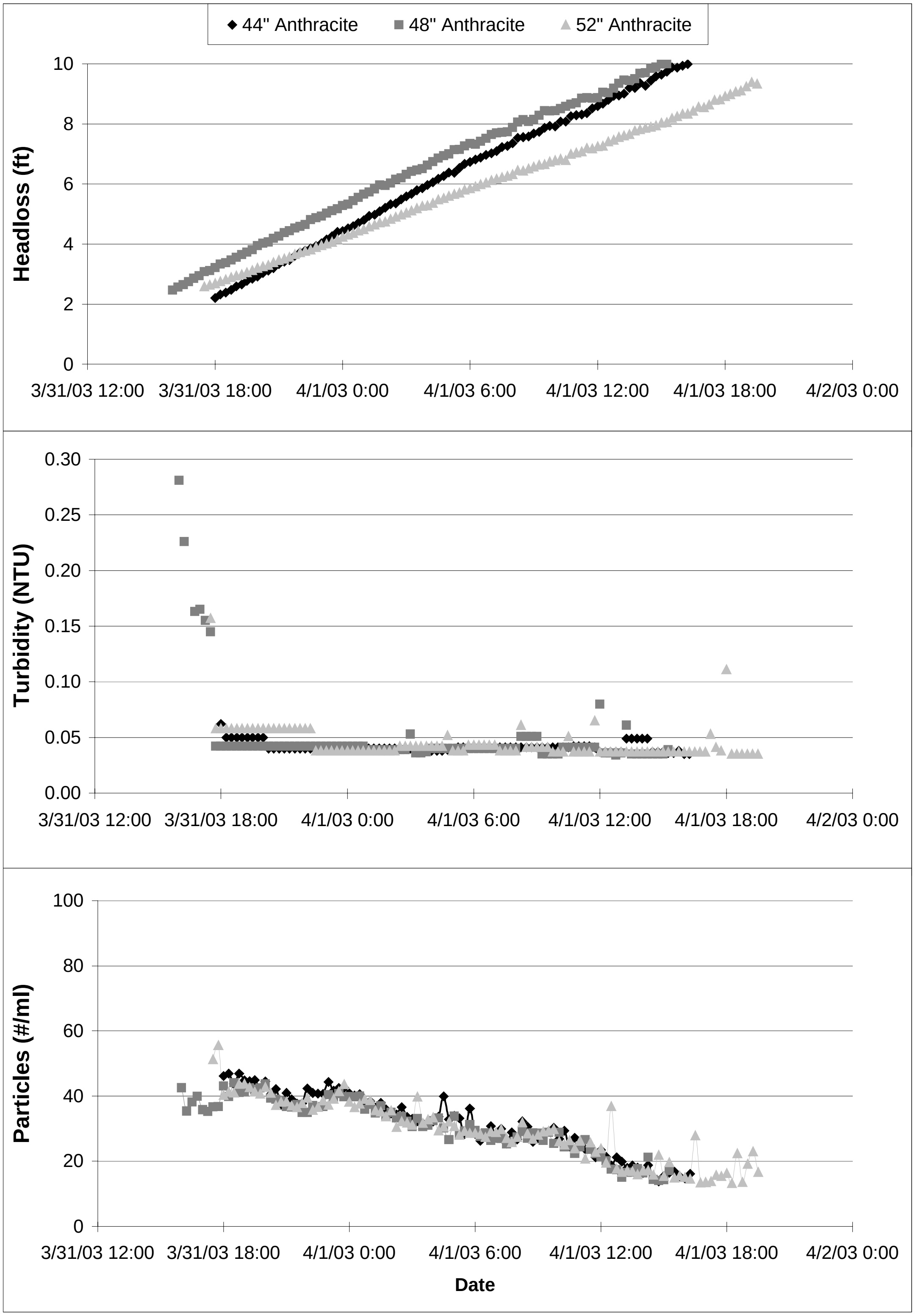
All filters were still dual media with 12" of sand under the anthracite

## Conclusions

This phase of testing included Actiflo clarification followed by granular media filtration, initially at filtration rates up to 10 $gpm/ft^2$ with a second set of runs up to 8 $gpm/ft^2$.

The Actiflo clarified water is filterable. All of the data indicated that filtration up to a rate of 8 $gpm/ft^2$ will produce filtered water quality meeting the drinking water regulations. The average filtered water quality was less than -0.1 NTU with average particle counts less than 34.1 counts/ml. For design of filters with Actiflo clarification, filtration rates up to from 4 to 8 $gpm/ft^2$ maybe used, with filter run times ranging from 24 hours to 100 hours depending on the loading rate used.

**Figure 41. GF with Varying Media Configurations; Headloss, Turbidity, and Particle Counts; Run AF1**



## Phase 1B, 2 and 3 MF/UF Testing

MF/UF was tested as a pretreatment to RO and to demonstrate that UF could produce a treated water meeting drinking water goals. One MF system, Memcor CMF-S, and one UF system, ZeeWeed 500-C, were tested during the study. Both were operated following clarification as a replacement for media filters. In addition, the ZeeWeed 500-C was tested in direct filtration mode, in which the Zenon was a standalone pretreatment with coagulation occurring in the process tank.

### Zenon Direct Filtration

The objective of Zenon direct filtration testing was to evaluate the Zenon process as a stand alone pretreatment system for direct comparison to Actiflo/SuperP clarification followed by granular media filtration. In direct filtration mode, flocculation is performed prior to ZeeWeed UF, but coagulation and filtration occur in the same tank.

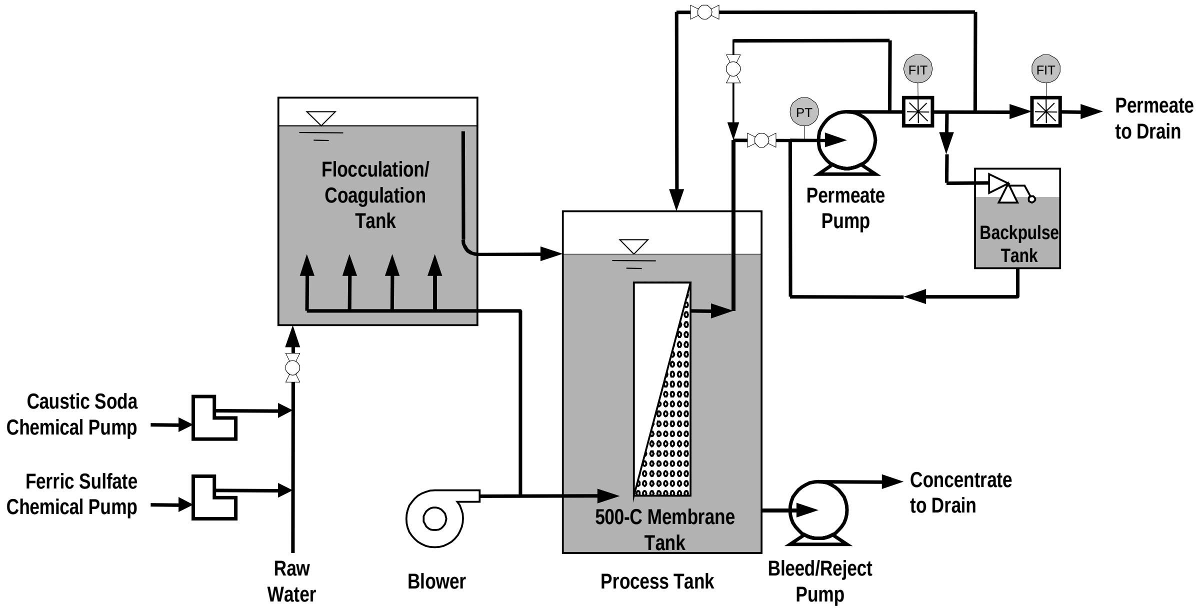
The objective of direct filtration testing was to gather the necessary data to develop full scale design recommendations for optimized flux, recovery, cleaning interval, and coagulant dosage and to accurately estimate full scale costs for a ZeeWeed based pretreatment system.

#### Equipment Description

ZeeWeed is a low-energy membrane treatment system that consists of hollow fiber UF modules immersed in a process tank containing the raw water being treated. The ZeeWeed hollow-fiber membrane has a 0.04-micron nominal and a 0.1-micron absolute pore size. These pore characteristics ensure that no particulate matter exceeding 0.1 microns in size, including Cryptosporidium oocysts and Giardia cysts, can pass through the membrane to the treated water stream. The loose, hollow fiber membranes are arranged in an assembly known as a “module” by connecting the fibers at both ends. During treatment, a vacuum is applied to the inside (lumen side) of the fibers at each end of the module. The resulting difference in pressure across the wall of the membrane caused water to flow from the outside of the fiber (feed side) through the membrane pores to the inside, thus becoming filtered (treated) water. The vacuum applied corresponds to the trans-membrane pressure for the system.

A simplified process schematic of the ZeeWeed process is shown in Figure 42. The system operated in continuous mode with no recirculation flow in this study.

**Figure 42. Process Flow Schematic for ZeeWeed System**




The undesired accumulation of foulants at the outside surface of the fibers is controlled by:

- Continuous or periodic introduction of air below the surface of the module to cause agitation of the fibers and scour suspended solids form the surface of the membrane, thereby mechanically removing the foulants
- Periodic backwashing of the membranes (reverse flow of filtered water through the pores from inside to outside)
- When the permeate-side vacuum becomes excessive, the membranes are chemically cleaned with chlorine, citric acid, or other chemical agents

Table 37 provides an operational description and summary of settings for ZeeWeed testing in direct filtration mode. As indicated in the table, the system was operated at a recovery of 90 percent for the duration of testing. Further, the air scrub was operated in a cyclic mode, whereby air scrubbing was cycled on and off at 10 second intervals.

To restore productivity of the membrane systems (reduced as a result of fouling) recovery cleans were performed. For the ZeeWeed membrane, two separate cleans were required for an effective recovery clean. The first clean was a chlorine clean and the second was a citric acid clean.

**Table 37. Operational Description and Settings for ZeeWeed Direct Filtration Testing**

| Parameter | Zenon |
|---|---|
| Driving Force | Filtrate Suction |
| Fiber Diameter | 1.9 mm |
| Module Dimensions | Length = 29" Width = 9" Height = 79" |
| Nominal Pore Size | 0.04 micron |
| Module Surface Area (External) | 660 sq.ft |
| Run Duration | Production for 15 minutes |
| Backpulse | Reverse flow for 15 seconds |
| Air Scrub | Cyclic diffused air @ 15 scfm (10-sec cycling interval) |
| Waste Stream | Continuous bleed from process tank at 90% Recovery |
| Typical Recovery Clean Solution - Chlorine | 1000 mg/L as $Cl_2$ (backpulse), 250 mg/L as $Cl_2$ (soak) |
| Typical Recovery Clean Solution - Citric Acid | Citric acid 4 g/L (backpulse), 1 g/L (soak) |
| Coagulant | Ferric Sulfate |

The goal for cleaning interval frequency was 4 to 6 weeks based on Zenon and CH2M HILL recommendations. A recovery clean was initiated based on trans-membrane pressure (TMP) loss of 6 psi assuming an initial TMP of 3 psi and a terminal TMP of 9 psi. Based on these limitations, the acceptable rates of daily TMP loss ranged from 0.21 psi/day to 0.14 psi/day (4 and 6 week cleaning intervals, respectively).

A clean was performed by first draining the process tank. Sodium hypochlorite was applied to 80 L of water in the backpulse tank to achieve a solution concentration of 1,000 mg/L as $Cl_2$. This solution was backpulsed through the membrane for 30 seconds followed by a 60 second relaxation (pause). This was continued until the solution was drained from the backpulse tank at which point the process tank was filled with water, resulting in a 250 mg/L as $Cl_2$ soak solution for the membrane. After two hours, the water was recirculated through the system to evaluate the TMP recovery and was again shut down. This was repeated every hour for approximately 2 to 4 hours more.

Once no additional TMP recovery was possible due to the chlorine clean solution, the tank was drained and flushed. The process was then repeated with a 4 g/L citric acid solution in the backpulse tank resulting in a 1 g/L soak solution. Further, the pH of the backpulse solution as well as the soak solution was reduced to 2 using hydrochloric acid.

For recovery of TMP during normal operation, maintenance cleans were performed. Maintenance cleans were similar to recovery cleans; however, the membrane was not allowed to soak in the solution. Rather, the membrane was placed back into production after the cleaning solution had been pumped through the membranes.

### Testing Summary

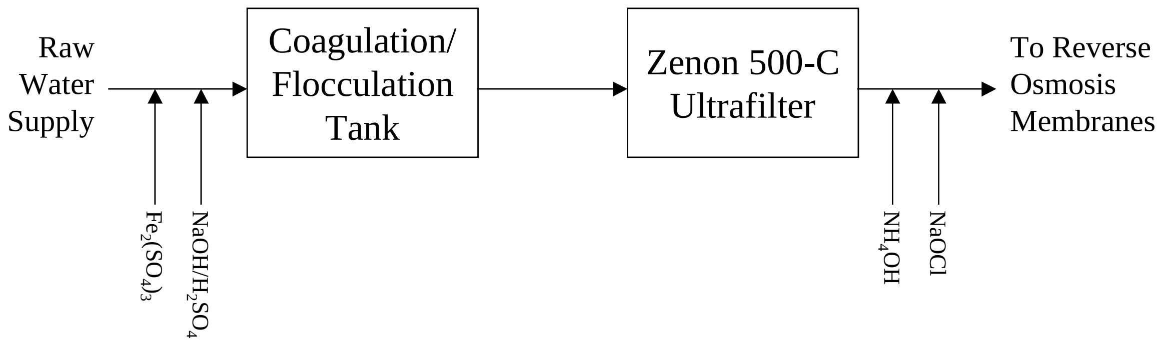
Table 38 summarizes the Zenon operating parameters during direct filtration testing. The testing was conducted from September 29, 2001 to October 25, 2002. During the testing, two coagulation optimizations and one flux optimization were performed. During Phase 1A, the pretreatment evaluation, a flux of 20, was tested. For the remaining phases of testing, alternative fluxes and various maintenance cleaning regimens were evaluated. Maintenance cleans were performed to recover pressure and extend membrane cleaning intervals.

**Table 38. Operating Parameters for Direct Filtration Testing of the Zenon 500-C Ultrafiltration**

| Date | Description | Target Flux (gfd) | Target Recovery (%) | Maintenance Cleans |
|---|---|---|---|---|
| 09/29/01 - 10/24/01 | Coagulation Optimization | 20 | 90 | None |
| 10/15/01 - 12/19/01 | Treatment Verification | 20 | 90 | None |
| 02/07/02 - 02/27/02 | Coagulation Optimization | 20 | 90 | None |
| 02/27/02 - 03/20/02 | Flux Optimization | Various | 90 | None |
| 03/21/02 - 03/25/02 | Flux Verification | 25 | 90 | None |
| 04/02/02 - 04/12/02 | Flux Verification | 25 | 90 | Aeration |
| 04/15/02 - 04/27/02 | Flux Verification | 25 | 90 | Chlorine (1000 ppm) |
| 04/27/02 - 05/23/02 | Flux Change | 20 | 90 | Chlorine (1000 ppm) |
| 05/30/02 - 06/11/02 | Flux Change | 25 | 90 | Chlorine (200 ppm) |
| 06/12/02 - 06/14/02 | Flux Verification | 25 | 90 | None |
| 06/15/02 - 06/20/02 | Flux Change | 20 | 90 | Chlorine (100 ppm) |
| 06/20/02 - 07/05/02 | Flux Change | 25 | 90 | Chlorine (100 ppm) |
| 07/06/02 - 07/09/02 | Flux Change | 20 | 90 | Chlorine (100 ppm) |
| 07/09/02 - 10/26/02 | Production | Various | 90 | NA |

Figure 43 is a simplified process schematic for direct filtration testing of the Zenon 500-C UF pilot unit. Ferric sulfate and either sodium hydroxide or sulfuric acid (depending on raw water alkalinity and coagulant dosage) were applied to the raw water prior to the flocculation tank. Following coagulation / flocculation the water flows into the membrane tank containing the ultrafiltration membranes. The UF permeate was then chloraminated with sodium hypochlorite and ammonium hydroxide.

**Figure 43. Process Schematic for Direct Filtration Testing of the Zenon 500-C Ultrafilter**




### Performance Testing

Performance testing of the Zenon pilot unit in direct filtration mode started in September 2001 and continued until October 2002. During the testing, two coagulation optimizations, a flux evaluation, and membrane verification testing were conducted.

#### *Coagulation Optimization*

Two coagulation optimizations were performed during testing. The first was performed at the start of Phase 1A, the pretreatment evaluation. The second was performed at the start of Phase 1B, the single element RO evaluation.

The goal of the coagulation optimization was to maximize organics removal and minimize dissolved iron in the UF permeate. When coagulating with iron salts, a lower pH will generally have a better organic removal efficiency. However, the iron is more soluble at a low pH, resulting in a higher level of dissolved iron in the permeate. When using conventional clarification processes, coagulation can be performed at a low pH, which achieves optimum organic removal. After clarification with conventional processes, the pH can be increased to decrease soluble iron levels prior to filtration.

However, with ZeeWeed direct filtration, coagulation and filtration occur in a single tank, and only a single pH condition can be achieved. When optimizing the ZeeWeed direct filtration process, the pH was first optimized to achieve a total iron concentration below 0.05 mg/L in the membrane permeate[11]. The next step was to optimize the coagulant dosage to achieve optimum NOM removal. NOM levels were based on $UV_{254}$ and color parameters.

The Phase 1A optimization was performed from September 29, 2001 to October 24, 2001. The optimization occurred during the rainy season when the raw water was characterized by higher than average levels of NOM, color, and $UV_{254}$ and lower than average salt levels. Average $UV_{254}$ and color levels were 1.53 abs/cm and 463 Pt-Co, respectively. ZeeWeed operating conditions were an average flux of 20 gfd and recovery of 90 percent.

On September 29, 2001, the pH optimization began using a coagulant dosage of 87.2 mg/L ferric sulfate. Different pH levels were tested ranging from 5.0 to 6.0. Figure 44 summarizes the pH optimization for Phase 1A. The top, middle, and bottom of the figure are divided into total iron concentration, $UV_{254}$ level, and color level as a function of coagulation pH. A pH between 5.8 and 6.0 was required to achieve a total permeate iron concentration of 0.05 mg/L. As expected, the color and $UV_{254}$ levels increased with increasing pH. Based on the results of the pH optimization, a coagulation pH of 5.8 was selected.

In order to determine the optimum coagulant dosage for color and $UV_{254}$ removal, it was necessary to evaluate higher coagulant dosages. Figure 45 summarizes the results of the coagulant optimization. During this evaluation, the pH was held constant with a target value of 5.8 based on the pH optimization. Based on the online pH data, the average pH was 5.8 and ranged from 4.3 to 6.6. Iron, $UV_{254}$, and color are plotted as a function of coagulant dosage. Coagulant dosages ranged from 109 mg/L to 218 mg/L. As expected, higher removals of $UV_{254}$ absorbance and color were achieved at higher coagulant dosages. Based on the results of the coagulant optimization, a coagulant dosage of 218 mg/L was selected as the optimum dosage for testing during the pretreatment evaluation.

[11] A goal of 0.05 mg/L iron was selected to minimize RO membrane fouling

**Figure 44. Total Iron, $UV_{254}$, and Color for Phase 1A pH Optimization Testing on Zenon 500C Ultrafiltration of Coagulated Lake Monroe Water**

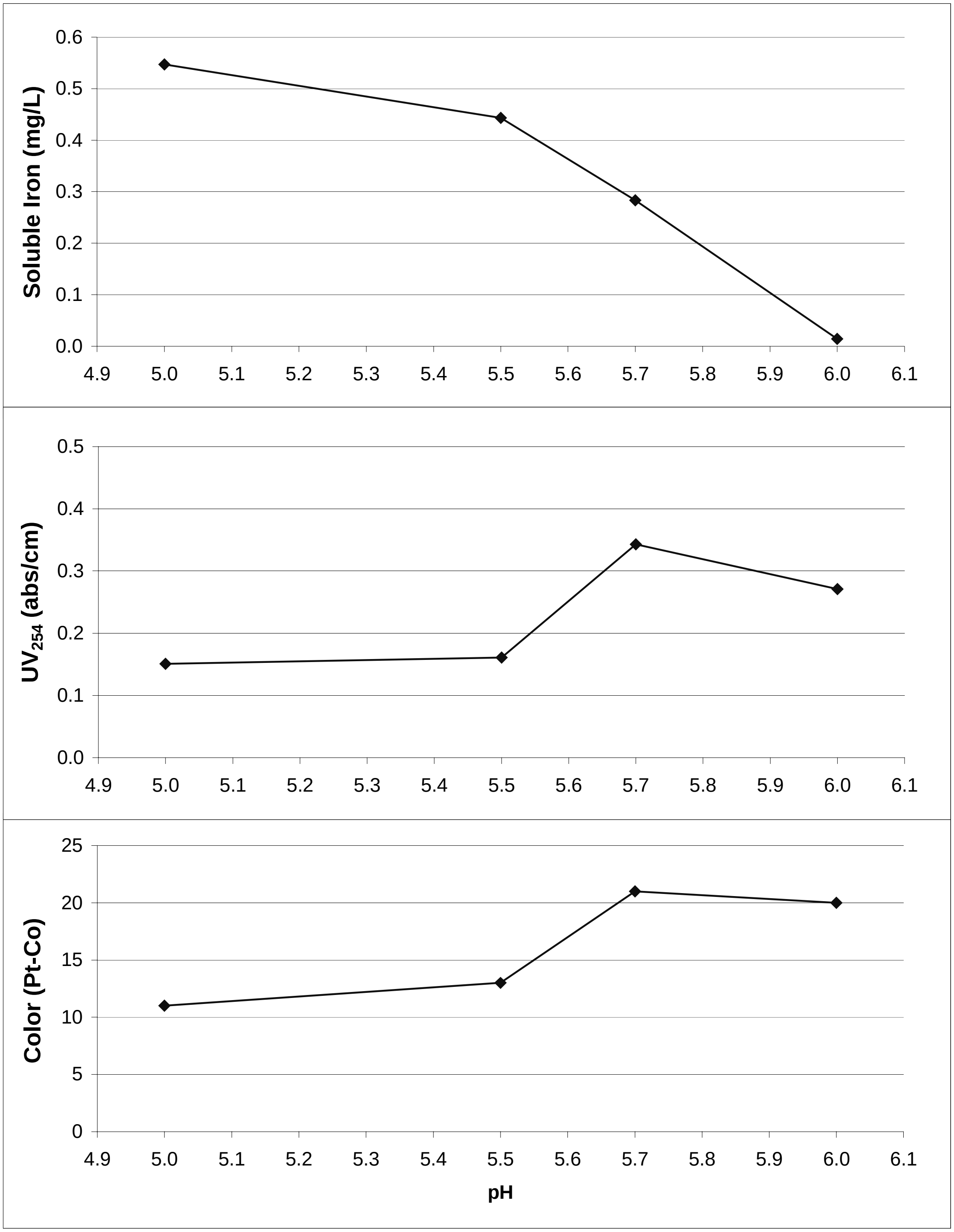
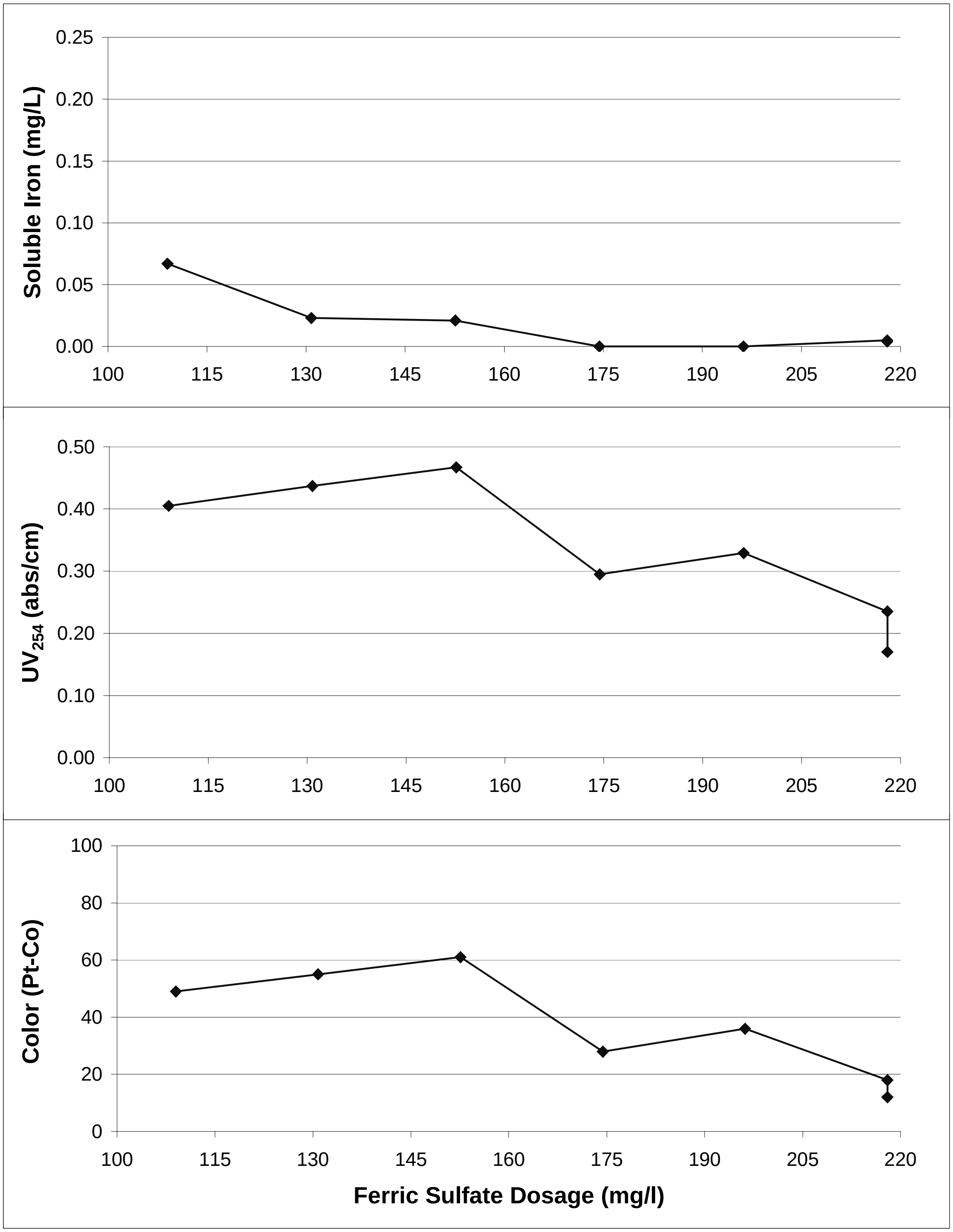


**Figure 45. Total Iron, $UV_{254}$, and Color for Phase 1A Coagulant Dosage Optimization Testing on Zenon 500C Ultrafiltration of Coagulated Lake Monroe Water**



Phase 1B optimization occurred during the dry season when the raw water was characterized by lower than average levels of NOM, color, and $UV_{254}$ and higher than average TDS and conductivity. The Phase 1B coagulation and pH optimization was performed from February 10, 2002 to February 21, 2002. During the Phase 1B optimization, average $UV_{254}$ and color levels were 0.95 abs/cm and 255 Pt-Co, respectively. These levels were significantly lower than the average levels from Phase 1A. Average flux was 20 gfd and the recovery for the ZeeWeed unit was 90 percent.

The pH optimization was performed on February 10 to 11, 2002 at a coagulant dosage of 131 mg/L ferric sulfate. Different pH levels were tested. These ranged from 5.0 to 6.0. Figure 46 summarizes the pH optimization for Phase 1B. The top, middle, and bottom of the figure are divided into total iron, $UV_{254}$, and color as a function of coagulation pH. As the figure illustrates, a pH of approximately 5.6 was required to achieve a total permeate iron concentration of 0.05 mg/L. Again, as expected, the color and $UV_{254}$ removals decreased with increasing pH. Based on the results of the pH optimization, a coagulation pH of 5.6 was selected for further testing.

Figure 47 summarizes the results of the coagulant optimization. In Figure 47, iron, $UV_{254}$ and color are plotted as a function of coagulant dosage. As the figure illustrates, coagulant dosages ranged from 87 mg/L to 174 mg/L. During this evaluation, pH was held constant with a target value of 5.6 based on the pH optimization. Based on online pH data, average pH was 5.6 and ranged from 5.4 to 5.8. Based on the results of this coagulant optimization, a coagulant dosage of 153 mg/L was selected for testing during Phase 1B. This dosage was the lowest dosage at which a negligible amount of additional UV254 removal could be achieved. As expected, this dosage is lower than the dosage determined during the Phase 1A optimization (218 mg/L) due to the lower color and $UV_{254}$ levels in Phase 1B as well as higher conductivity, resulting in an additional compression of the electrical double layer and more efficient coagulation.

**Figure 46. Total Iron, UV254, and Color for Phase 1B pH Optimization Testing on Zenon 500C Ultrafiltration of Coagulated Lake Monroe Water**

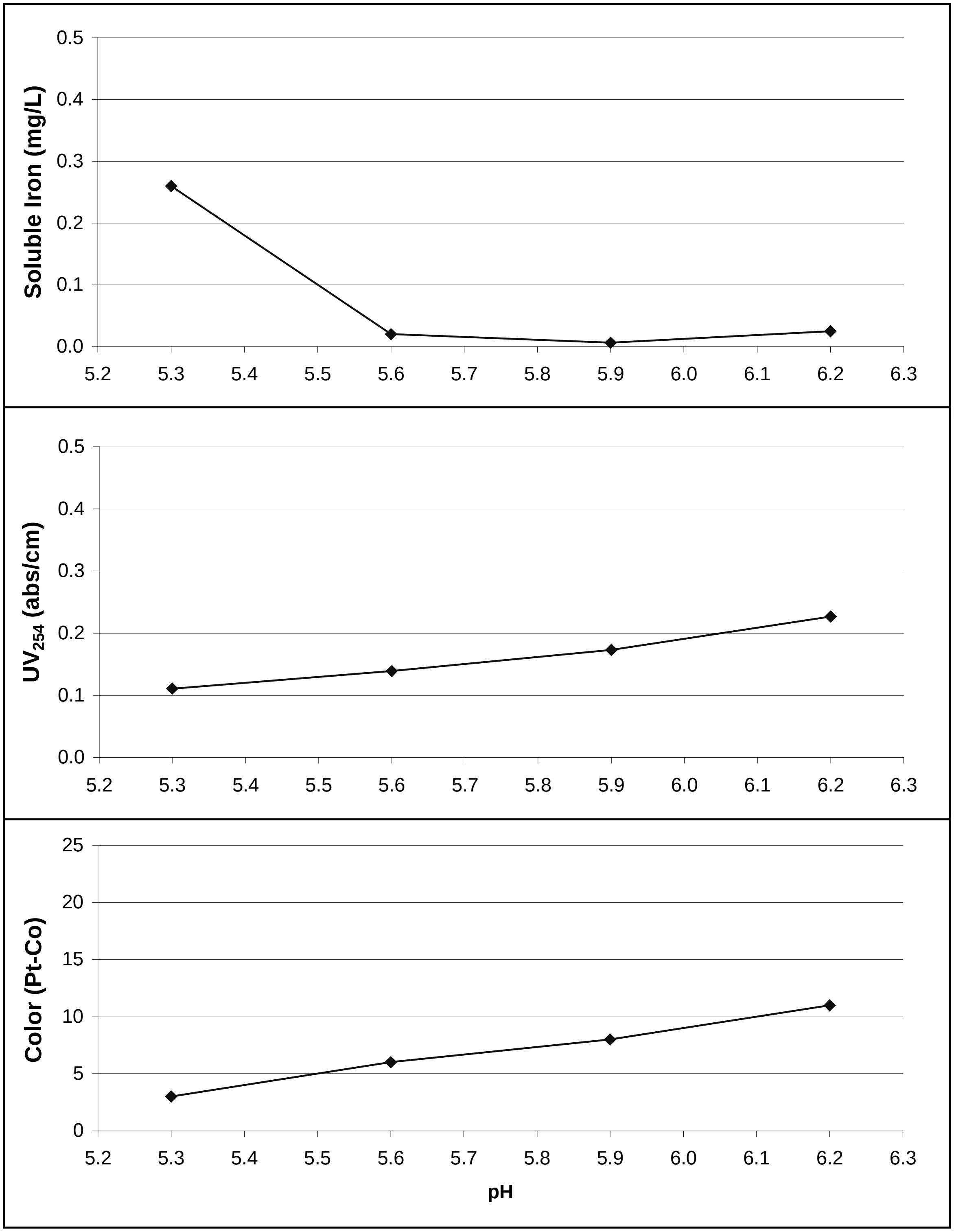
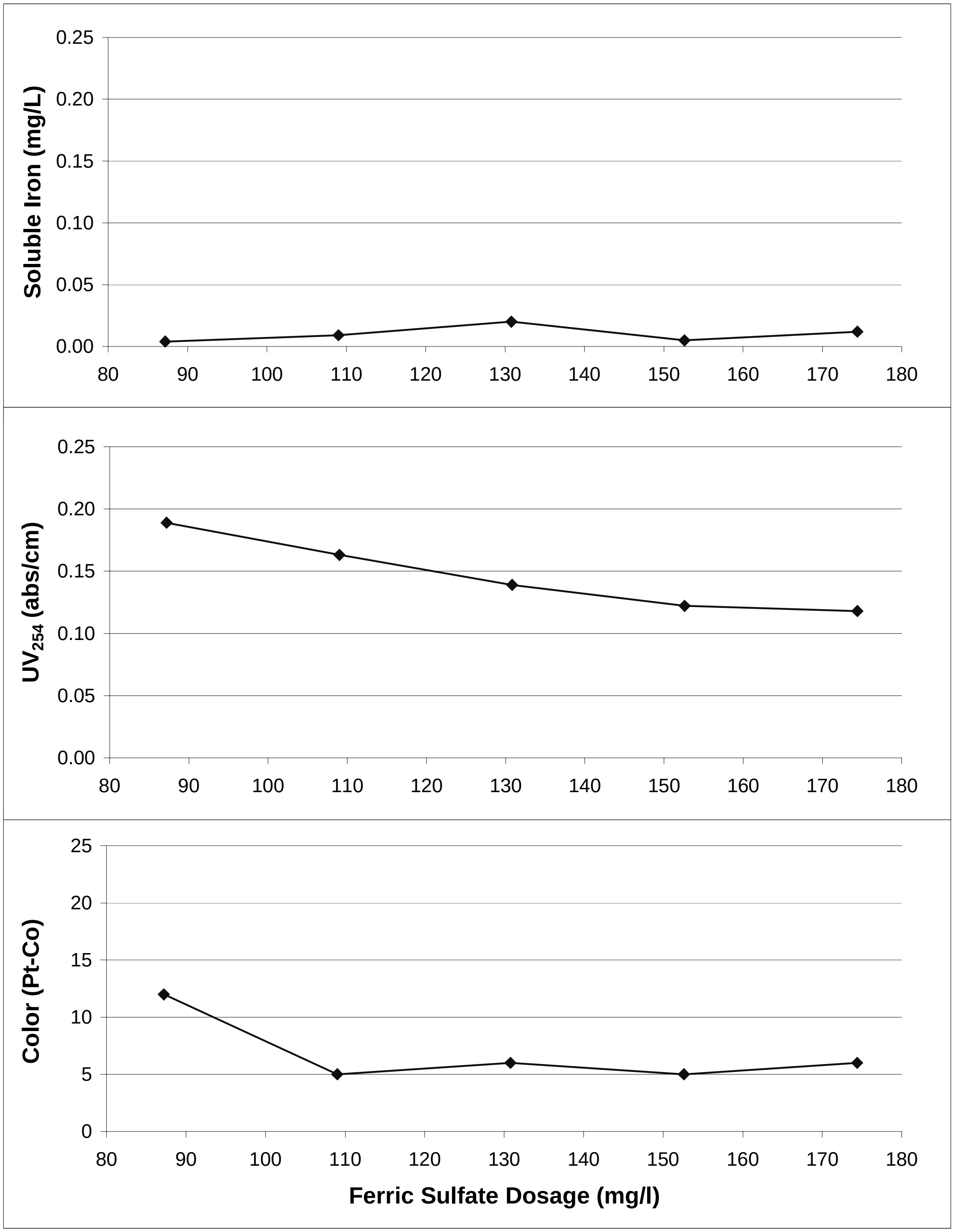


**Figure 47. Total Iron, $UV_{254}$, and Color for Phase 1B Coagulant Dosage Optimization Testing on Zenon 500C Ultrafiltration of Coagulated Lake Monroe Water**



### *Flux Optimization*

In order to maximize the productivity from the Zenon membrane, during Phase 1B a flux optimization was performed. The optimization was performed at a ferric sulfate dosage of 153 mg/L and a coagulation pH of 5.7

The results of the flux optimization are summarized in Table 39 and Figure 48. Table 39 provides the temperature, flux, and permeability for the optimization testing. Linear regressions were performed using the TMP, permeability, and temperature corrected permeability data to estimate the daily change in these parameters. These trends are also presented in Table 39.

**Table 39. Performance Trends for Zenon 500C Ultrafiltration Flux Optimization Testing on Coagulated Lake Monroe Water**

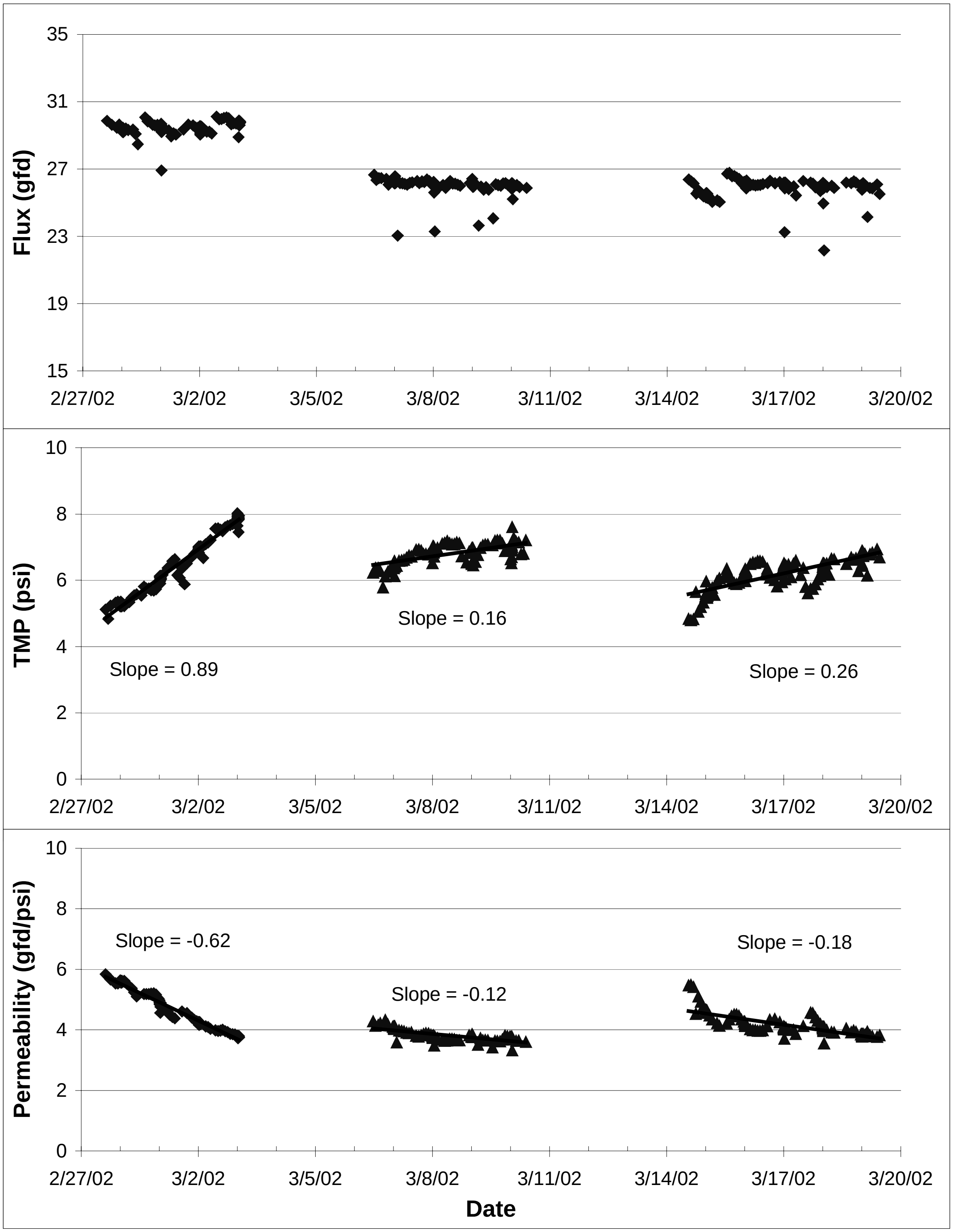
| Date | Average Temp | Average Flux | Normalized Flux | TMP Change | Permeability | | Temperature Corrected Permeability | |
|---|---|---|---|---|---|---|---|---|
| | ($^oC$) | (gfd) | (gfd@20 $^oC$) | (Δpsi/day) | (gfd/psi) | (Δgfd/psi/day) | (gfd/psi) | (Δgfd/psi/day @20$^oC$) |
| 02/27/02 - 03/03/02 | 16.4 | 29.2 | 31.8 | 0.89 | 4.5 | -0.62 | 6.1 | -0.74 |
| 03/06/02 - 03/10/02 | 18.6 | 25.9 | 26.8 | 0.16 | 3.8 | -0.12 | 3.9 | -0.21 |
| 03/14/02 - 03/19/02 | 22.8 | 25.7 | 23.9 | 0.26 | 4.1 | -0.18 | 3.8 | -0.21 |

As Figure 48 illustrates, the flux optimization began at a net flux of 30 gfd on February 27, 2002. The linear regression of the TMP data suggests a TMP increase rate of 0.89 psi/day. This suggested unstable membrane performance, as the cleaning interval was calculated to be approximately 1.5 weeks.

On March 6$^{th}$, 2002, the target flux was reduced to 25 gfd. As Table 39 shows, the TMP increased at a rate of 0.16 psi/day during the next four days and a corresponding cleaning interval of more than 4 weeks. From March 14th to 20th,2002, the rate of TMP increase was 0.26 psi/day which also suggests a cleaning interval of more than 4 weeks. Both runs at the target flux of 25 gfd suggested stable membrane performance.

Based on the results of the flux optimization, a target flux of 25 gfd was selected for further testing during Phase 1B.

**Figure 48. Flux, TMP, and Permeability for Zenon 500C Ultrafiltration Optimization Testing on Coagulated Lake Monroe Water**



### *Verification Testing*

After the optimizations during Phase 1A and Phase 1B, verification testing was conducted. The Phase 1A testing was conducted from November 11, 2001 to December 19, 2001. Following the next coagulation and flux optimization in Phase 1B, verification testing was conducted from March 21, 2002 to October 26, 2002. Table 40 summarizes the average temperature, flux, and permeability results, respectively, of this testing. Table 40 also summarizes the trends in TMP, permeability, and normalized permeability. To determine these trends, linear regressions were performed using TMP, permeability, and normalized permeability data. The average daily TMP change provides an indication of cleaning interval.

**Table 40. Performance Summary for Zenon 500C Ultrafiltration Testing on Coagulated Lake Monroe Water**

| Run No. | Date | Average Temp | Average Flux | Normalized Flux | TMP Change | Permeability* | | Temperature Corrected Permeability* | |
|---|---|---|---|---|---|---|---|---|---|
| | | (°C) | (gfd) | (gfd@20°C) | (Δpsi/day) | (gfd/psi) | (Δgfd/psi/day) | (gfd/psi) | (Δgfd/psi/day @20°C) |
| 1 | 11/26/01-12/19/01 | 22.7 | 21.0 | 19.7 | 0.02 | 7.2 | -0.04 | 6.7 | -0.05 |
| 2 | 03/21/02-03/25/02 | 22.6 | 26.2 | 24.6 | 0.43 | 6.7 | -0.83 | 6.3 | -0.78 |
| 3 | 04/02/02-04/12/02 | 23.2 | 25.9 | 24.0 | 0.31 | 4.4 | -0.24 | 4.1 | -0.21 |
| 4 | 04/15/02-04/27/02 | 27.0 | 25.8 | 21.7 | 0.27 | 4.5 | -0.26 | 3.8 | -0.26 |
| 5 | 04/27/02-05/23/02 | 28.7 | 20.3 | 16.5 | 0.00 | 3.1 | 0.00 | 2.5 | 0.01 |
| 6 | 05/30/02-06/11/02 | 29.8 | 26.2 | 20.9 | 0.38 | 5.8 | -0.21 | 4.6 | -0.19 |
| 7 | 06/12/02-06/14/02 | 29.8 | 25.5 | 20.0 | 0.63 | 5.6 | -0.88 | 4.4 | -0.69 |
| 8 | 06/15/02-06/20/02 | 29.3 | 21.2 | 16.8 | -0.01 | 5.2 | -0.02 | 4.1 | -0.01 |
| 9 | 06/20/02-07/05/02 | 28.6 | 25.4 | 20.6 | 0.04 | 4.0 | -0.03 | 3.2 | -0.02 |
| 10 | 07/06/02-07/08/02 | 28.6 | 19.3 | 15.6 | -0.03 | 3.3 | 0.07 | 2.7 | 0.04 |
| 11 | 07/09/02-10/26/02 | 29.7 | 16.3 | 12.9 | NA | 2.3 | NA | 1.8 | NA |

* Negative values indicate a loss of permeability

To further illustrate data trends, Figures 49, 50, 51, and 52 illustrate flux, TMP, and permeability as a function of date (from November 2001 to October 2002). Linear regressions were performed on the TMP and the permeability data and are also illustrated in these figures.

Run No. 1 was conducted from November 26, 2001 to December 20, 2001 during the initial pretreatment evaluation. As Table 38 illustrates, the target flux was 20 gfd and recovery of 90 percent. No maintenance cleans were used during this run.

Figure 49 summarizes the data collected during this initial pretreatment evaluation. During this run, the average flux was 21.0 gfd, slightly higher than the target flux. As Table 40 suggests, the average temperature during this initial testing phase was 22.7° C resulting in a normalized flux of 19.7 gfd.

As the trend line in Figure 49 illustrates, the average daily TMP increase was 0.02 psi/day. This suggests stable membrane performance and indicates a cleaning interval much greater than 6 weeks.

The testing ended in December 2001 for data analysis and development of testing protocols for the next phase of testing. The testing was restarted in February 2002 with a coagulation and flux optimization previously described. Based on the results of this flux optimization, a flux of 25 gfd was selected for testing beginning in March 2002.

Flux verification testing was conducted from March 21, 2002 to April 27, 2002 using a target flux of 25 gfd (test Run Nos. 2-4). Based on the results summarized in Table 40, the average flux was 26.2 gfd. Figure 50 summarizes the flux, TMP, and permeability data collected during the flux verification testing. During Run No. 2 from March 21, 2002 to March 25, 2002, there was an average daily TMP increase of 0.43 psi/day indicating an unacceptable rate of fouling and an average permeability loss of 0.83 gfd/psi per day.

The ZeeWeed unit was shut down on March 27, 2002 and restarted April 2, 2002. During Run No. 3, the pilot plant had the same rapid increase in TMP. To reduce the rate of fouling, several different approaches were tested. The first method of reducing the TMP increase was overnight aeration of the membrane with the permeate pump de-energized (relaxation) which occurred on April 9, 2002. The aeration decreased the TMP by approximately 2 psi. However, when the pilot was restarted, the TMP again increased rapidly. This resulted in a TMP increase of 0.31 psi/day, 0.12 psi/day less than that observed in the previous run. However, the overnight relaxation decreased online production. Further, the rate of TMP increase still resulted in a cleaning interval of less than 4 weeks.

On April 12, 2002 at the conclusion of Run No. 3, a recovery clean was initiated. Run No. 4 was initiated on April 15, 2002. The average flux during this run 25.8 gfd. As illustrated in Figure 50, the TMP again increased at an unacceptable rate. To slow the rate of fouling, a chlorine maintenance clean was performed on April 20, 2002. During the maintenance clean, a 1,000 mg/L as $Cl_2$ solution was backpulsed through the membrane. The maintenance clean resulted in a TMP reduction of approximately 2.2 psi (see Figure 50).

**Figure 49. Flux, TMP, and Permeability for Zenon 500C Ultrafiltration Initial Verification Testing on Coagulated Lake Monroe Water (Phase 1A); Run No. 1**

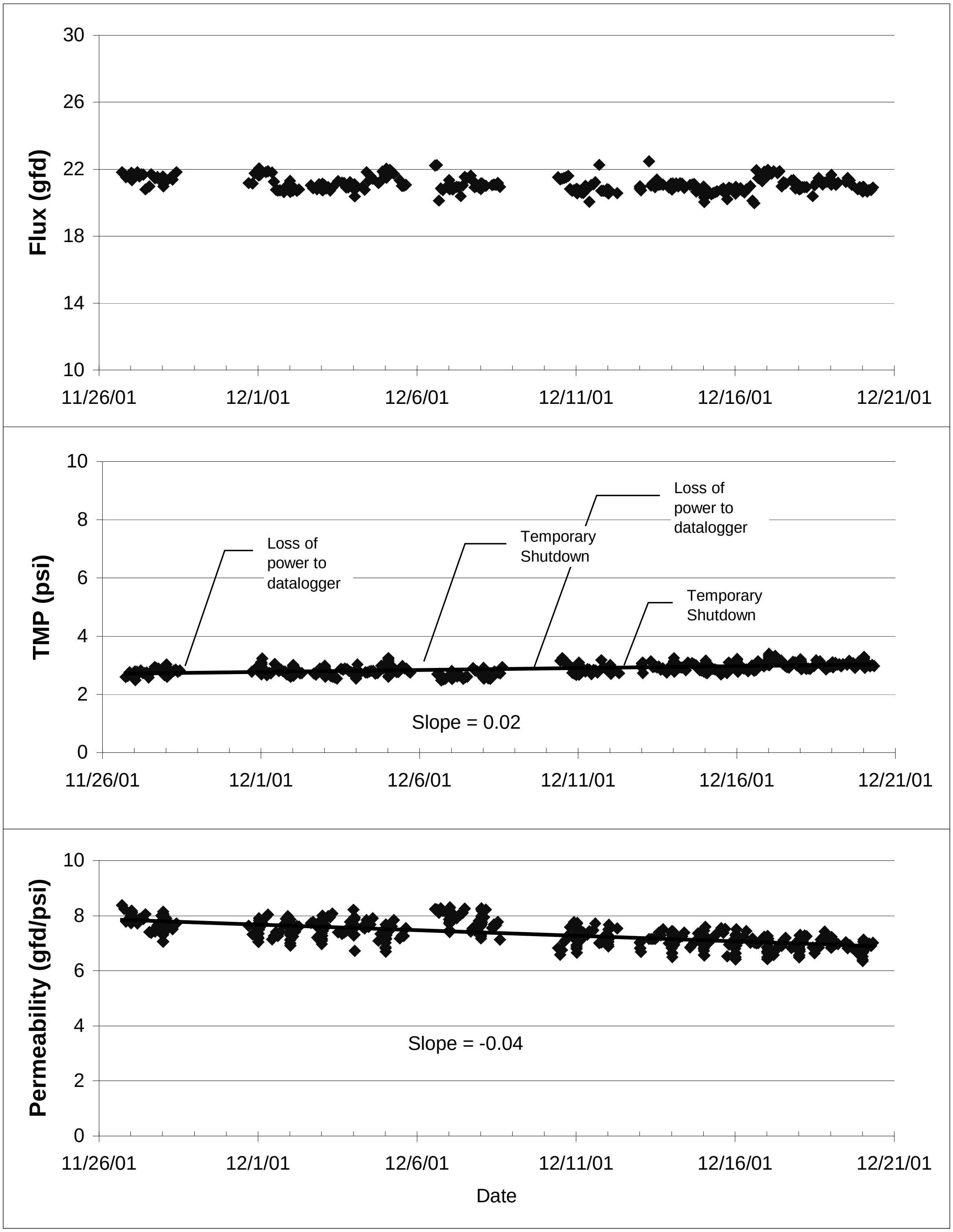
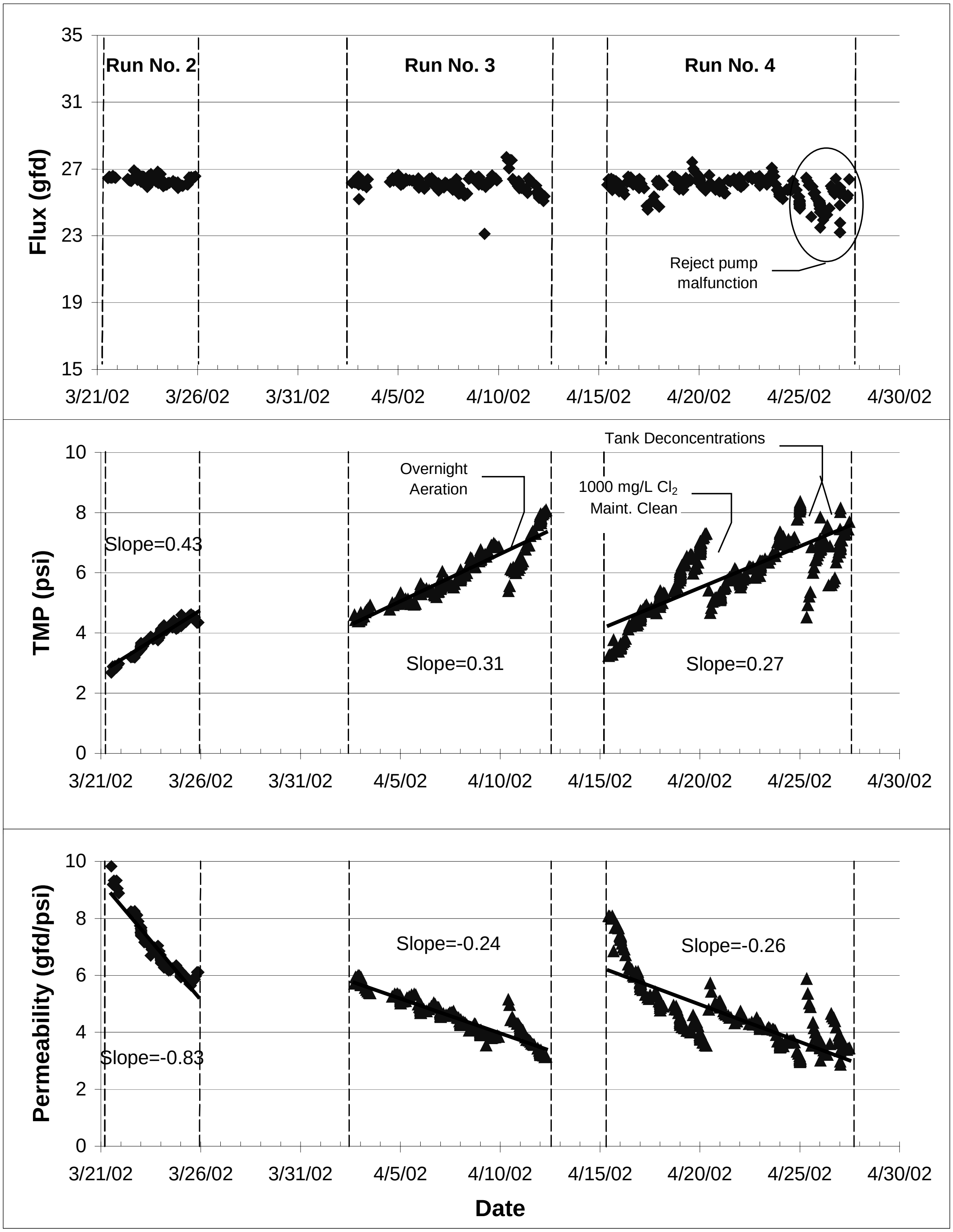


**Figure 50. Flux, TMP, and Permeability for Zenon 500-C Ultrafiltration 25 gfd Verification Testing on Coagulated Lake Monroe Water; Run Nos. 2-4**



As Figure 50 suggests, there was a high degree of variability in flux after April 25, 2002. This resulted in TMP increases. The reject pump, responsible for pumping solids from the process tank, malfunctioned twice resulting in increases in flux due to an increased solids concentration in the process tank. Following these malfunctions, the tank was deconcentrated (drained) and restarted. On April 25, 2002 and April 26, 2002, full tank deconcentrations were performed. As a result of the maintenance clean and the deconcentrations, a daily TMP loss of 0.27 psi/day was achieved suggesting that maintenance cleans and tank deconcentrations would be an effective way of controlling fouling on the membrane.

However, the rate of TMP loss during Run No. 2, 3, and 4 resulted in a cleaning interval less than 4 weeks, suggesting an unacceptable fouling rate at a flux of 25 gfd.

Due to the unacceptable fouling rates at 25 gfd, the flux was reduced to 20 gfd and a new maintenance cleaning regimen was started. As Table 38 indicates, deconcentrations and chlorinated maintenance cleans at 200 mg/L as $Cl_2$ were performed to reduce the rate of fouling.

Generally, the maintenance cleans were performed every other day (3 per week), with tank deconcentrations being performed on the days maintenance cleans were not performed (2 per week). In Figure 51, maintenance cleans are represented by triangles in the TMP portion of the figure, while tank deconcentrations are represented by circles in the TMP portion of the figure.

The average flux during Run No. 5 was 20.3 gfd. The linear regression suggests an average TMP change of -0.002 psi/day, which would indicate a decrease in TMP. The daily permeability loss was 0.002 gfd/psi per day. The daily change in temperature corrected permeability was 0.01 gfd/psi per day.

A full clean was not conducted prior to the start of this filter run. Only chlorinated maintenance cleans were performed. Chlorinated maintenance cleans are generally effective at removing organic and microbial matter from the membrane surface and pores, but are not effective at removing iron foulants (oxides). The ability of the chlorinated cleans to effectively control fouling suggest the iron oxides were released from membrane surface when the organics were oxidized.

**Figure 51. Flux, TMP, and Permeability for Zenon 500-C Ultrafiltration 20 gfd Verification Testing on Coagulated Lake Monroe Water; Run No. 5**

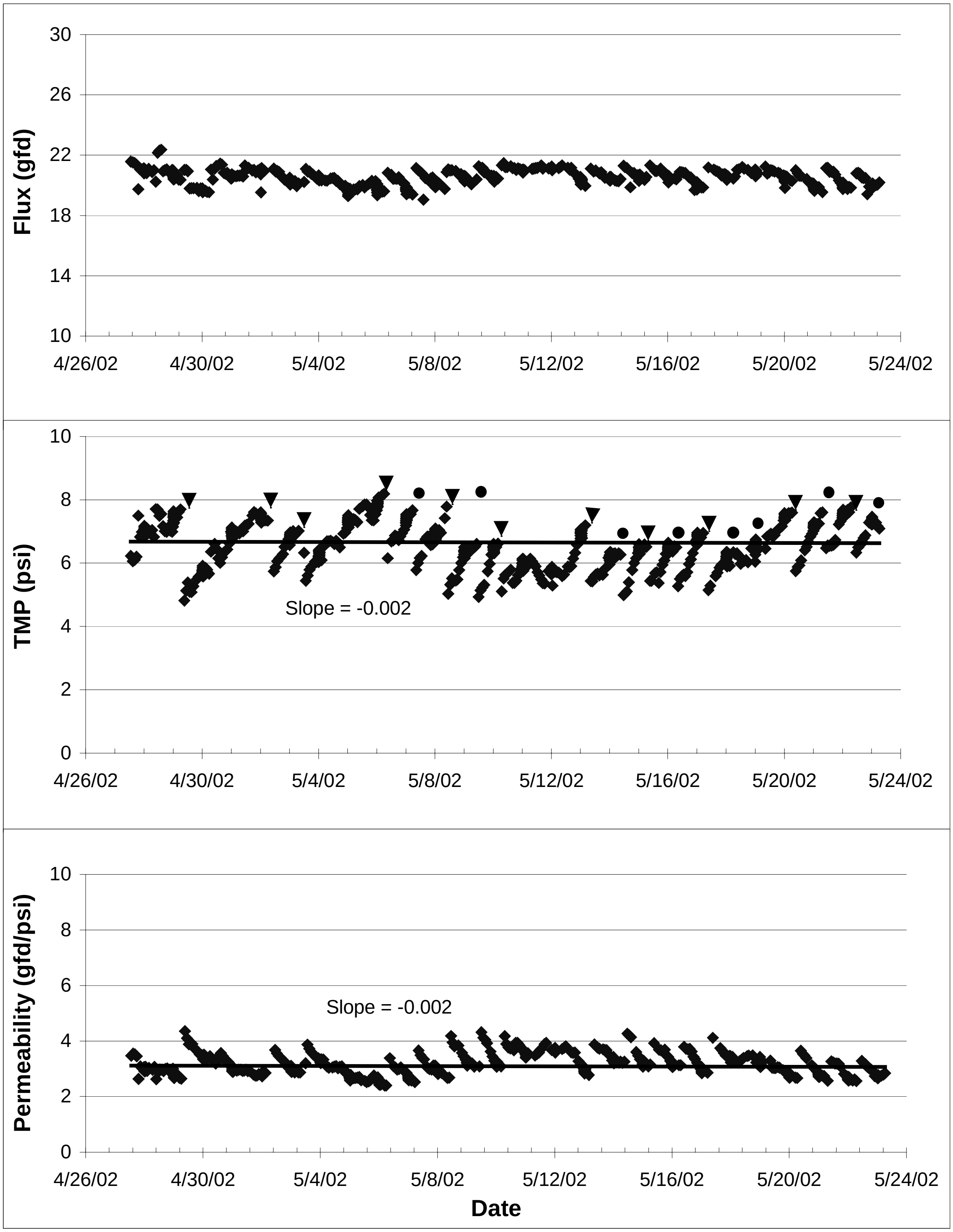


Figure 52 illustrates the results of five different runs (Run Nos. 6-10) conducted at nominal fluxes of 20 gfd and 25 gfd and at different maintenance clean regimens. During this testing, comparisons were made between filtration runs both with and without maintenance cleans performed. Again, maintenance cleans and tank deconcentrations are represented by triangles and circles, respectively.

Prior to the start of this testing, a full clean of the membrane system was performed.

Run No. 6 was conducted from May 30, 2002 to June 11, 2002. During this run, the average flux was 26.2 gfd. This increased flux was based on the results of Run No. 5 which had an acceptable fouling rate at 20 gfd. During this run, chlorinated maintenance cleans at a concentration of 200 mg/L as $Cl_2$, were performed every other day with deconcentrations performed on the off days for maintenance cleans. As the figure suggests, the daily TMP loss was 0.38 psi/day resulting in a cleaning interval of approximately 2 weeks, a high and unacceptable rate of fouling.

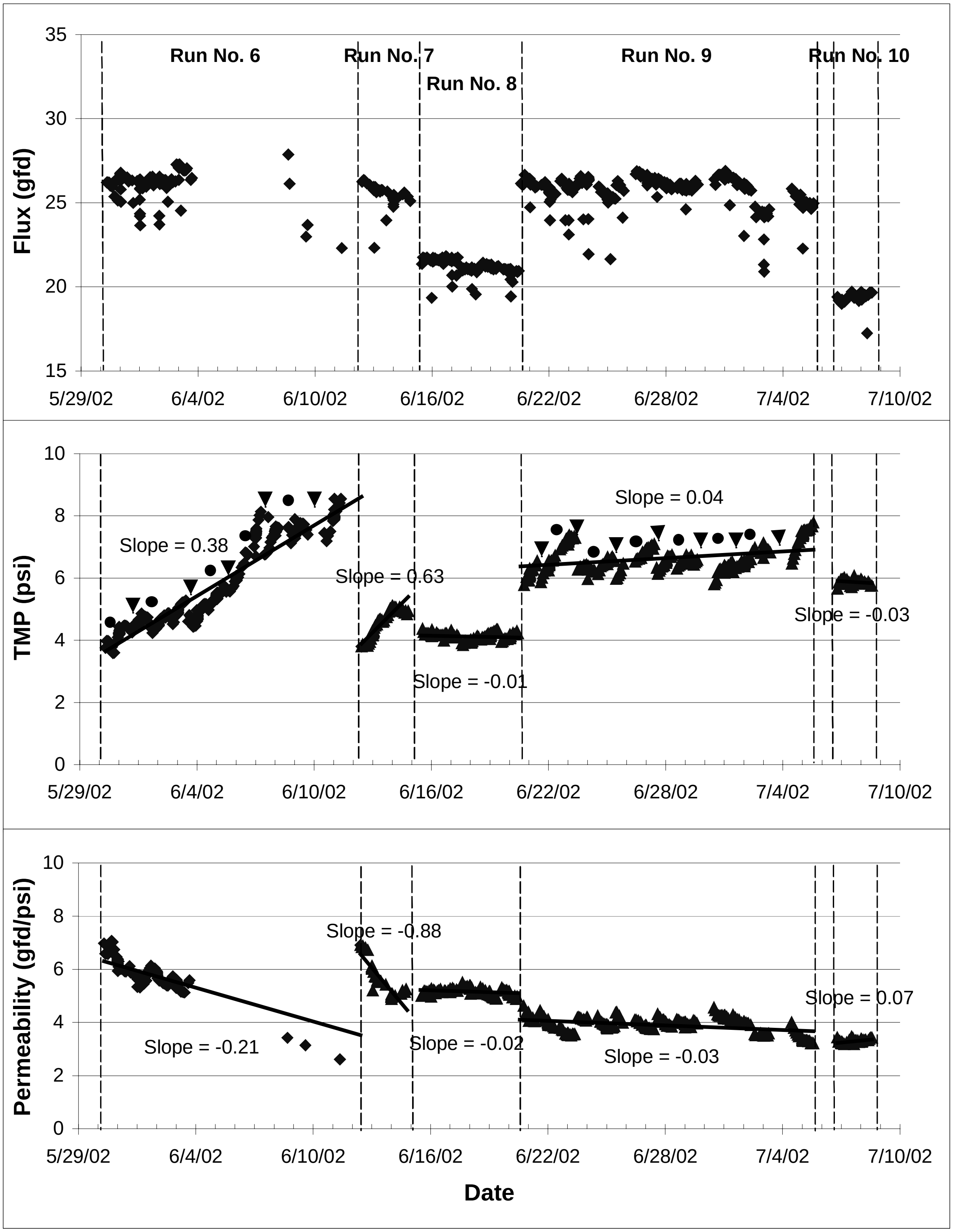
Prior to the start of Run No. 7, a recovery clean was performed on the membrane. Run No. 7 was conducted from June 12, 2002 to June 14, 2002, at an average flux of 25.5 gfd. No maintenance cleans were performed during this run. As a result, the TMP rate of increase was 0.63 psi/day, 0.25 psi/day higher than when maintenance cleans were performed resulting in an unacceptable clean-in-place (CIP) frequency of approximately 1.5 weeks.

Due to the high rate of fouling, the average flux was decreased to a target flux of 20 gfd. During Run No. 8 (June 15, 2002 to June 20, 2002), the average flux was 21.2 gfd resulting in a decrease of TMP (0.01 psi/day), suggesting very stable membrane performance.

Run No. 9 lasted from June 20, 2002 to July 5, 2002, during which the rate of TMP increase was 0.04 psi/day at an average flux of 25.4 gfd and a normalized flux of 20.6 gfd. During this run, citric acid maintenance cleans were performed. During this run, 100 mg/L chlorine maintenance cleans were performed and deconcentrations were performed.

For Run No. 10, the target flux was again reduced to 20 gfd with no maintenance cleans or tank deconcentrations performed. This run was very brief (July 7, 2002 and July 8, 2002). TMP decreased at a rate of 0.03 psi/day. The average flux was 19.3 gfd with a normalized flux of 15.6 gfd.

**Figure 52. Flux, TMP, and Permeability for Zenon 500-C Ultrafiltration Extended Verification Testing on Coagulated Lake Monroe Water; Run Nos. 6-10**



Results for Run Nos. 8 and 10 demonstrate that a flux of 20 gfd can be effectively used. During Run Nos. 6 and 7, a flux of 25 gfd resulted in an unacceptable cleaning interval, while Run No. 9 resulted in an acceptable cleaning interval.

As Table 40 suggests, Run No. 11 included the remainder of Zenon testing on coagulated Lake Monroe water. This run, from July 9, 2002 to October 26, 2002, was at an average flux of 16.3 gfd, with maintenance cleans no longer being performed. The purpose of the testing was to produce feed water for the RO membranes. Therefore, the data as a function of time are not presented.

### Water Quality Summary

Tables 41 and 42 summarize the results from daily sampling of raw water and Zenon permeate, respectively. This data set is for the period September 2001 to October 2002. These tables summarize average, maximums, minimums, standard deviation, and coefficient of variance for each parameter including turbidity, apparent color, and $UV_{254}$.

The data in Table 41 is a subset of the data summarized in Table 13. During the Zenon 500-C coagulated water testing, raw water apparent color ranged from 115 Pt-Co to 520 Pt-Co with an average of 294 Pt-Co. Average $UV_{254}$ during testing was 1.070 abs/cm and ranged from 1.715 abs/cm to a minimum of 0.424 abs/cm which occurred during a heavy rain event. Average conductivity was 85.0 S/m and ranged from 31.3 S/m to 185.9 S/m.

**Table 41. Raw Water Quality for Zenon 500-C Ultrafiltration Testing on Coagulated Lake Monroe Water**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| pH | | 7.2 | 8.3 | 5.8 | 0.4 | 0.05 |
| Temperature | ($^{o}$C) | 26.2 | 31.7 | 14.7 | 4.1 | 0.16 |
| Alkalinity | (mg/L as $CaCO_3$) | 61 | 115 | 37 | 10 | 0.17 |
| Turbidity | (NTU) | 4.5 | 58.6 | 0.8 | 2.1 | 0.46 |
| Conductivity | (S/m) | 85.0 | 185.9 | 31.3 | 42.8 | 0.50 |
| Apparent Color | (Pt-Co) | 294 | 520 | 115 | 101 | 0.34 |
| $UV_{254}$ | (abs/cm) | 1.070 | 1.715 | 0.424 | 0.354 | 0.33 |

Table 42 also summarizes the ferric sulfate dosages used during ZeeWeed direct filtration testing. For discussion, ferric sulfate dosages are presented as pure ferric sulfate. Average ferric sulfate dosages for the Zenon process were 174 mg/L and ranged from 153 mg/L to 218 mg/L.

The average coagulation pH was 5.8 for testing as measured in the flocculation/coagulation tank. Because the Zenon process has an aeration system to assist in solids removal from the membrane system, continual air stripping of the water occurs resulting in removal of $CO_2$ from the water and a subsequent increase in pH. The average filtered water pH for testing was 6.6.

Average ultrafiltered water apparent color and $UV_{254}$ were 8 Pt-Co and 0.142 abs/cm, respectively. Turbidity ranged from 0.078 NTU to 0.034 NTU with an average of 0.045 NTU. Particle counts ranged from 200 counts/ml to 0 counts/ml with an average of 9 counts/ml. Generally, the maximum particle count and turbidity levels corresponded with pilot unit startups and were likely the result of air or insoluble iron in the permeate.

**Table 42. Zenon Permeate Water Quality for Zenon 500-C Ultrafiltration Testing on Coagulated Lake Monroe Water**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **Ferric Dosage Pure** | **(mg/L)** | 174 | 218 | 153 | 13 | 0.08 |
| **Coagulation pH** | | 5.8 | 7.3 | 3.5 | 0.3 | 0.06 |
| **Filtered pH** | | 6.6 | 7.9 | 5.0 | 0.5 | 0.08 |
| **Alkalinity** | **(mg/L as $CaCO_3$)** | 9 | 32 | 2 | 6 | 0.62 |
| **Turbidity** | **(NTU)** | 0.045 | 0.078 | 0.034 | 0.006 | 0.13 |
| **Particle Counts** | **(#/mL)** | 9.0 | 200.0 | 0.0 | 9.8 | 1.09 |
| **Apparent Color** | **(Pt-Co)** | 8 | 61 | 0 | 10 | 1.17 |
| **$UV_{254}$** | **(abs/cm)** | 0.142 | 0.467 | 0.034 | 0.069 | 0.48 |
| **Iron** | **(mg/L)** | 0.085 | 0.547 | 0.000 | 0.099 | 1.17 |

Table 43 summarizes and Figure 53 illustrates the average turbidity, apparent color, and $UV_{254}$ removal from the raw water by the Zenon process. As Table 43 and Figure 43 illustrate, the turbidity removal was 99.0 percent, the apparent color removal was 97.2 percent, and the $UV_{254}$ removal was 86.7 percent.

**Table 43. Average Turbidity, Apparent Color, and UV254 Removals for Zenon 500-C Ultrafiltration Testing on Coagulated Lake Monroe Water**

| Parameter | Units | Raw | Filtered | Cumulative Removal |
|---|---|---|---|---|
| **Turbidity** | **(NTU)** | 4.5 | 0.045 | 99.0% |
| **Apparent Color** | **(Pt-Co)** | 294 | 8 | 97.2% |
| **$UV_{254}$** | **(abs/cm)** | 1.070 | 0.142 | 86.7% |

**Figure 53. Raw and Filtered Water Quality Levels for Zenon 500-C Ultrafiltration Testing on Coagulated Lake Monroe Water**

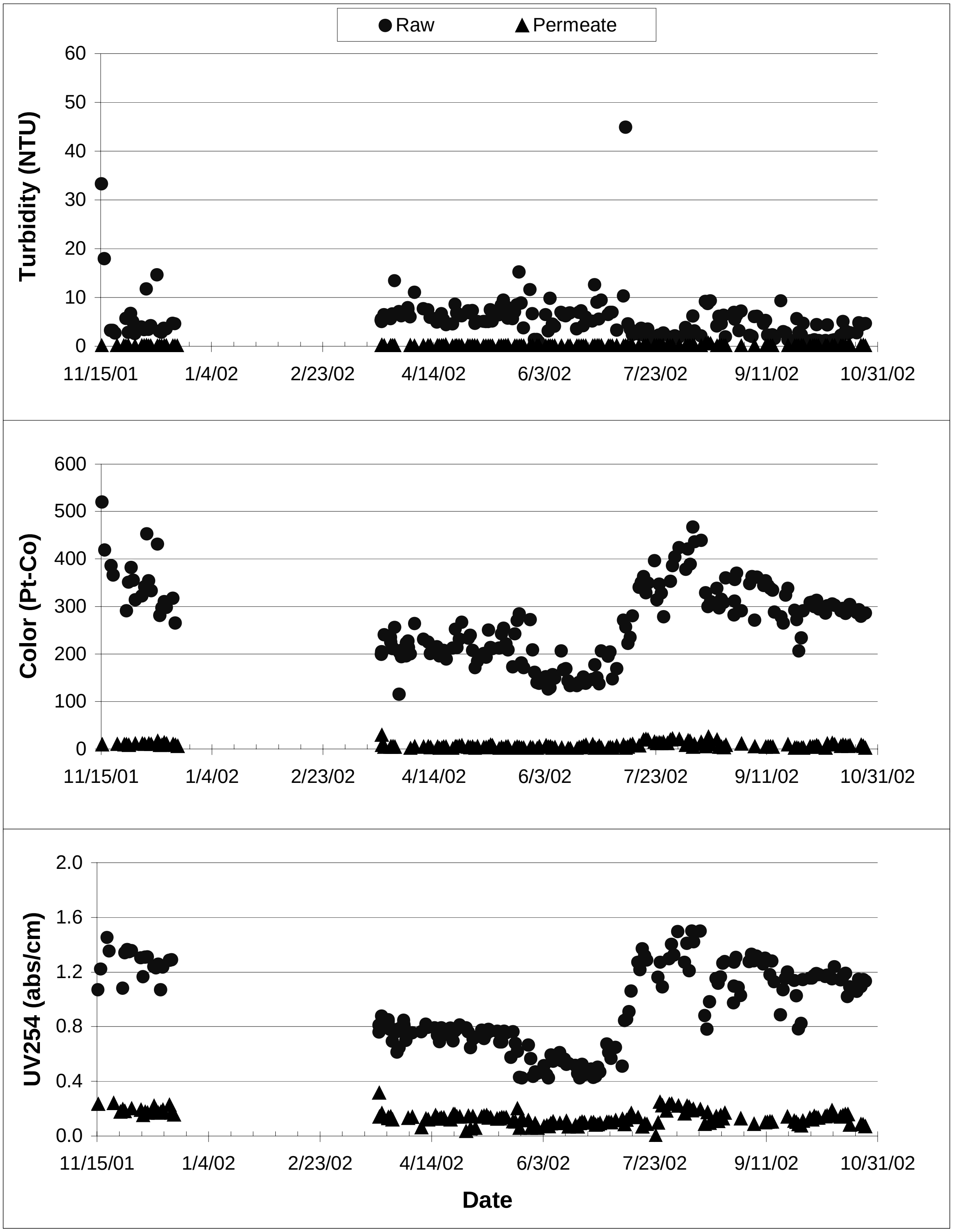


Table 44 summarizes the verification testing results for the various fluxes and cleaning regimens previously described. This table summarizes process temperature, TMP, flux, and permeability. They also provide the permeate turbidity and particle counts during the various filter runs.

**Table 44. Operation Summary for Zenon 500-C Ultrafiltration Testing on Coagulated Lake Monroe Water (all results are averages)**

| Run No. | Date | Temp | TMP | Turbidity | Particle Counts | Flux | | Permeability | |
|---|---|---|---|---|---|---|---|---|---|
| | | (°C) | (psi) | (NTU) | (#/mL) | (gfd) | ($gfd_{20^oC}$) | (gfd/psi) | ($gfd/psi_{20^oC}$) |
| 1 | 11/26/01-12/19/01 | 22.7 | 2.9 | 0.045 | 2.1 | 21.0 | 19.7 | 7.2 | 6.7 |
| 2 | 03/21/02-03/25/02 | 22.6 | 4.0 | 0.040 | 2.5 | 26.2 | 24.6 | 6.7 | 6.3 |
| 3 | 04/02/02-04/12/02 | 23.2 | 6.0 | 0.039 | 4.3 | 25.9 | 24.0 | 4.4 | 4.1 |
| 4 | 04/15/02-04/27/02 | 27.0 | 6.0 | 0.039 | 4.3 | 25.8 | 21.7 | 4.5 | 3.8 |
| 5 | 04/27/02-05/23/02 | 28.7 | 6.7 | 0.039 | 5.2 | 20.4 | 16.5 | 3.1 | 2.5 |
| 6 | 05/30/02-06/11/02 | 29.8 | 5.8 | 0.040 | 4.5 | 26.2 | 20.9 | 5.8 | 4.6 |
| 7 | 06/12/02-06/14/02 | 29.8 | 4.6 | 0.038 | 4.8 | 25.5 | 20.0 | 5.6 | 4.4 |
| 8 | 06/15/02-06/20/02 | 29.3 | 4.1 | 0.039 | 2.6 | 21.2 | 16.8 | 5.2 | 4.1 |
| 9 | 06/20/02-07/05/02 | 28.6 | 6.5 | 0.040 | 5.4 | 25.4 | 20.6 | 4.0 | 3.2 |
| 10 | 07/06/02-07/08/02 | 28.6 | 5.9 | 0.043 | 4.4 | 19.3 | 15.6 | 3.3 | 2.7 |
| 11 | 07/09/02-10/26/02 | 29.7 | 7.5 | 0.048 | 17.2 | 16.3 | 12.9 | 2.3 | 1.8 |

Figure 54 illustrates the coagulation pH, turbidity, and particle counts during the Phase 1A initial pretreatment evaluation (Run 1) from November 26, 2001 to December 20, 2001. These results illustrate that coagulation pH was well controlled during this operating period. Further, the permeate was of consistently high quality based on turbidity and particle counts. As Table 44 indicates, average turbidity for this run was 0.045 NTU with average particle counts of 2.1 counts/ml.

Figure 55 illustrates the turbidity, particle counts, and coagulation pH for Run Nos. 2, 3, and 4. As Table 44 indicates, the average turbidities ranged from 0.040 to 0.039 during the three separate runs. Average particle counts ranged from 2.5 counts/ml to 4.3 counts/ml. These levels were achieved at average fluxes ranging from 25.8 gfd to 26.2 gfd for the three runs. Again, these results illustrate that coagulation pH was well controlled during this operating period.

**Figure 54. Turbidity, Particle Counts, and pH for Zenon 500-C Ultrafiltration Initial Pretreatment Evaluation Testing on Coagulated Lake Monroe Water; Run 1**

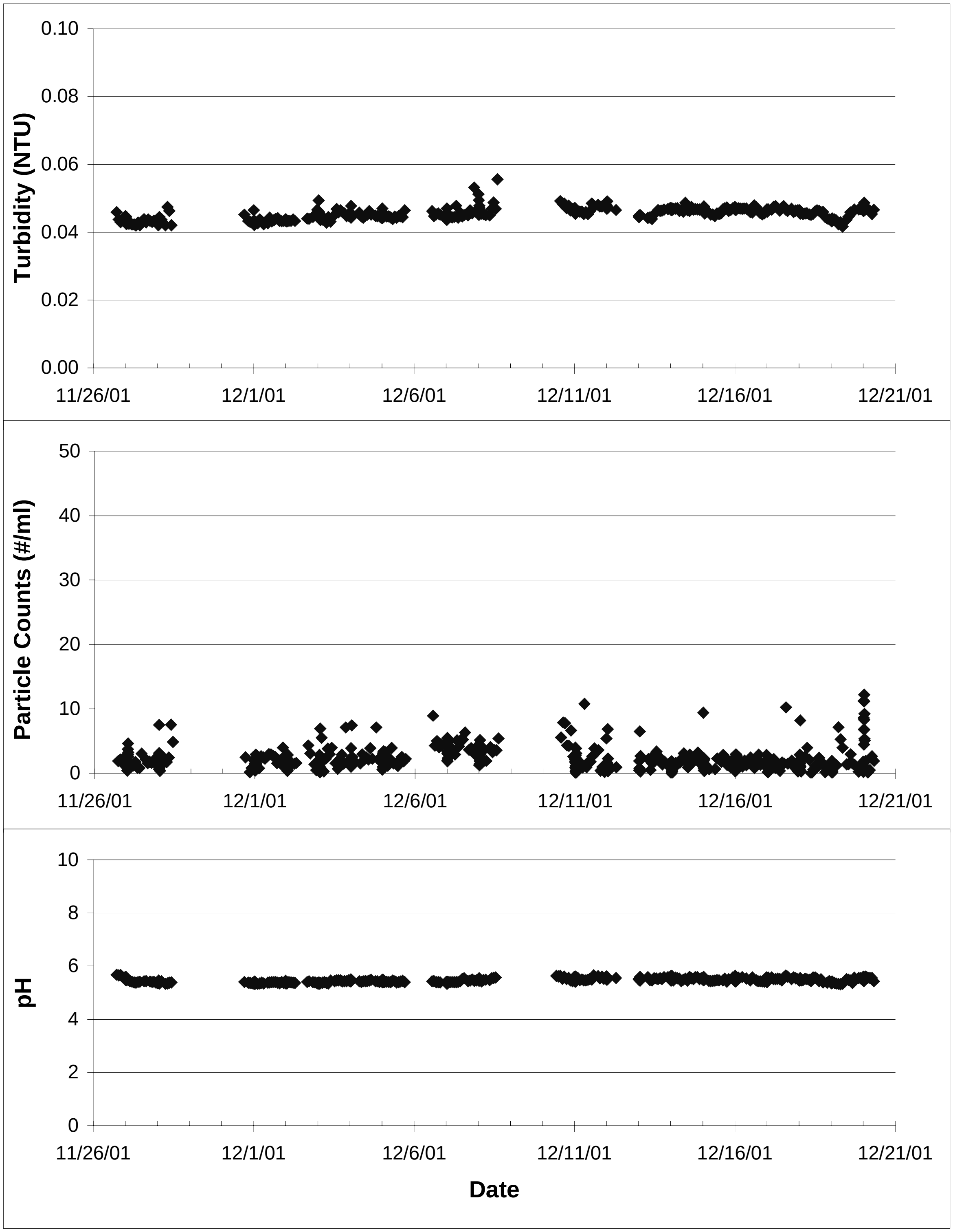


**Figure 55. Turbidity, Particle Counts, and pH for Zenon 500-C Ultrafiltration 25 gfd Flux Verification Testing on Coagulated Lake Monroe Water (Run Nos. 2-4)**

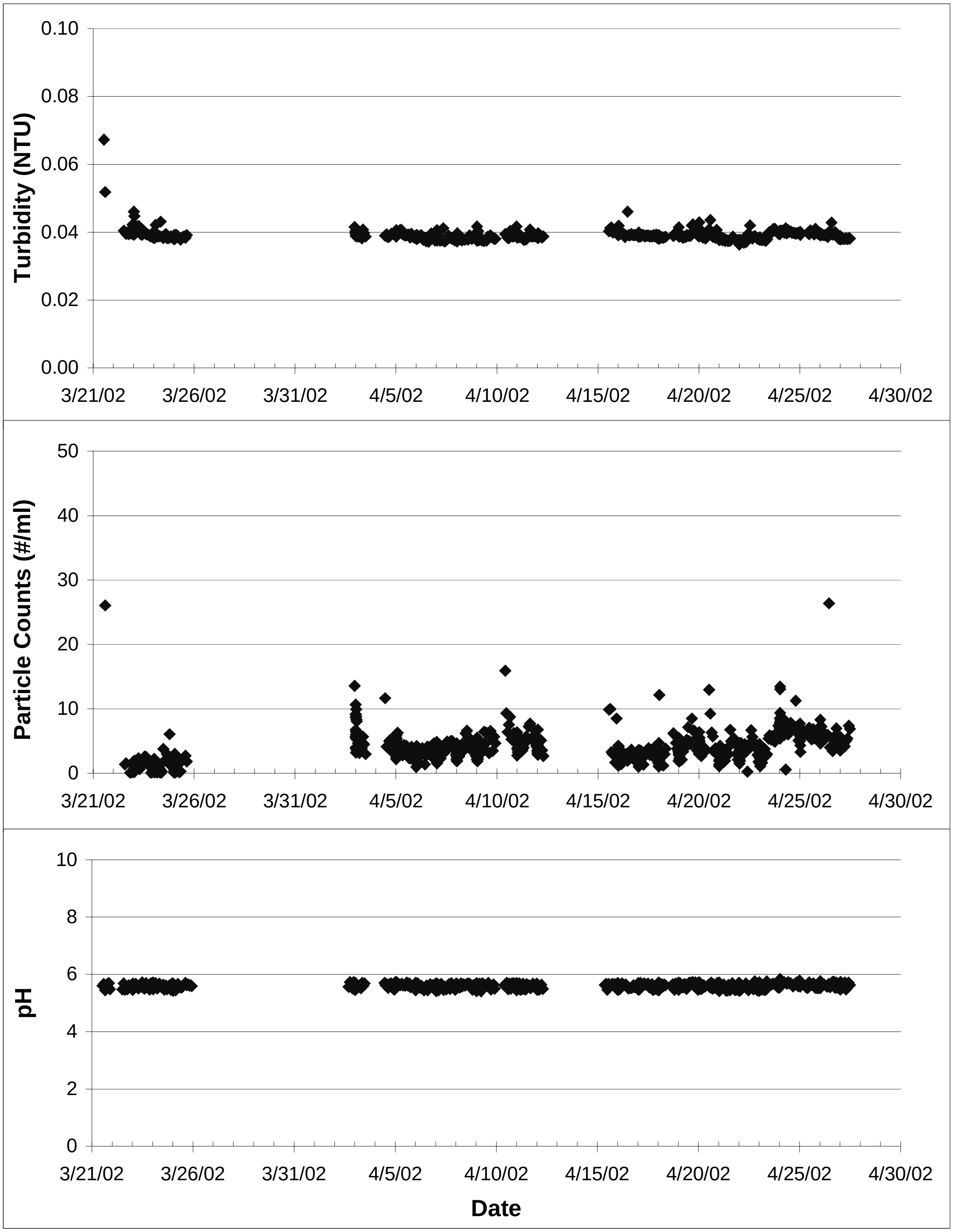


Figure 56 illustrates the coagulation pH, turbidity, and particle counts for Run 5. This figure illustrates that coagulation pH was well controlled during this operating period. As Table 44 suggests, the average turbidity during this evaluation period was 0.039 NTU with average particle counts of 5.2 counts/ml. These levels were achieved at an average flux of 20.4 gfd.

Figure 57 illustrates the turbidity, particle counts, and coagulation pH for Run Nos. 6 to 10. Average fluxes for these runs ranged from 26.2 gfd to 19.3 gfd. Average turbidity during these runs ranged from 0.038 NTU to 0.043 NTU, while average particle counts ranged from 2.6 to 5.4 counts/ml. As the figure illustrates, there were high particle count deviations from June 16, 2002 to June 22, 2002. These deviations were likely due to soluble iron in the system following a maintenance clean or contamination in the degassing tank prior to the turbidimeter and particle counter.

### Conclusions

Based on the results of testing conducted during the period September 2001 to October 2002, the design parameters were developed for the ZeeWeed 500-C membrane operating in direct filtration mode treating coagulated Lake Monroe water. The design conditions summarized in Table 45 represent the recommended flux and operating conditions.

Table 45 suggests a design flux of 20 gfd with a recovery of 90 percent. These operating parameters resulted in a cleaning interval of greater than 6 weeks. In particular, data from November 26, 2001 to December 20, 2001, suggests that the system was operated at 20 gfd with a projected cleaning interval of greater than 6 weeks.

Generally, maintenance cleans were not needed to maintain an acceptable cleaning interval. However, from April 28, 2002 to May 26, 2002, maintenance cleans were performed 3 times per week to reduce the cleaning interval to an acceptable level.

Higher fluxes were evaluated during testing; however, these higher fluxes were determined to have higher than acceptable fouling rates based on a 4 to 6 week cleaning interval.

**Figure 56. Turbidity, Particle Counts, and pH for Zenon 500-C Ultrafiltration 20 gfd Verification Testing on Coagulated Lake Monroe Water (Run No. 5)**

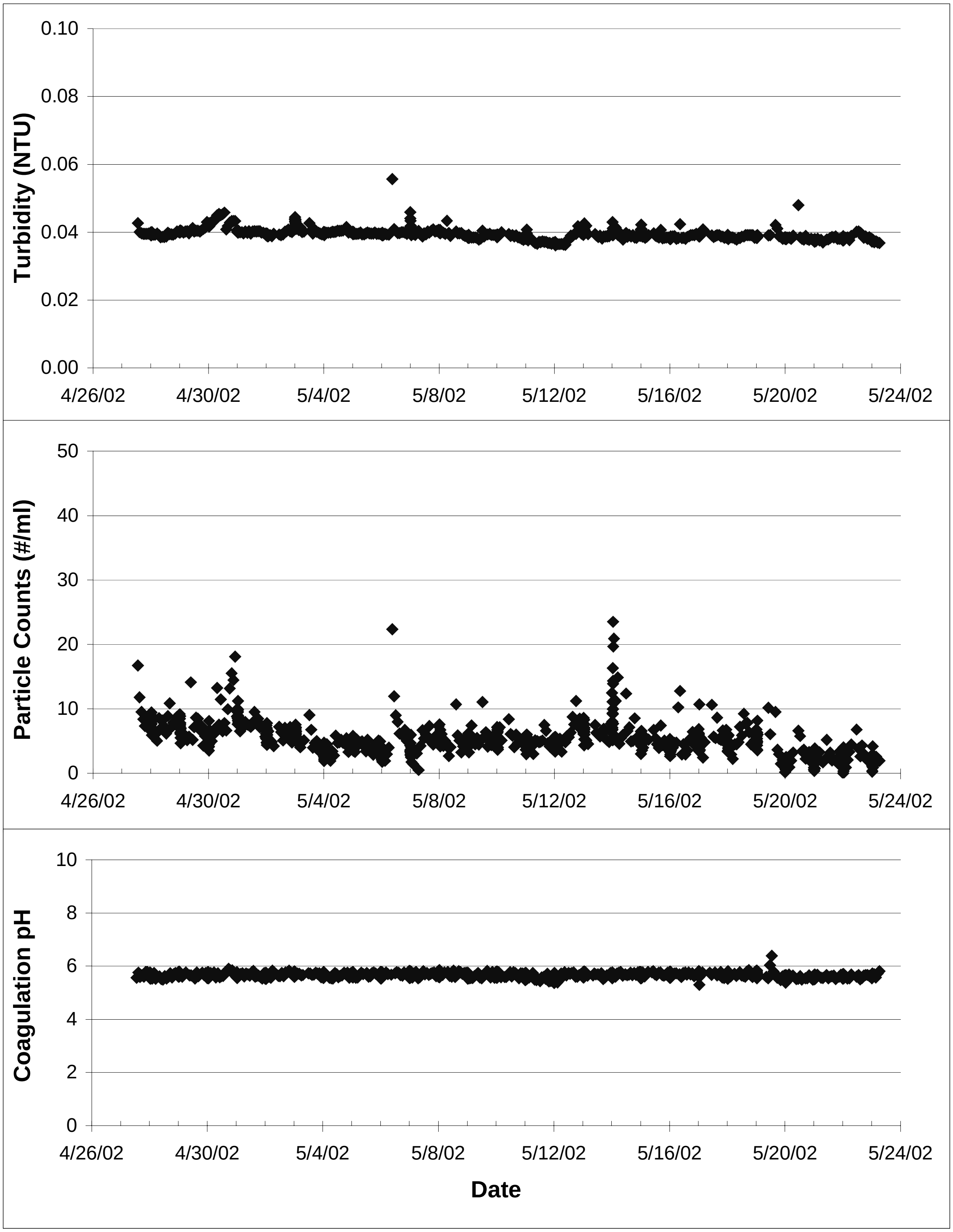


**Figure 57. Turbidity, Particle Counts, and pH for Zenon 500-C Ultrafiltration Extended Verification Testing on Coagulated Lake Monroe Water (Run Nos. 6-10)**

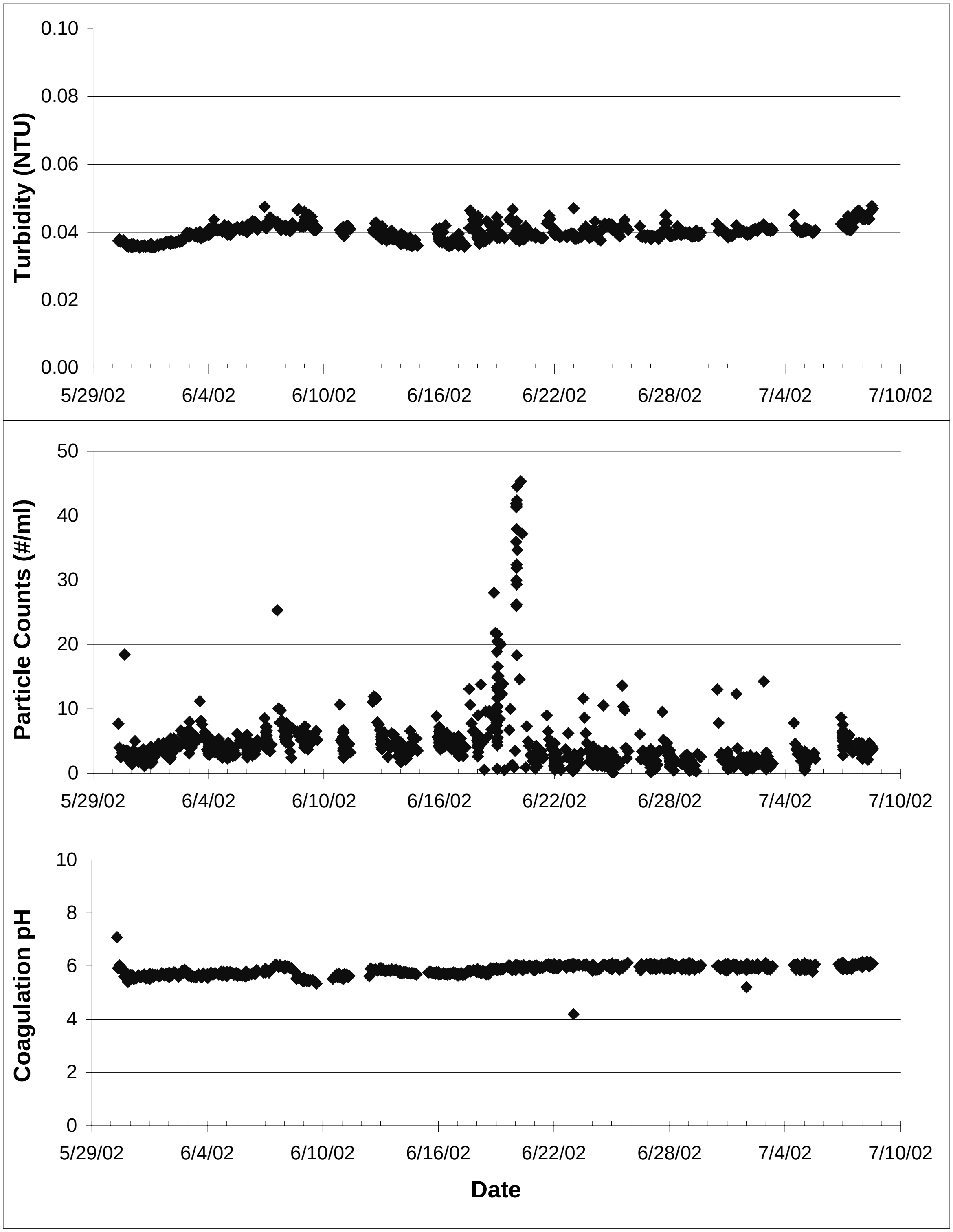


**Table 45. Design Parameters for a ZW 500-C Membrane Plant Treating Coagulated Water**

| Parameter | Units | ZW-500 |
|---|---|---|
| **Instantaneous Flux** | gfd | 20 |
| **Recovery** | % | 90% |
| **Backwash/pulse duration** | Seconds | 15 |
| **Production Duration** | Minutes | 15 |
| **Maintenance Clean (during times of high fouling)** | Tank Drain<br>Clean | One Tank Deconcentration per Day<br>200 mg/L $Cl_2$ Every other day |
| **Recovery Cleaning Interval** | Weeks | 6 weeks (10/10 cyclic aeration) |
| **Recovery Clean - Chlorine** | Backpulse<br>Soak<br>Duration | 1000 ppm<br>250 ppm<br>4-6 hours |
| **Recovery Clean - Citric acid** | Backpulse<br>Soak<br>Duration | 4 g/L<br>1 g/L<br>4-6 hours |

## Actiflo Clarification - Zenon Ultrafiltration

Testing was conducted using the Zenon 500-C UF membrane as an alternative to dual media filtration for polishing the Actiflo clarified effluent. The goal was to develop performance data that could be used to estimate design conditions for the ZeeWeed 1000 (ZW-1000) UF membrane system. The ZW-1000 unit is a more cost effective membrane system for treatment of low solids clarified water.[12]

Based on the results of testing and previous side-by-side comparisons of the Zenon ZW-1000 and the Zenon 500-C membranes, design parameters were developed for the Zenon ZW-1000 for use in a full scale design.

### Equipment Description

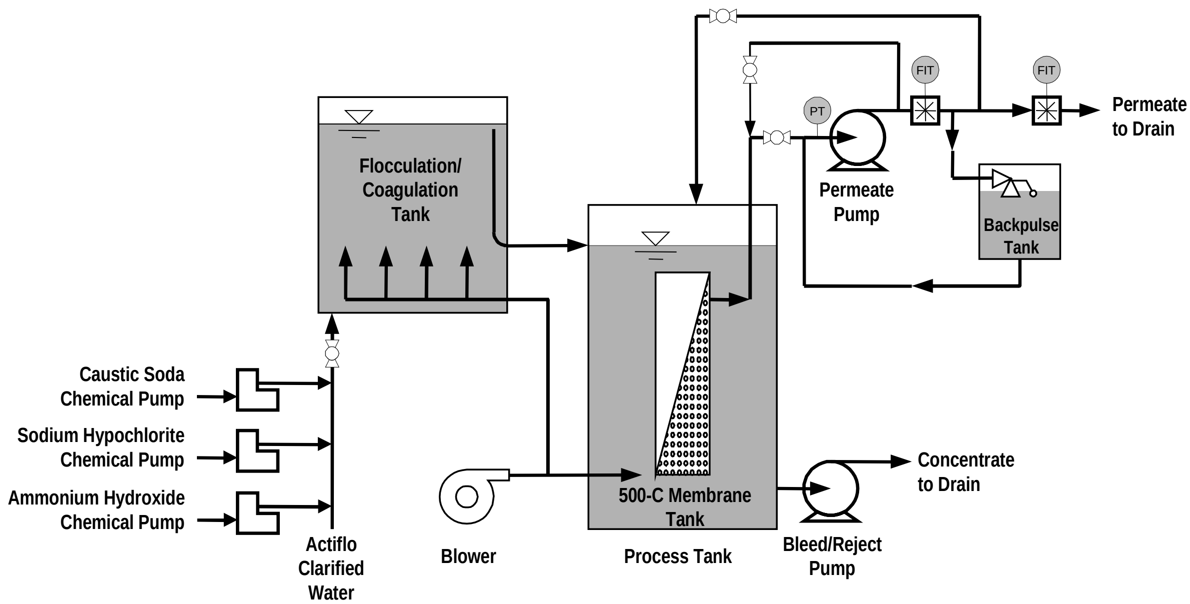
ZeeWeed is a low-energy membrane treatment system that consists of hollow fiber UF modules immersed in a process tank containing the raw water being treated. The ZeeWeed hollow fiber membrane has a 0.04-micron nominal and a 0.1-micron absolute pore size. These pore characteristics ensure that no particulate matter exceeding 0.1 microns in size, including Cryptosporidium oocysts and Giardia cysts, can pass through the membrane to the treated water stream. The loose, hollow fiber

[12] Testing was conducted using the ZeeWeed 500-C unit as a ZeeWeed 1000 pilot unit was not available.

membranes are arranged in an assembly known as a “module” by connecting the fibers at both ends. During treatment, a vacuum is applied to the inside (lumen side) of the fibers at each end of the module. The resulting difference in pressure across the wall of the membrane caused water to flow from the outside of the fiber (feed side) through the membrane pores to the inside, thus becoming filtered (treated) water. The vacuum applied corresponds to the TMP for the system.

A simplified process schematic of the ZeeWeed process is shown in Figure 58.

**Figure 58. Process Flow Schematic for ZeeWeed System; Clarified Water Testing**




The system operated in both continuous and batch mode in this study (no recirculation flow).

The undesired accumulation of foulants at the outside surface of the fibers was controlled by:

- Continuous or periodic introduction of air below the surface of the module to cause agitation of the fibers and scour suspended solids form the surface of the membrane, thereby mechanically removing the foulants
- Periodic backwashing of the membranes (reverse flow of filtered water through the pores from inside to outside)

- When the permeate-side vacuum becomes excessive, the membranes are chemically cleaned with chlorine, citric acid, or other chemical agents

Table 46 is an operational description and summary of the settings for ZeeWeed testing on the clarified water. As indicated in the table, the system operated at a recovery of 95 percent in both continuous and batch mode. In batch mode, the unit did not have a continuous reject stream, but rather, had tank drains and rinses every 4 hours to remove accumulated solids from the process tank.

Further, the air scrub was operated in a cyclic mode, whereby air scrubbing was cycled on and off at 10 second intervals. Further, during air flow optimization, the air scrubbing was cycled on and off at 10 seconds onto 30 seconds off.

To restore productivity of the membrane systems (due to fouling), recovery cleans were performed. For the ZeeWeed membrane, two separate cleans were required for an effective recovery clean. The first clean was a chlorine clean and the second was a citric acid clean.

**Table 46. Operational Description and Settings for ZeeWeed Clarified Water Testing**

| Parameter | Zenon |
|---|---|
| Driving Force | Filtrate Suction |
| Fiber Diameter | 1.9 mm |
| Module Dimensions | Length = 29" Width = 9" Height = 79" |
| Nominal Pore Size | 0.04 micron |
| Module Surface Area (External) | 660 sq.ft |
| Continuous Mode | |
| Filtration | 15 minute run duration |
| Solids Removal | Continuous bleed from process tank at 95% Recovery |
| Backpulse | 15 seconds reverse flow of ZW filtrate |
| Batch Mode | |
| Filtration | 15 minute run duration |
| Solids Removal | Tank drain and rinse after 4 hours of filtration (95% Recovery) |
| Backpulse | 15 seconds reverse flow of ZW filtrate |
| Air Scrub (on/off in seconds) | Cyclic diffused air @ 15 scfm (10/10 or 10/30) |
| Typical Recovery Clean Solution - Chlorine | 1000 mg/L as $Cl_2$ (backpulse), 250 mg/L as $Cl_2$ (soak) |
| Typical Recovery Clean Solution - Citric Acid | Citric acid 4 g/L (backpulse), 1 g/L (soak) |

A clean was performed by first draining the process tank. Sodium hypochlorite was applied to 80 L of water in the backpulse tank to achieve a solution concentration of 1,000 mg/L as $Cl_2$. This solution was backpulsed through the membrane for 30 seconds followed by a 60 second relaxation (pause). This was continued until the solution was drained from the backpulse tank at which point the process tank was filled with water, resulting in a 250 mg/L as $Cl_2$ soak solution for the membrane. After two hours, the water was recirculated through the system to evaluate the TMP recovery and was again shut down. This was repeated every hour for approximately 2 to 4 hours more.

Once no additional TMP recovery was possible due to the chlorine clean solution, the tank was drained and flushed. The process was then repeated with a 4 g/L citric acid solution in the backpulse tank resulting in a 1 g/L soak solution. Further, the pH of the backpulse solution as well as the soak solution was reduced to 2 using hydrochloric acid.

For the recovery of the TMP during normal operation, maintenance cleans were performed. Maintenance cleans were similar to recovery cleans; however, the membrane was not allowed to soak in the solution. Rather, the membrane was placed back into production after the cleaning solution had been pumped through the membranes.

The goal for cleaning interval frequency was 4 to 6 weeks based on Zenon and CH2M HILL recommendations. A recovery clean was initiated based on TMP loss of 6 psi assuming an initial TMP of 3 psi and a terminal TMP of 9 psi. Based on these limitations, the acceptable rates of daily TMP loss ranged from 0.21 psi/day to 0.14 psi/day (4 and 6 week cleaning intervals, respectively).

### Testing Summary

The Zenon 500-C was tested using Actiflo clarified effluent from November 2002 to January 2003. During testing different fluxes, operating modes, maintenance cleaning regimens, and aeration modes were tested to optimize operating conditions for the ZW 500-C.

Table 47 summarizes the operating parameters for clarified water testing on the ZW 500-C. As the figure illustrates, fluxes of 30 gfd, 35 gfd, and 40 gfd were evaluated. The first flux evaluation, 30 gfd, was tested from November 11, 2002 to November 15, 2002. Based on the favorable results at 30 gfd, higher fluxes were evaluated. A flux of 35 gfd was tested under various operating parameters from November 15, 2002 to December 16, 2002. To determine the maximum operating flux, a flux of 40 gfd was evaluated from January 10, 2003 to January 16, 2003.

Two modes of operation were tested on the pilot system, continuous and batch modes. The continuous mode represents the normal operating mode for the ZW-500-C. The batch mode is the normal operating mode for the ZW-1000. In a continuous mode, the system was operated for 15 minute runs with 15 second backpulses. To remove accumulated solids in the process tank, solids were pumped out of the system at a constant flow rate to achieve a recovery of 95 percent. In batch mode, the system operated for 4 hours with no solids removal, was drained and flushed to remove the solids, and returned to operation.

Aeration was tested at two different modes—10 seconds on/10 seconds off and 10 seconds on/30 seconds off. This was done to optimize air requirements and reduce operating and capital costs.

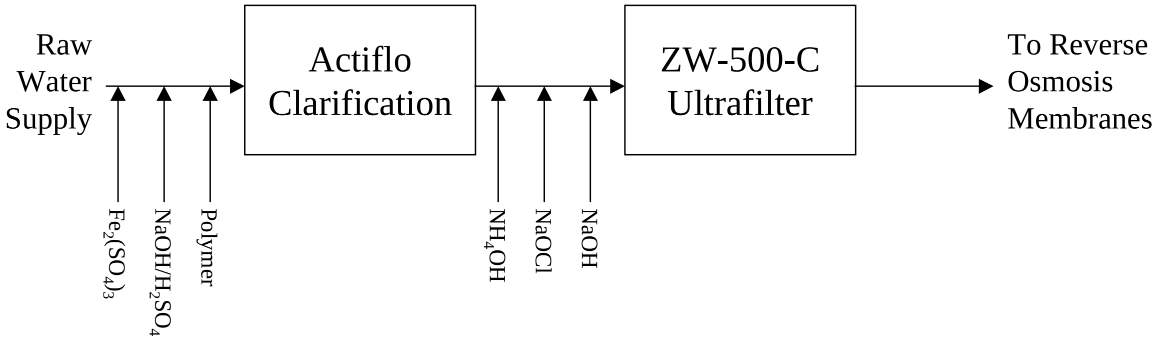
Three different maintenance cleans were employed: no maintenance cleans, chlorine maintenance cleans, and citric acid maintenance cleans. Maintenance cleans are designed to oxidize and/or dissolve organic or biological matter (chlorine clean) or dissolve acid soluble material (citric acid cleans) and subsequently extend membrane run time. In general, maintenance cleans during testing were performed every other day.

**Table 47. Operating Parameters for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent**

| Run No. | Date | Target Flux (gfd) | Recovery (%) | Operational Mode | Cyclic Aeration (on/off) | Maint. Cleans | Chemical Concen-tration |
|---|---|---|---|---|---|---|---|
| 12 | 11/11/02-11/15/02 | 30 | 95 | 15 min run/15 sec backpulse | 10/10 | None | NA |
| 13 | 11/15/02-11/19/02 | 35 | 95 | 15 min run/15 sec backpulse | 10/10 | Chlorine | 100 mg/L |
| 14 | 11/19/02-11/22/02 | 35 | 95 | 15 min run/15 sec backpulse | 10/10 | Citric Acid | 1 g/L |
| 15 | 11/22/02-12/02/02 | 35 | 95 | 15 min run/15 sec backpulse | 10/30 | Citric Acid | 1 g/L |
| 16 | 12/02/02-12/20/02 | 35 | 95 | Batch - 40 tank drains/week | 10/30 | Citric Acid | 1 g/L |
| 17 | 01/10/03-01/16/03 | 40 | 95 | 15 min run/15 sec backpulse | 10/10 | Citric Acid | 1 g/L |

The process schematic for clarified water testing of the ZW-500-C unit is illustrated in Figure 59. Feed water to the ZW-500-C pilot unit was Actiflo clarified effluent that was dosed with ammonia and chlorine to form chloramines and the with sodium hydroxide to increase pH to 6.5 to 7.5.

**Figure 59. Process Schematic for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent**




### Performance

Table 48 summarizes the results for the average temperature, flux, and permeability for the different operating conditions evaluated. Linear regressions were performed on the pressure and permeability data to estimate the rate of change in both TMP and permeability for each run.

As Table 48 suggests, the rate of change in TMP ranged from -0.07 psi/day during Run No. 14 to +0.91 psi/day during Run No. 17a. Negative TMP changes indicate a reduction in TMP. The rate of change in temperature corrected permeability ranged from 0 gfd/psi per day (no change) during Run No. 14 to -0.80 gfd/psi per day during Run 17b.

**Table 48. Performance Summary for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent**

| Run No. | Date | Average Temp | Average Flux | Normalized Flux | TMP Change | Permeability* | | Temperature Corrected Permeability* | |
|---|---|---|---|---|---|---|---|---|---|
| | | (°C) | (gfd) | (gfd@20°C) | (Δpsi/day) | (gfd/psi) | (Δgfd/psi/day) | (gfd/psi) | (Δgfd/psi/day @20°C) |
| 12 | 11/11/02-11/15/02 | 27.2 | 29.6 | 24.8 | 0.07 | 9.1 | -0.21 | 7.6 | -0.08 |
| 13 | 11/15/02-11/19/02 | 22.8 | 35.4 | 32.9 | 0.44 | 7.9 | -0.70 | 7.4 | -0.48 |
| 14 | 11/19/02-11/22/02 | 22.6 | 35.6 | 33.4 | -0.07 | 6.9 | 0.06 | 6.5 | 0.00 |
| 15 | 11/22/02-12/02/02 | 20.7 | 35.3 | 34.8 | 0.21 | 5.4 | -0.18 | 5.3 | -0.14 |
| 16a | 12/02/02-12/09/02 | 20.4 | 35.2 | 35.0 | 0.34 | 6.2 | -0.35 | 6.2 | -0.31 |
| 16b | 12/16/02-12/20/02 | 19.2 | 35.5 | 36.2 | 0.24 | 5.0 | -0.17 | 5.1 | -0.25 |
| 17a | 01/10/03-01/12/03 | 15.4 | 38.5 | 42.5 | 0.91 | 4.7 | -0.53 | 5.3 | -0.60 |
| 17b | 01/15/03-01/16/03 | 15.4 | 38.5 | 43.1 | 0.69 | 6.2 | -0.71 | 6.9 | -0.80 |

* Negative values indicate a loss of permeability

Figure 60 illustrates the change in flux, TMP, and permeability during Run No. 12. The average flux was 29.6 gfd for this run and the system was operated without maintenance cleans. The average rate of change in TMP during this run was 0.07 psi/day. Based on the calculated rate of change in TMP, a cleaning interval of approximately 12 weeks was calculated.

Table 48 illustrates the flux, TMP, and permeability during testing conducted at the target flux of 35 gfd, evaluated from November 15, 2002 to December 20, 2002. Five different operational conditions were evaluated during Run Nos. 13 to 16b.

Figure 61 illustrates ZW-500-C performance at this flux.

During Run No 13, the average TMP loss was 0.44 psi/day suggesting a cleaning interval of approximately 2 weeks. During this run, 100 mg/L chlorine maintenance cleans were performed to attempt to control the rate of fouling. Chlorine maintenance cleans are represented by the dark squares on the TMP portion of the figure.

Based on the low effectiveness of the chlorinated maintenance cleans in controlling fouling, the cleaning chemical was changed to citric acid (1 g/L) for Runs 14 to16b conducted from November 19, 2002 to December 20, 2002. Citric acid cleans are represented by the dark triangles on the TMP portion of the figure.

During Run 14, the TMP actually decreased and there was only a slight decrease in normalized permeability, as illustrated in Figure 61.

During Run 15, in which aeration was decreased to 10 seconds on/30 seconds off, TMP loss was 0.21 psi/day, equivalent to a cleaning interval of approximately 4 weeks.

For Run No. 16, the operational mode was changed from continuous to batch. During this run, a down time in operation occurred from December 9, 2002 to December 16, 2002, due to a malfunction of the blower unit. The data presented in Table 48 and Figure 61 is separated into two data sets for this set of operating parameters—12/03/02 to 12/09/03 and 12/16/02 to 12/20/02—to account for this down time event (Run 16a and 16b).

**Figure 60. Flux, TMP, and Temperature Corrected Permeability for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent at 30 gfd (Run 12)**

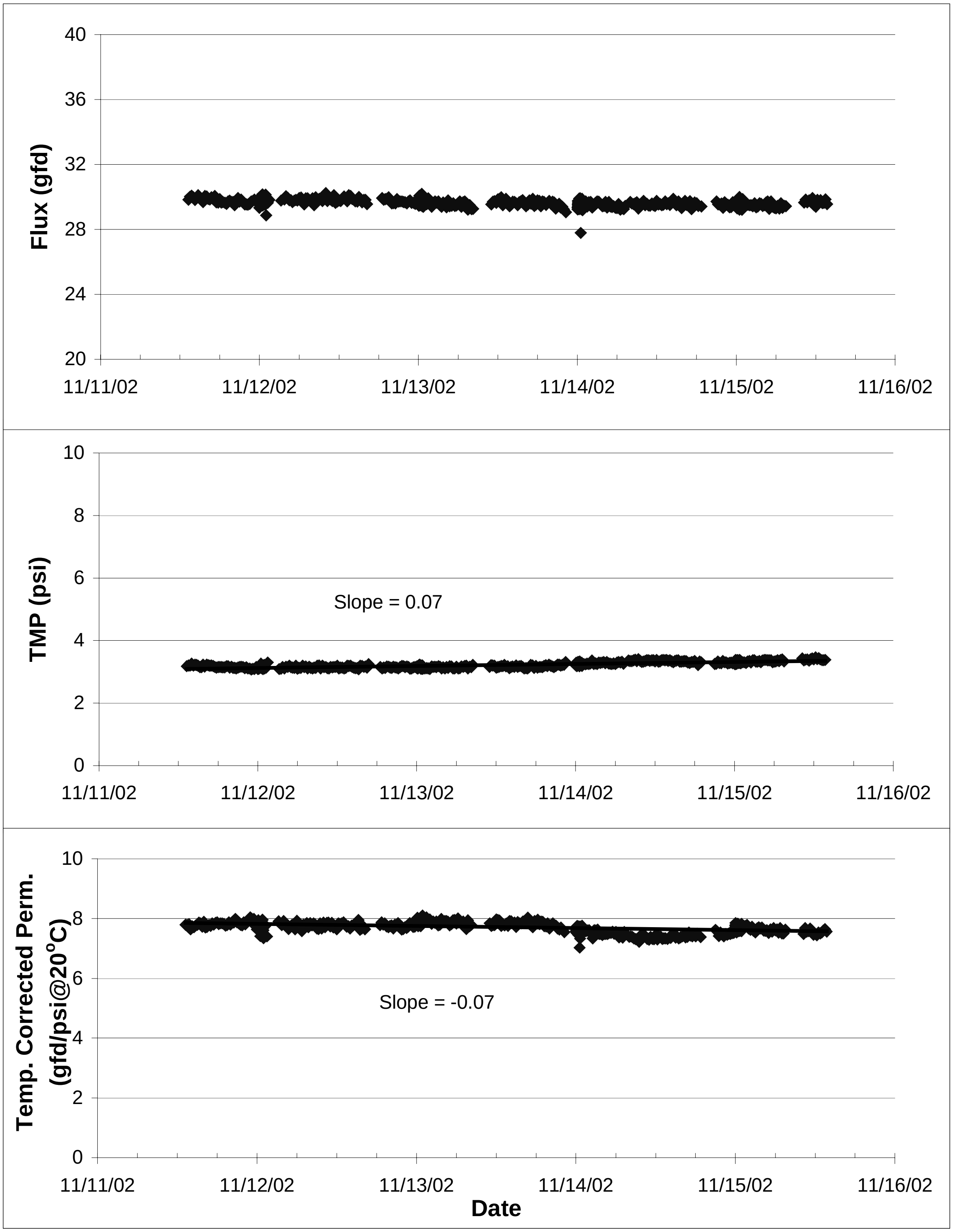
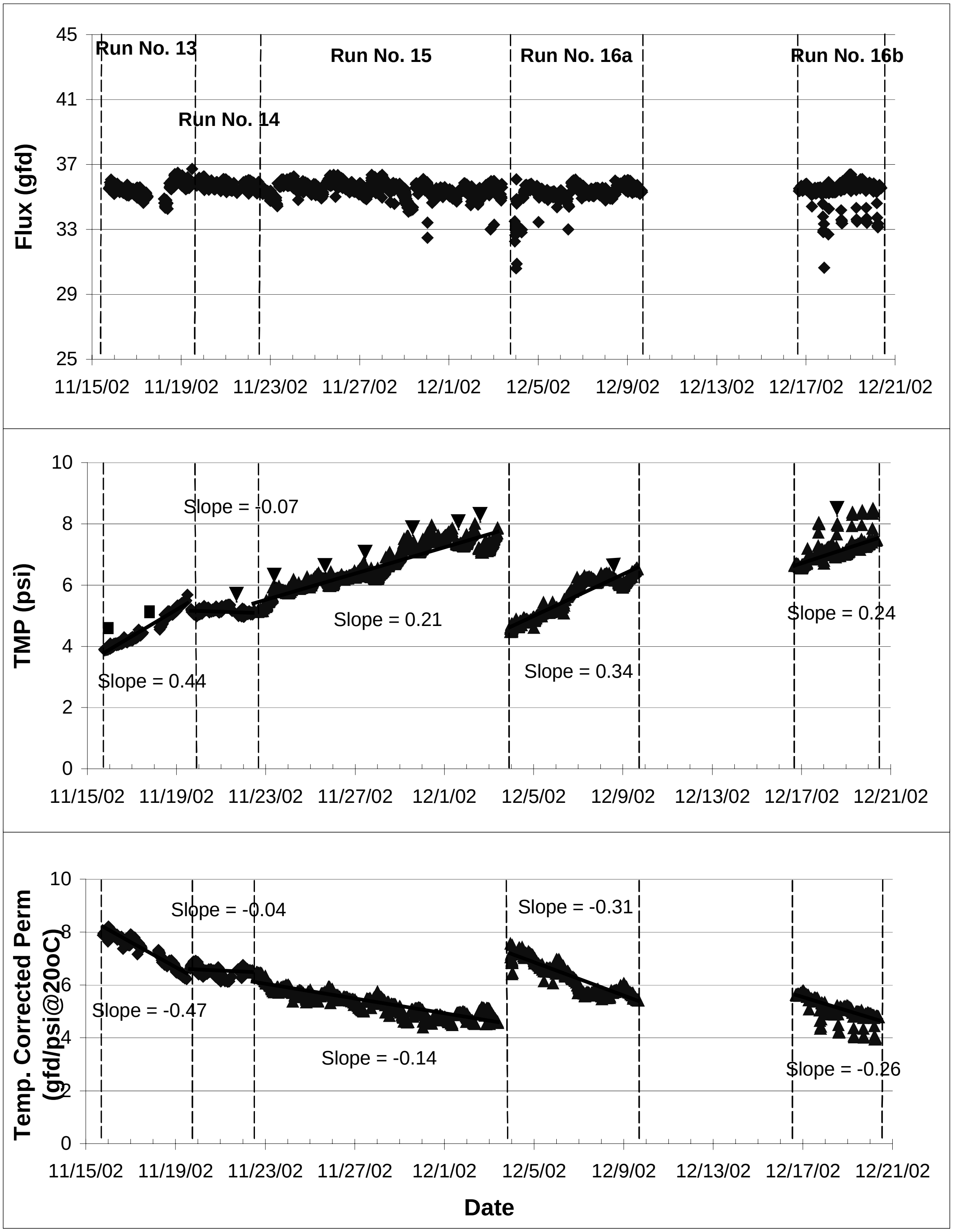


**Figure 61. Flux, TMP, and Permeability for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent at 35 gfd; (Run Nos. 13-16)**



During Run 16a, TMP loss was 0.34 psi/day suggesting an unacceptable fouling rate and a cleaning interval of approximately 2.5 weeks. However, during this 6 day run, only one maintenance clean was performed, compared to the targeted three. Thus, the fouling rate would most likely have been significantly less had maintenance cleans been performed as planned.

Performance during Run 16b suggests a fouling rate of 0.24 psi/day, resulting in a cleaning interval of approximately 3.5 weeks. During this four day run, only one maintenance clean was performed on December 18, two days into the filter run. Again, had the additional maintenance clean been performed as planned, the fouling rate would have been lower.

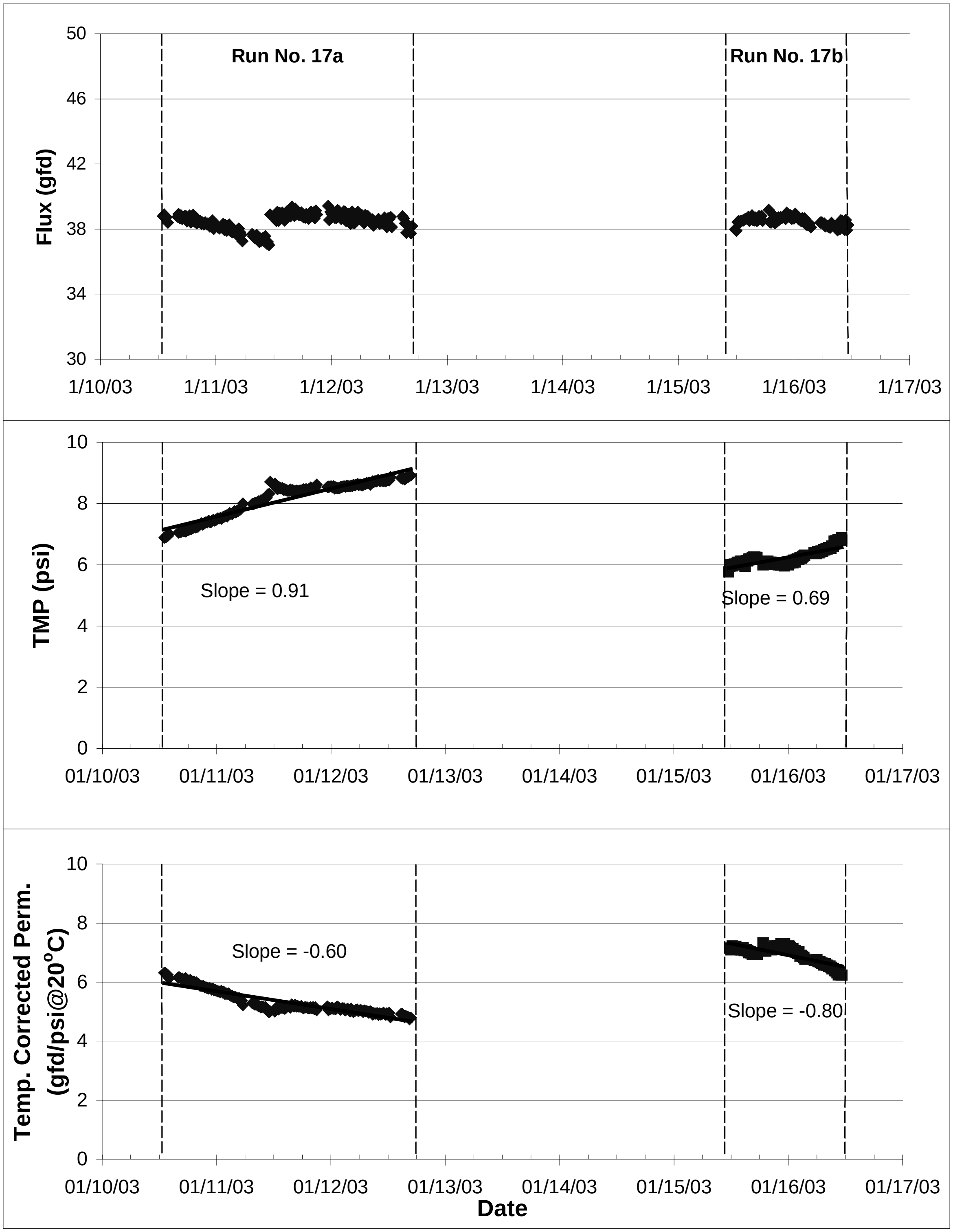
Figure 62 presents the flux, TMP, and permeability for Zenon 500-C UF testing on Actiflo clarified effluent. The final set of tests conducted with the ZW-500-C on clarified water was conducted at a target flux of 40 gfd. The pilot unit was operated in a continuous mode with 15 minute filter runs and 15 second backwashes at a 95 percent recovery and 10/10 cyclic aeration. This testing was divided into two separate runs. The first run, Run No. 17a, was performed from January 10, 2003 to January 12, 2003. Based on the results of Run No. 17a, a CIP was performed and a second run, Run No. 17b, was performed to validate the results of the first run. A 1 g/L citric acid maintenance clean was performed during each run, equivalent to once every other day.

The daily TMP loss for Run 17a was 0.91 psi/day. Values close to this high rate were also observed during Run No. 17b. During the second run, following the CIP, the daily pressure loss was 0.69 psi/day, suggesting a cleaning interval of just over 1 week. This rate of fouling clearly indicates that operation at a flux of 40 gfd would be unacceptable for a full scale design.

### Water Quality Summary

Tables 49, 50, and 51 summarize the results for the daily sampling and analysis of raw, Actiflo clarified, and Zenon streams, respectively. The data is for the period November 11, 2002 to January 16, 2003, and includes average, maximum, minimum, standard deviation, and coefficient of variance for each water quality parameter. In addition, Table 50 summarizes the coagulation dosage and pH data for the Actiflo process while Table 51 summarizes the filtration pH of the ZeeWeed 500-C.

**Figure 62. Flux, TMP, and Permeability for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent at 40 gfd (Run No. 17a and 17b)**



During the ZW 500-C clarified water testing, average $UV_{254}$ of raw water during testing was 0.920 abs/cm, while average conductivity was 69.4 S/m. During this evaluation, the raw water $UV_{254}$ was higher than average and the conductivity was lower than average suggesting rainy season conditions for testing.

**Table 49. Raw Water Quality for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| pH | | 7.0 | 7.4 | 6.4 | 0.2 | 0.03 |
| Temperature | ($^{o}$C) | 18.7 | 25.5 | 13.5 | 3.4 | 0.18 |
| Alkalinity | (mg/L as $CaCO_3$) | 62 | 105 | 19 | 19 | 0.31 |
| Turbidity | (NTU) | 5.9 | 16.4 | 2.2 | 1.7 | 0.29 |
| Conductivity | (S/m) | 69.4 | 86.5 | 44.8 | 11.6 | 0.17 |
| Apparent Color | (Pt-Co) | 246 | 371 | 201 | 31 | 0.12 |
| $UV_{254}$ | (abs/cm) | 0.920 | 1.018 | 0.772 | 0.070 | 0.08 |

Table 50 summarizes the ferric sulfate dosages for the Actiflo process during the ZW 500-C evaluation. For this discussion, ferric sulfate dosages are presented as pure ferric sulfate. As the table indicates, the average ferric sulfate dosages for the Actiflo process were 144 mg/L and ranged from 173 mg/L to 116 mg/L.

Average polymer dosages during testing were 0.31 mg/L and ranged from 0.45 mg/L to 0.25 mg/L. Cytec® Superfloc® C-1592 PG a medium charge density cationic polymer was used for treatment. It should be noted that cationic polymer can cause membrane fouling. The potential impact of polymer carryover on membrane performance was not directly evaluated during this testing.

The average coagulation pH was 4.2 for testing, resulting in an average soluble iron concentration to the Zenon 500-C of 0.78 mg/L. This concentration is very high and most likely was the cause of the high fouling rates observed.

Average apparent color and $UV_{254}$ after clarification were 9 Pt-Co and 0.068 abs/cm, respectively. Turbidity ranged from 1.42 NTU to 0.18 NTU with an average of 0.31 NTU.

**Table 50. Actiflo Clarified Water Quality for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **Ferric Dosage (pure)** | **(mg/L)** | 144 | 173 | 116 | 17 | 0.11 |
| **Polymer** | **(mg/L)** | 0.31 | 0.45 | 0.25 | 0.06 | 0.19 |
| **Coag pH** | | 4.2 | 5.2 | 3.7 | 0.3 | 0.07 |
| **Turbidity** | **(NTU)** | 0.31 | 1.42 | 0.18 | 0.12 | 0.41 |
| **Iron** | **(mg/L)** | 0.78 | 1.25 | 0.37 | 0.21 | 0.26 |
| **Apparent Color** | **(Pt-Co)** | 9 | 21 | 3 | 3 | 0.40 |
| **$UV_{254}$** | **(abs/cm)** | 0.068 | 0.083 | 0.054 | 0.008 | 0.12 |

As Table 51 shows, the average permeate turbidity was 0.041 NTU and ranged from a maximum of 0.154 NTU to 0.025 NTU. The maximum turbidity level corresponded with a startup of the pilot system and was the result of either insoluble iron or air in the permeate following startup.

Average particle counts ranged from 0.0 counts/mL to 90.5 counts/mL with an average of 2.9 counts/mL. Again, as with the turbidity, the maximum particle count level corresponded with a startup of the pilot unit and was likely the result of air or insoluble iron in the permeate.

**Table 51. Zenon Permeate Water Quality for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **pH** | | 6.8 | 7.6 | 6.2 | 0.5 | 0.07 |
| **Alkalinity** | **(mg/L as $CaCO_3$)** | 25 | 51 | 15 | 7 | 0.26 |
| **Turbidity** | **(NTU)** | 0.041 | 0.154 | 0.025 | 0.005 | 0.12 |
| **Particle Counts** | **(#/ml)** | 2.9 | 90.5 | 0.0 | 5.8 | 1.98 |
| **Apparent Color** | **(Pt-Co)** | 1 | 5 | 0 | 2 | 1.05 |
| **$UV_{254}$** | **(abs/cm)** | 0.085 | 0.099 | 0.069 | 0.008 | 0.09 |
| **Iron** | **(mg/L)** | 0.034 | 0.091 | 0.000 | 0.029 | 0.86 |
| **Total $Cl_2$** | **(mg/L as $Cl_2$)** | 3.344 | 5.450 | 1.100 | 1.401 | 0.42 |

Table 52 summarizes and Figure 63 illustrates the removal of turbidity, apparent color, and $UV_{254}$ removal by Actiflo clarification, ZW 500-C, and cumulative removal by both processes.

Cumulative turbidity removal was 99.3 percent, the cumulative apparent color removal was 99.4 percent, and the cumulative $UV_{254}$ was 90.8 percent. The table suggests an increase in $UV_{254}$

through the ultrafilter following clarification. Average clarified $UV_{254}$ was 0.068 abs/cm and the average filtered $UV_{254}$ was 0.085 abs/cm, an increase of 25 percent. However, the average pH of the Actiflo clarified water was 4.2 and the average pH of the Zenon permeate was 6.8. This increase is most likely the result of the higher ZeeWeed permeate pH, as $UV_{254}$ measurement is pH dependant.

**Table 52. Average Turbidity, Apparent Color, and UV254 Removals for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent**

| Parameter | Units | Averages | | | Removals | | |
|---|---|---|---|---|---|---|---|
| | | Raw | Clarified | Filtered | Raw to Clarified | Clarified to Filtered | Cumulative Removal |
| Turbidity | (NTU) | 5.9 | 0.31 | 0.041 | 94.8% | 86.7% | 99.3% |
| Apparent Color | (Pt-Co) | 246 | 9 | 1 | 96.5% | 82.9% | 99.4% |
| $UV_{254}$ | (abs/cm) | 0.920 | 0.068 | 0.085 | 92.6% | -25.2% | 90.8% |

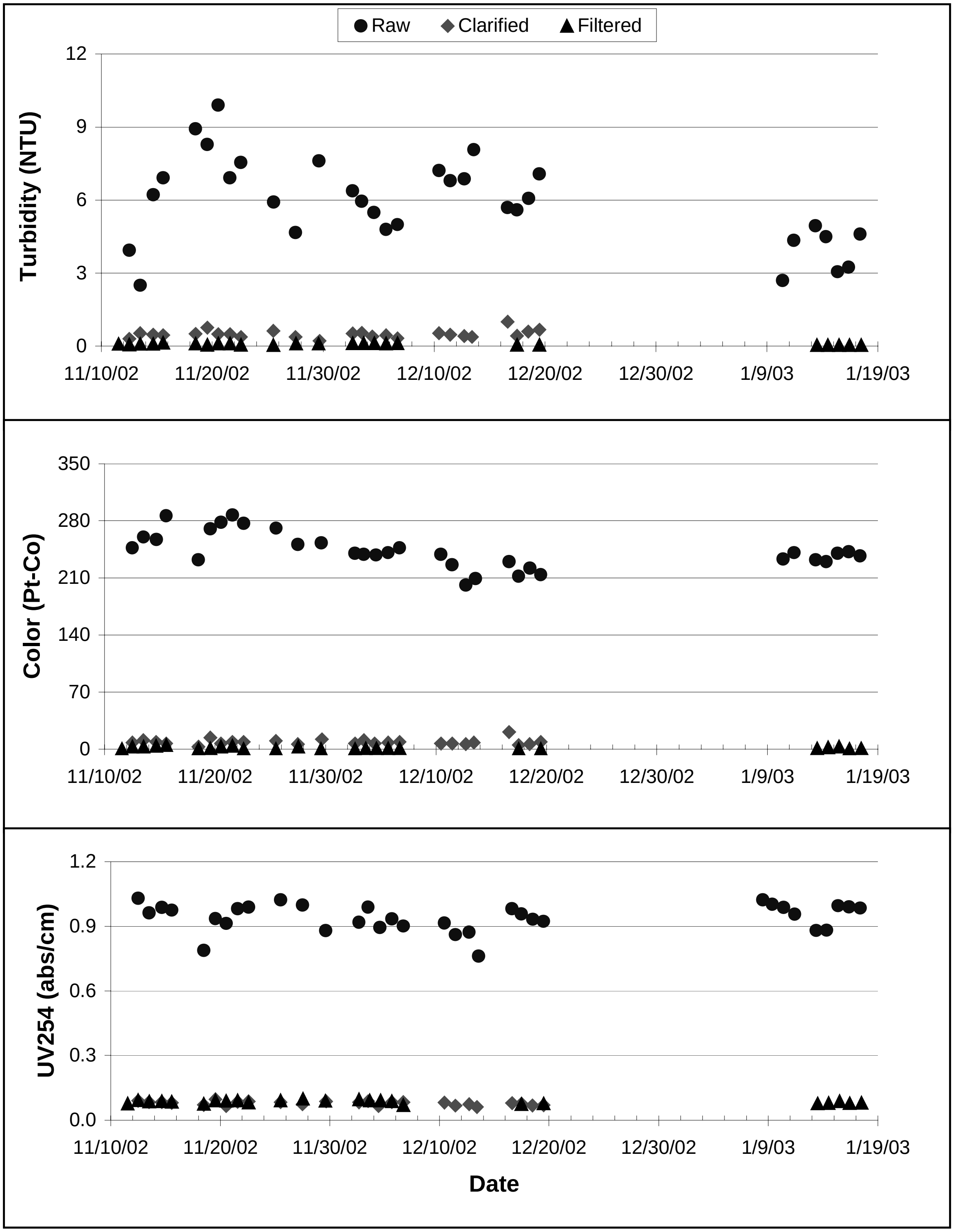
Table 53 provides an operational summary of the ZW 500-C during clarified water testing. The table summarizes average temperature and permeate particle counts and turbidity. The table also provides the flux, permeability, and temperature corrected flux and permeability.

As Table 53 indicates, temperatures decreased steadily during the testing period, causing temperature corrected flux to increase from 24.8 gfd to 43.1 gfd. All results are presented as averages.

**Table 53. Operation Summary for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent**

| Run No. | Date | Temp | TMP | Turbidity | Particle Counts | Flux | | Permeability | |
|---|---|---|---|---|---|---|---|---|---|
| | | (°C) | (psi) | (NTU) | (#/mL) | (gfd) | ($gfd_{20^oC}$) | (gfd/psi) | ($gfd/psi_{20^oC}$) |
| 12 | 11/11/02-11/15/02 | 27.2 | 3.3 | 0.055 | NA | 29.6 | 24.8 | 9.1 | 7.6 |
| 13 | 11/15/02-11/19/02 | 22.8 | 4.6 | 0.043 | NA | 35.4 | 32.9 | 7.9 | 7.4 |
| 14 | 11/19/02-11/22/02 | 22.6 | 5.2 | 0.039 | 2.7 | 35.6 | 33.4 | 6.9 | 6.5 |
| 15 | 11/22/02-12/02/02 | 20.7 | 6.7 | 0.039 | 1.2 | 35.3 | 34.8 | 5.4 | 5.3 |
| 16a | 12/02/02-12/09/02 | 20.4 | 5.6 | 0.041 | 3.2 | 35.2 | 35.0 | 6.2 | 6.2 |
| 16b | 12/16/02-12/20/02 | 19.2 | 7.1 | 0.041 | 7.8 | 35.5 | 36.2 | 5.0 | 5.1 |
| 17a | 01/10/03-01/12/03 | 15.4 | 7.8 | 0.038 | 3.7 | 38.5 | 42.5 | 4.7 | 5.3 |
| 17b | 01/15/03-01/16/03 | 15.4 | 6.2 | 0.039 | 1.8 | 38.5 | 43.1 | 6.2 | 6.9 |

**Figure 63. Raw, Clarified, and Filtered Water Quality Levels for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent**



Figures 64, 65, and 66 illustrate turbidity and particle counts for the 30, 35, and 40 gfd ZW-500-C runs on clarified water (Run Nos. 12 to 17). Particle count data was not available during Run No. 12 at 30 gfd and Run No. 13 at 35 gfd due to a particle counter malfunction.

These figures illustrate that the permeate was of consistently high quality based on turbidity and particle counts. As indicated in Table 53, the average turbidity for these runs ranged from 0.038 to 0.055 NTU while average particle counts ranged from of 1.2 to 7.8 counts/ml.

### Conclusions

Following the completion of pilot testing on clarified water, Zenon in conjunction with CH2M HILL, developed recommended parameters for full scale design of both ZW-500 and ZW-1000 equipment. The selection of the design parameters was based on:

- Clarified water quality during testing
- ZW-500-C performance results on clarified water
- Pilot studies where ZW-1000 and ZW-500 units were tested on a common source water
- ZW-1000 pilot studies on feed water having similar quality to that provided by Actiflo clarification of Lake Monroe water.

#### *ZW-500-C Design Parameters*

Table 54 summarizes the selected design criteria for ZW-500-C operation of clarified water.

**Table 54. Design Parameters for a ZW 500-C Membrane Plant Treating Clarified Water**

| Parameter | Units | ZW-500 |
|---|---|---|
| **Instantaneous Flux** | gfd | 35 |
| **Recovery** | % | 95% |
| **Backwash/pulse duration** | Seconds | 15 |
| **Production Duration** | Minutes | 15 |
| **Maintenance Cleaning Routine** | Tank Drain<br>Backpulse | One Tank Drain per Day<br>1 g/L Citric Acid Every Other Day |
| **Recovery Cleaning Interval** | Weeks | 6 Weeks (10/30 Cyclic Aeration)<br>9 Weeks (10/10 Cyclic Aeration) |
| **Recovery Clean - Chlorine** | Backpulse<br>Soak<br>Duration | 1000 ppm<br>250 ppm<br>4-6 hours |
| **Recovery Clean - Citric acid** | Backpulse<br>Soak<br>Duration | 4 g/L<br>1 g/L<br>4-6 hours |

**Figure 64. Turbidity for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent at 30 gfd (Run No. 12)**

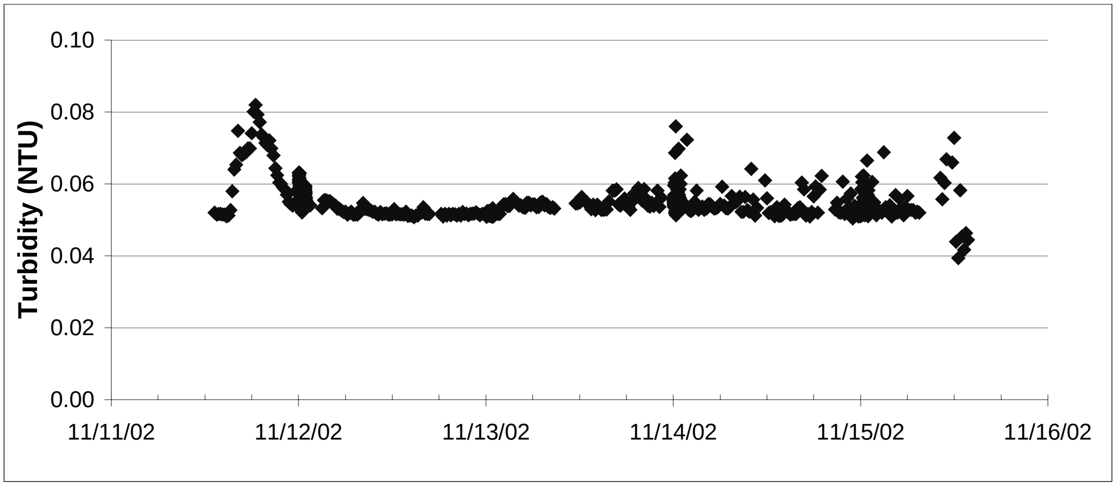



**Figure 65. Turbidity and Particle Counts for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent at 35 gfd (Run Nos. 13-16)**

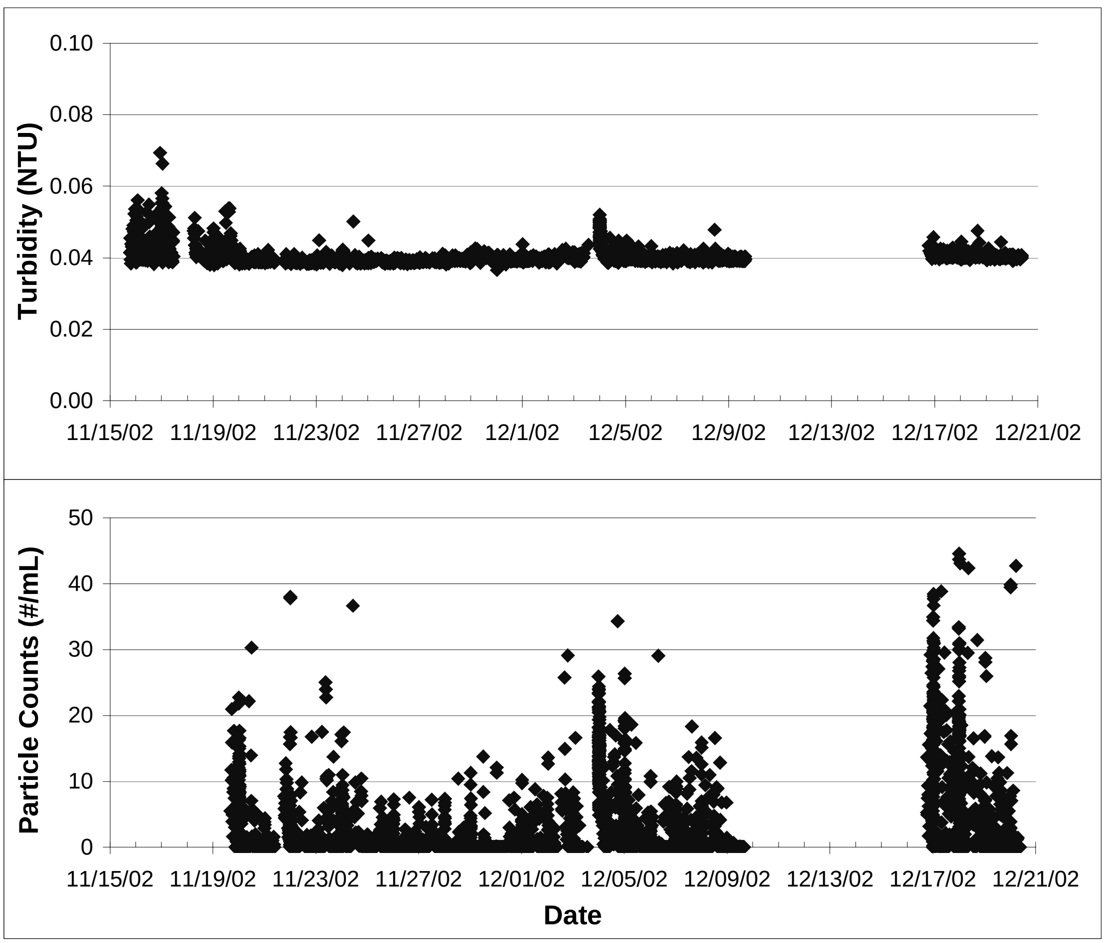
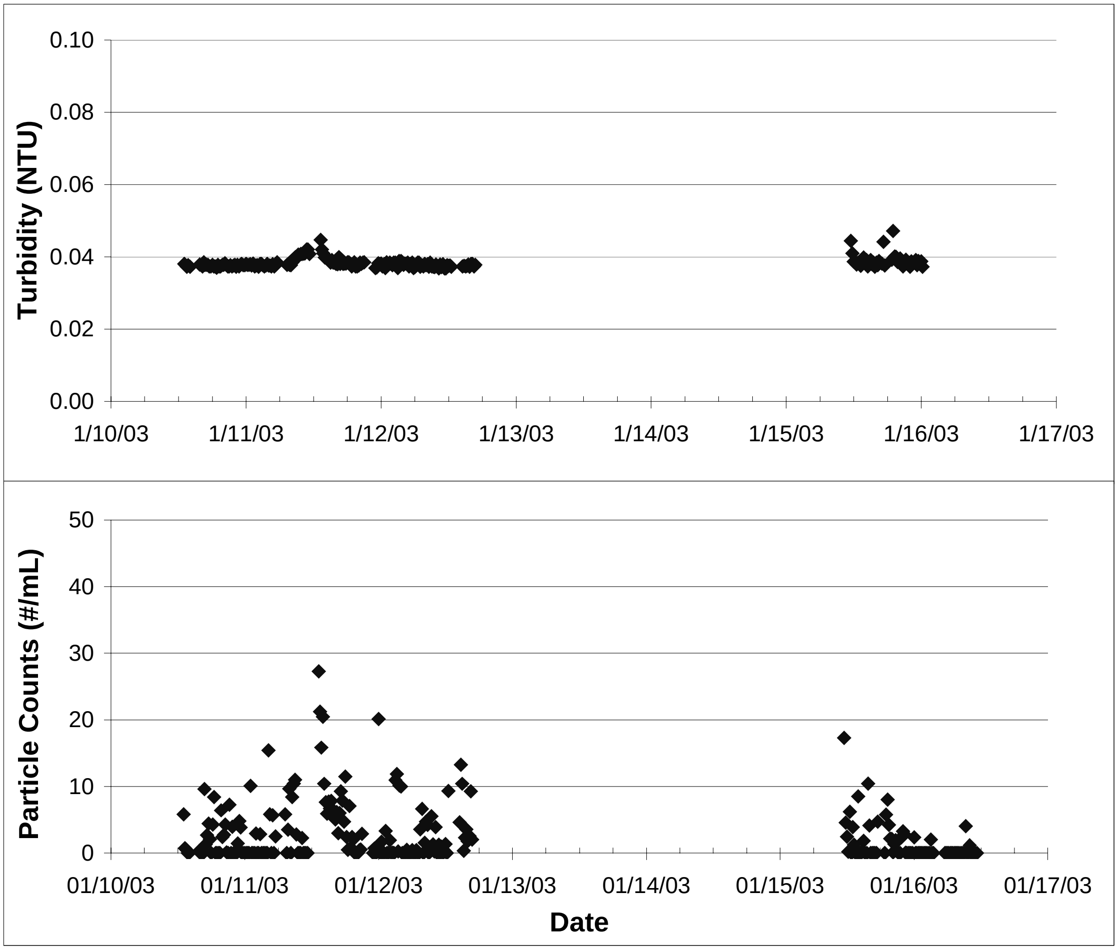


**Figure 66. Turbidity and Particle Counts for Zenon 500-C Ultrafiltration Testing on Actiflo Clarified Effluent at 40 gfd (Run No. 17)**




These criteria reflect a feed water having a high level of dissolved iron and associated iron fouling.

### *ZW 1000 Design Parameters*

The Zenon ZW-1000 membrane is recommended for filtration of clarified water. The operation and design parameters for a ZW-1000 were simulated using the ZW-500-C membrane at the recommendation of Zenon due to the unavailability of a ZW-1000 membrane pilot unit for testing. Since the Zenon ZW-500-C membrane pilot was used for simulation of the ZW-1000 testing, correlations were developed to formulate ZW-1000 design parameters using the 500-C data developed in this study. Further, information from other ZeeWeed studies, including side-by-side comparisons between ZW-500-C and the ZW-1000, as well as ZW-

1000 studies on similar waters were used for the correlations. All correlations were provided by Zenon.

Zenon has performed three pilot studies with side by side testing of ZW-1000 and ZW-500-C membranes on the same water source. The key finding from these studies was, given the same feed water quality conditions, the sustainable flux for the ZW-500 unit was approximately 1.5 times higher than that for the ZW-1000 unit.

In addition, in studies using the ZW-1000 membrane conducted on low turbidity feed waters (similar to that produced by Actiflo clarification), CIP intervals of 4 to 6 weeks could be achieved by operating at recoveries of 92 to 93 percent and fluxes of 23 to 30 gfd, depending on feed water temperature.

Table 55 summarizes the design conditions for a full scale ZW-1000 system. This condition was the outcome after consideration of several factors including the known feed water quality results, optimized flux of 35 gfd for the ZW-500 pilot on clarified Lake Monroe water, and conservative application of a flux proportionality factor of 1.5 (between ZW-500-C and ZW-1000).

**Table 55. Design Parameters for a ZW 1000C Membrane Plant Treating Clarified Water**

| Parameter | Units | ZW-1000 |
|---|---|---|
| **Instantaneous Flux** | gfd | 20 |
| **Recovery** | % | 92% |
| **Backwash/pulse duration** | Seconds | 60 |
| **Maintenance Cleaning Routine** | Tank Drain<br>Backpulse<br>Backpulse | 7 Tank Drains/Week<br>5 with 50 ppm NaOCl<br>2 with 1 g/L Citric Acid |
| **Recovery Clean Interval** | Weeks | 4 (T < 60 $^oF$)<br>6 (T > 60 $^oF$) |
| **Recovery Clean - Chlorine** | Backpulse<br>Duration<br>Frequency | 1000 ppm<br>4-6 hours<br>10 Times/Year |
| **Recovery Clean - Citric acid** | Backpulse<br>Duration<br>Frequency | 4 g/L (Adjusted to pH ~2)<br>4-6 hours<br>10 Times/Year |

### Actiflo Clarification - Memcor Filtration

Testing was conducted using the Memcor CMF-S microfiltration (MF) membrane as a second alternative to dual media filtration for Actiflo clarified effluent. Testing included operation at a variety of flux rates and recoveries with the goal to optimize membrane productivity and develop criteria for full scale design of a Memcor MF plant.

### Equipment Description

A simplified flow schematic of the Memcor CMF-S MF unit is shown in Figure 67. The pilot unit was a fully automatic unit. Major process parameters including flow, pressure, and temperature were collected and stored in an integral data logger.

Feed water is pumped to the bottom of the membrane process tank using a low-lift pump. The hollow fiber MF modules are suspended in an atmospheric process tank. During filtration, water is drawn through the membrane using pressure differential developed from the suction of the permeate pump. Particulate matter greater than 0.1 • m are removed at the surface of the membrane using a sieving filtration mechanism. The filtrate flow is maintained at a constant rate independent of particle deposition on the membrane using a variable frequency drive on the filtrate pump. A portion of the microfiltered water is stored in a tank located within the skid boundaries for use during the backwash step.

As particulate matter accumulates on the membrane surface, the hydraulic resistance of the membranes increases, resulting in a higher differential pressure. The unit automatically performs a backwash to remove particulate matter, restoring the TMP. CMF-S uses a proprietary backwash process to remove particulate matter from the surface of the membrane and purge the process tank of accumulated particles. The CMF-S backwash consists of a period of aeration within the membrane module fiber bundle to loosen particulate matter on the membrane surface. The permeate is pumped back through the membrane lumens and through the fiber walls, displacing particulate matter from the membrane and back into the bulk process tank water. A valve is opened at the bottom of the process tank, which rapidly drains the process tank.

Over a period of time, some fouling of the membrane will occur which can not be recovered by backwashing alone. As the TMP approaches approximately 12 psi, a chemical clean-in-place procedure is required to restore the TMP.

For surface applications, the clean-in-place procedure consists of two parts: a citric acid based clean and a sodium hypochlorite based clean.

**Figure 67. Process Flow Schematic for Memcor CMF-S System; Clarified Water Testing**

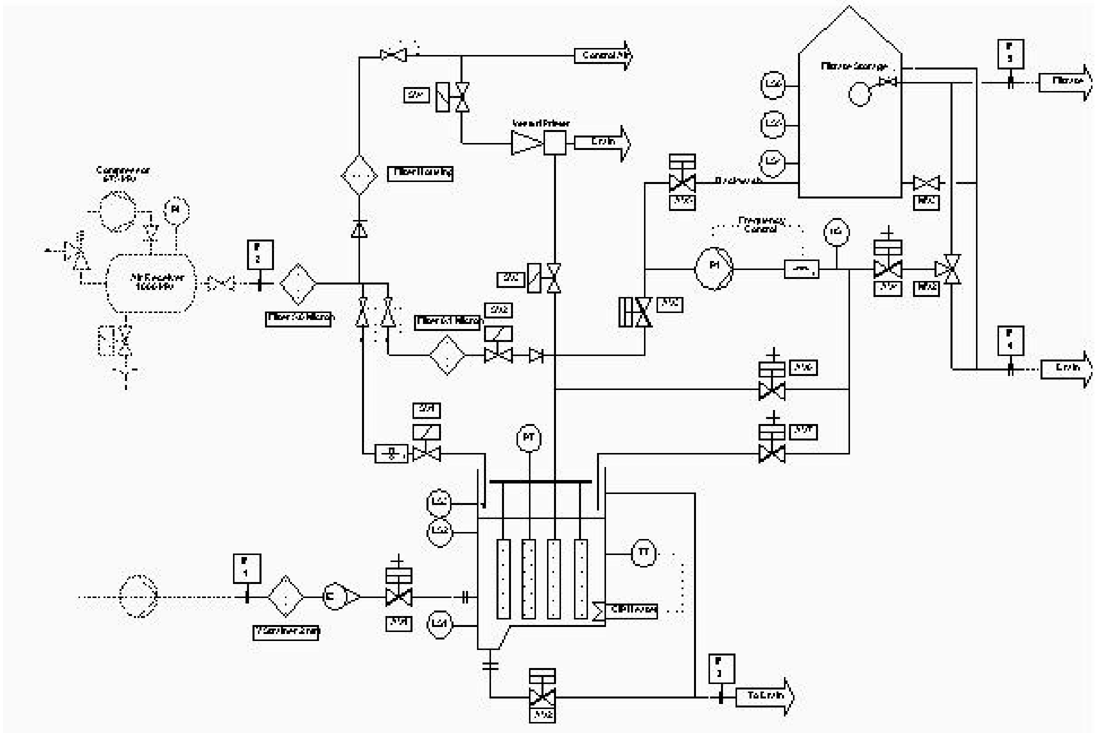


Table 56 summarizes the CMF-S operational settings during testing. As the table indicates, filtration runs were 30 minutes in duration with tank dumps and backwashes at the end of the run for solids removal. Chlorinated maintenance cleans were performed once per day at a concentration of 200 mg/L as $Cl_2$.

**Table 56. Operational Description and Settings for Memcor CMF-S Clarified Water Testing**

| Parameter | Memcor |
|---|---|
| Driving Force | Filtrate Suction |
| Fiber Diameter | 0.8 mm OD / 0.5 mm ID |
| Module Dimensions | 4.7" Diam; 46" L |
| Nominal Pore Size | 0.1 micron |
| Module Surface Area (External) | 275 sq.ft/module |
| Batch Mode | |
| Filtration | 30 minute run duration |
| Solids Removal | Tank drain, backpulse, and air scour after 30 min run |
| Backpulse | Every 30 min during tank drain |
| Maintenance Clean | Once per day for 30 minutes; 200 mg/L as $Cl_2$ |
| Typical Recovery Clean Solution - Chlorine | 400 mg/L as $Cl_2$ |
| Typical Recovery Clean Solution - Citric Acid | 2% Citric acid |

### Testing Summary

Table 57 summarizes the operating parameters employed during Memcor CMF-S pilot testing which started January 16, 2003 and concluded April 2, 2003. The Memcor CMF-S pilot unit was operated in batch mode with backwashes every 30 minutes. Automated maintenance cleans were performed once a day using a 200 mg/L $Cl_2$ solution.

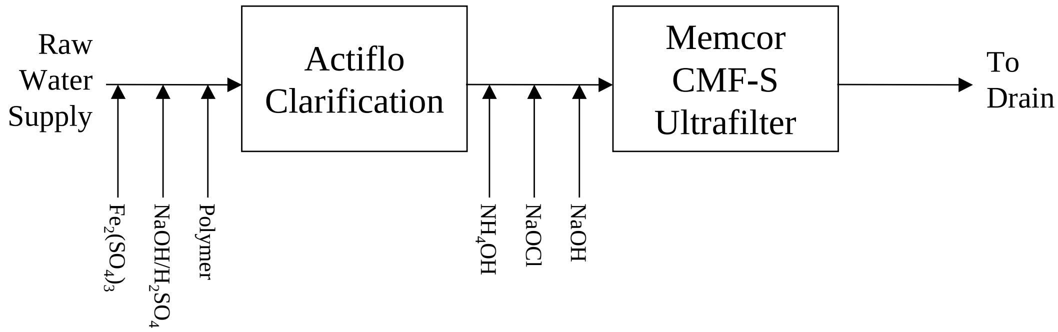
Pilot testing consisted of evaluation of several different fluxes and recoveries. Run 1 was conducted from February 2, 2003 to February 12, 2003 at a target flux of 30 gfd and recovery of 93 percent. Based on favorable performance at this condition, a target flux and recovery of 40 gfd and 94 percent, respectively, was tested from February 13, 2003 to March 12, 2003. Finally, the maximum design flux of 45 gfd and recovery of 95 percent was evaluated during the final run (Run No. 3) from March 27, 2003 to April 2, 2003.

**Table 57. Operating Parameters for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent**

| Run No. | Date | Target Flux (gfd) | Recovery (%) | Operational Mode | Maintenance Cleans |
|---|---|---|---|---|---|
| 1 | 02/04/03 - 02/12/03 | 30 | 93 | Batch - 30 min run w/backwash | Chlorine - 200 ppm |
| 2 | 02/13/03 - 03/12/03 | 40 | 94 | Batch - 30 min run w/backwash | Chlorine - 200 ppm |
| 3 | 03/27/03 - 04/02/03 | 45 | 95 | Batch - 30 min run w/backwash | Chlorine - 200 ppm |

The process schematic for clarified water testing of the Memcor CMF-S unit is illustrated in Figure 68. Raw water flowed to the Actiflo unit with effluent from the Actiflo unit serving as feed to the CMF-S. Prior to the membrane treatment, sodium hypochlorite and ammonium hydroxide were dosed to form chloramines; sodium hydroxide was then fed to the chloraminated water to adjust the pH to a target value of 7.0.

**Figure 68. Process Schematic for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Water**




The data presented are representative of a properly operated Actiflo/Memcor CMF-S process. The following data collected during non-representative periods are not included:

- Testing without pH adjustment of the Actiflo clarified effluent
- Actiflo operational upsets due to caustic feed problems
- Detachment of module end (air) caps, which increased fouling due to loss of air scouring during backwashing
- Feed pump problems resulting in loss of flow or reduced flow

Because sufficient data on the performance of RO membranes treating UF water had been generated during Zenon operation, no RO testing was performed using CMF-S permeate.

### Performance Summary

Table 58 summarizes the average temperature, flux, and permeability results from testing. The rate of change values for TMP and permeability were estimated by linear regression.

The rate of change in TMP ranged from -0.07 psi/day (negative TMP indicates a reduction in TMP) during the Run No. 1 to +0.39 psi/day for Run No. 3. The permeability rate of change ranged from +0.11 gfd/psi per day to -0.42 gfd/psi per day. The temperature corrected permeability rate of change ranged from +0.10 gfd/psi per day to -0.23 gfd/psi per day.

**Table 58. Performance Summary for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Water**

| Run No. | Date | Average Temp | Average Flux | Normalized Flux | TMP Change | Permeability | | Temperature Corrected Permeability | |
|---|---|---|---|---|---|---|---|---|---|
| | | ($^{o}$C) | (gfd) | (gfd@20$^{o}$C) | (Δpsi/day) | (gfd/psi) | (Δgfd/psi/day) | (gfd/psi) | (Δgfd/psi/day @20$^{o}$C) |
| 1 | 02/04/03-02/12/03 | 14.9 | 31.6 | 35.7 | -0.07 | 7.3 | 0.11 | 8.2 | 0.10 |
| 2 | 02/20/03-03/12/03 | 20.3 | 39.1 | 38.8 | 0.07 | 7.3 | -0.10 | 7.3 | -0.12 |
| 3 | 03/27/03-04/02/03 | 20.7 | 44.9 | 44.2 | 0.39 | 7.0 | -0.42 | 6.8 | -0.23 |

Figure 69 illustrates the flux, TMP, and permeability during the 30 gfd flux evaluation. The test lasted from February 4, 2003 to February 12, 2003. As the figure demonstrates, there were several interruptions during the filter run. A power surge and the loss of operation of the external sump pump resulted in two shutdowns on February 6, 2003 and February 7, 2003, respectively.

The TMP decreased at a rate of 0.07 psi/day suggesting a decrease in the TMP required for filtration at an average flux of 31.6 gfd. The permeability increased at a rate of 0.11 gfd/psi per day and the temperature corrected permeability increase was 0.10 gfd/psi per day. This suggests a decline in membrane fouling.

Prior to this run and during initial testing, operational problems with the Actiflo system resulted in high turbidity/high soluble iron feed water being fed to the CMF-S. As a result, the system fouled rapidly, and a recovery clean was subsequently performed. However, this clean may not have been completely effective and permeability and TMP may have been recovered during daily maintenance cleans and backpulses performed throughout this run.

Figure 70 shows the changes in flux, TMP, and permeability during Run 2, which occurred from February 20, 2003 to March 12, 2003. During this run, there were several interruptions in operation. The unit shutdown on March 3, 2003 for several days due to an automatic shutdown of the system (the automated shutdown setting was not adjusted prior to the start of testing). Three other shutdowns—March 9, 2003; March 10, 2003; and March 11, 2003—occurred due to power surges. One air cap detached around March 3 resulting in slightly decreased backwash efficiency.

**Figure 69. Flux, TMP, and Permeability for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent at 30 gfd (Run 1)**

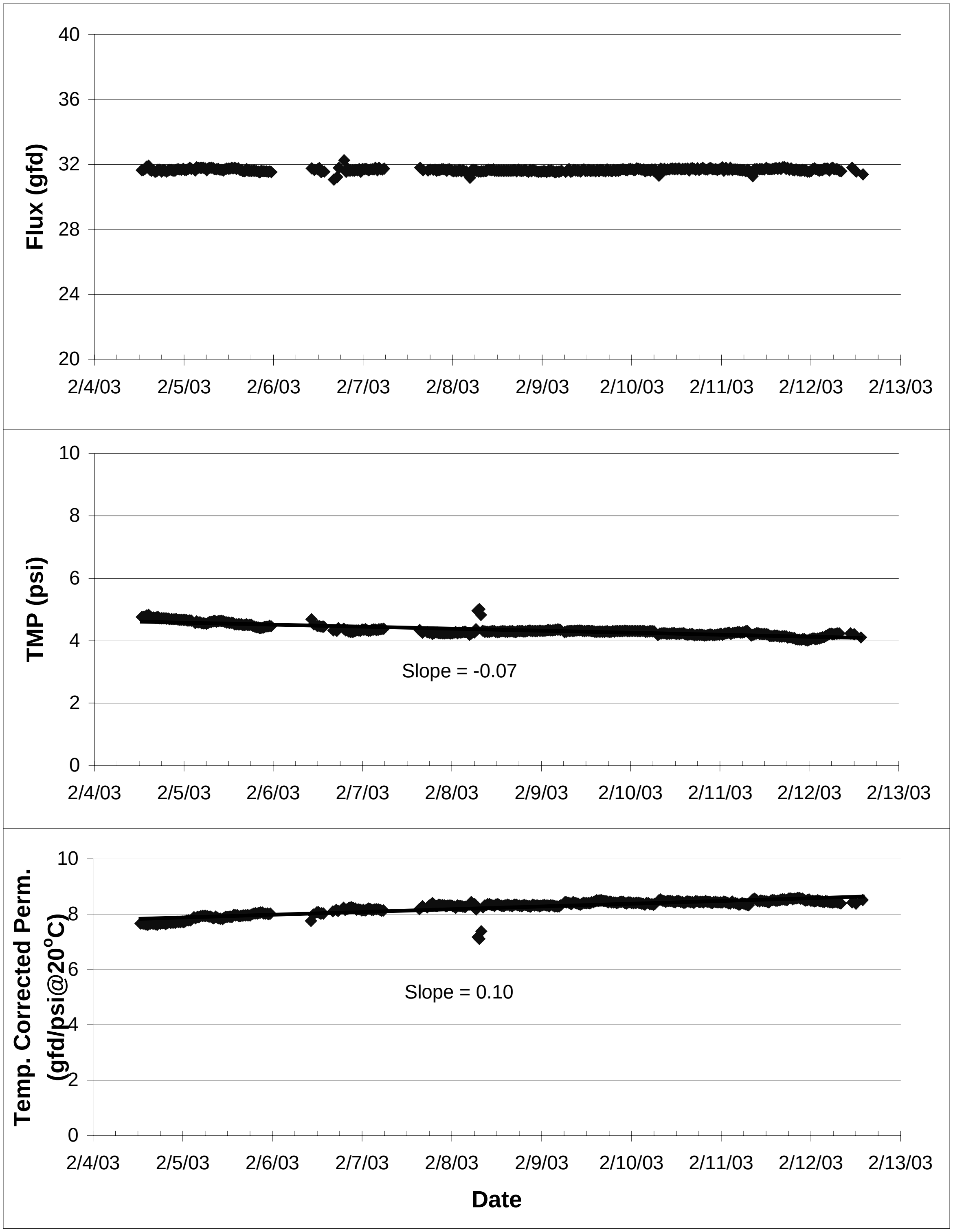
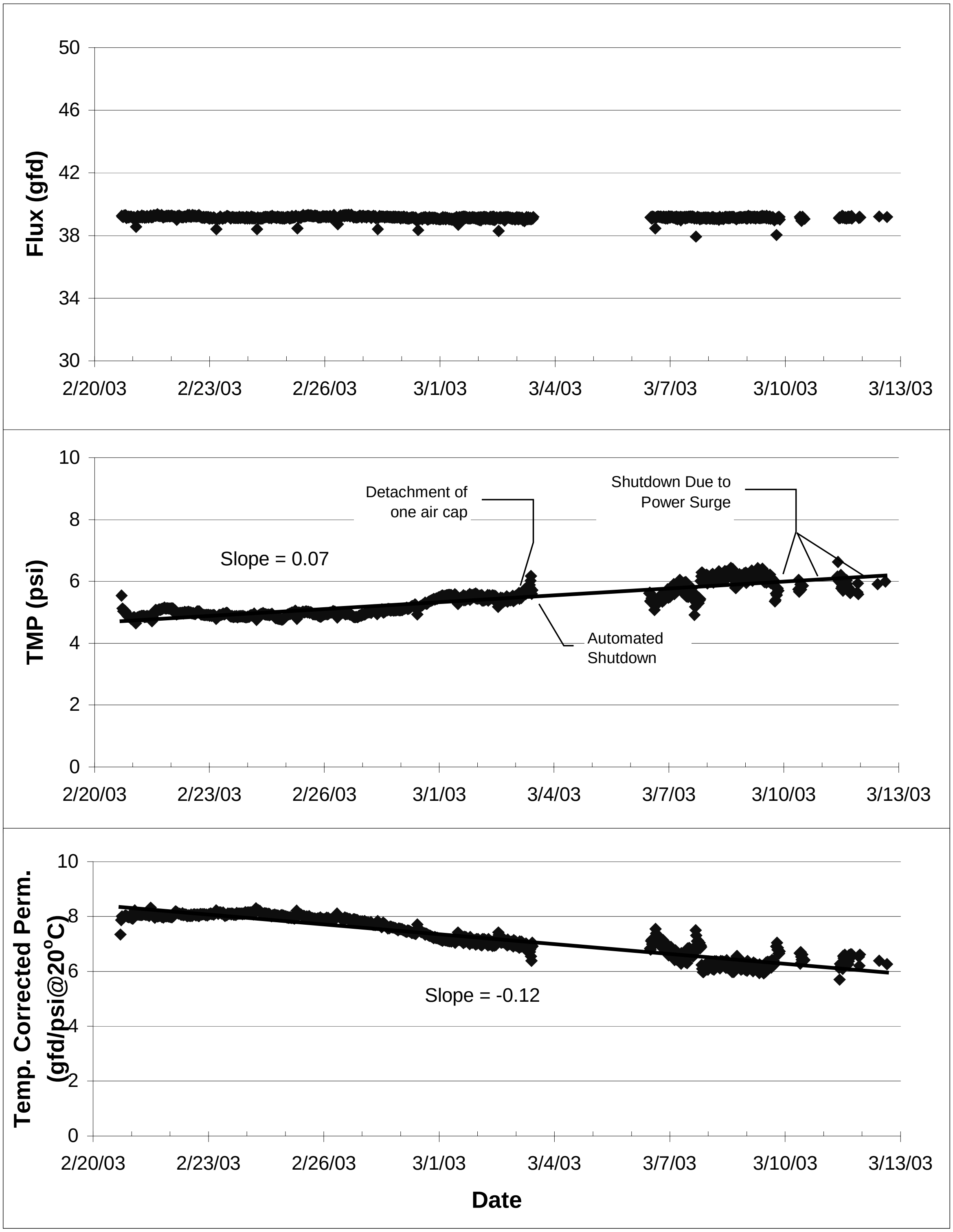


**Figure 70. Flux, TMP, and Permeability for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent at 40 gfd (Run No. 2)**



The rate of TMP increase during this run was 0.07 psi/day. This rate of TMP increase translates into an acceptable cleaning interval of more than 6 weeks. Permeability loss rate was 0.10 gfd/psi per day with a loss in temperature corrected permeability of 0.12 gfd/psi per day.

Figure 71 shows the changes in the flux, TMP, and permeability during Run No. 3, which occurred from March 27, 2003 to April 2, 2003. The target flux during this run was 45 gfd.

The rate of TMP increase for this run was 0.39 psi/day, resulting in an estimated cleaning interval of less than 3 weeks. Permeability loss was 0.42 gfd/psi per day, while temperature corrected permeability loss was 0.23 gfd/psi per day. The latter value is twice the rate of loss measured during Run No. 2 and indicated that 40 gfd is the appropriate design flux.

### Water Quality Summary

Tables 59, 60, and 61 summarize the results of sampling and analysis of raw, clarified, and CMF-S filtrate water quality, respectively. The data was collected from February 4, 2003 to April 2, 2003. Each table summarizes the average, maximum, minimum, standard deviation, and coefficient of variance for each water quality parameter. The coagulation dosage and pH for the Actiflo process are summarized in Table 60, while Table 61 summarizes the filtration pH for the Memcor CMF-S process.

As Table 59 shows, during the Memcor CMF-S evaluation, the average apparent color was 263 Pt-Co, average $UV_{254}$ was 0.938 abs/cm, and the average conductivity was 55.5 S/m. These organic parameters were higher than average and the conductivity was lower than average, suggesting the occurrence rainy season conditions during testing.

**Table 59. Raw Water Quality for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **pH** | | 7.0 | 7.2 | 6.4 | 0.2 | 0.02 |
| **Temperature** | **($^{o}$C)** | 17.7 | 24.6 | 10.4 | 4.3 | 0.24 |
| **Alkalinity** | **(mg/L as $CaCO_3$)** | 40 | 80 | 19 | 15 | 0.37 |
| **Turbidity** | **(NTU)** | 5.9 | 16.0 | 2.4 | 2.0 | 0.35 |
| **Conductivity** | **(S/m)** | 55.5 | 67.0 | 41.2 | 6.4 | 0.12 |
| **Apparent Color** | **(Pt-Co)** | 263 | 395 | 168 | 38 | 0.15 |
| **$UV_{254}$** | **(abs/cm)** | 0.938 | 1.145 | 0.455 | 0.126 | 0.13 |

**Figure 71. Flux, TMP, and Permeability for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent at 45 gfd**

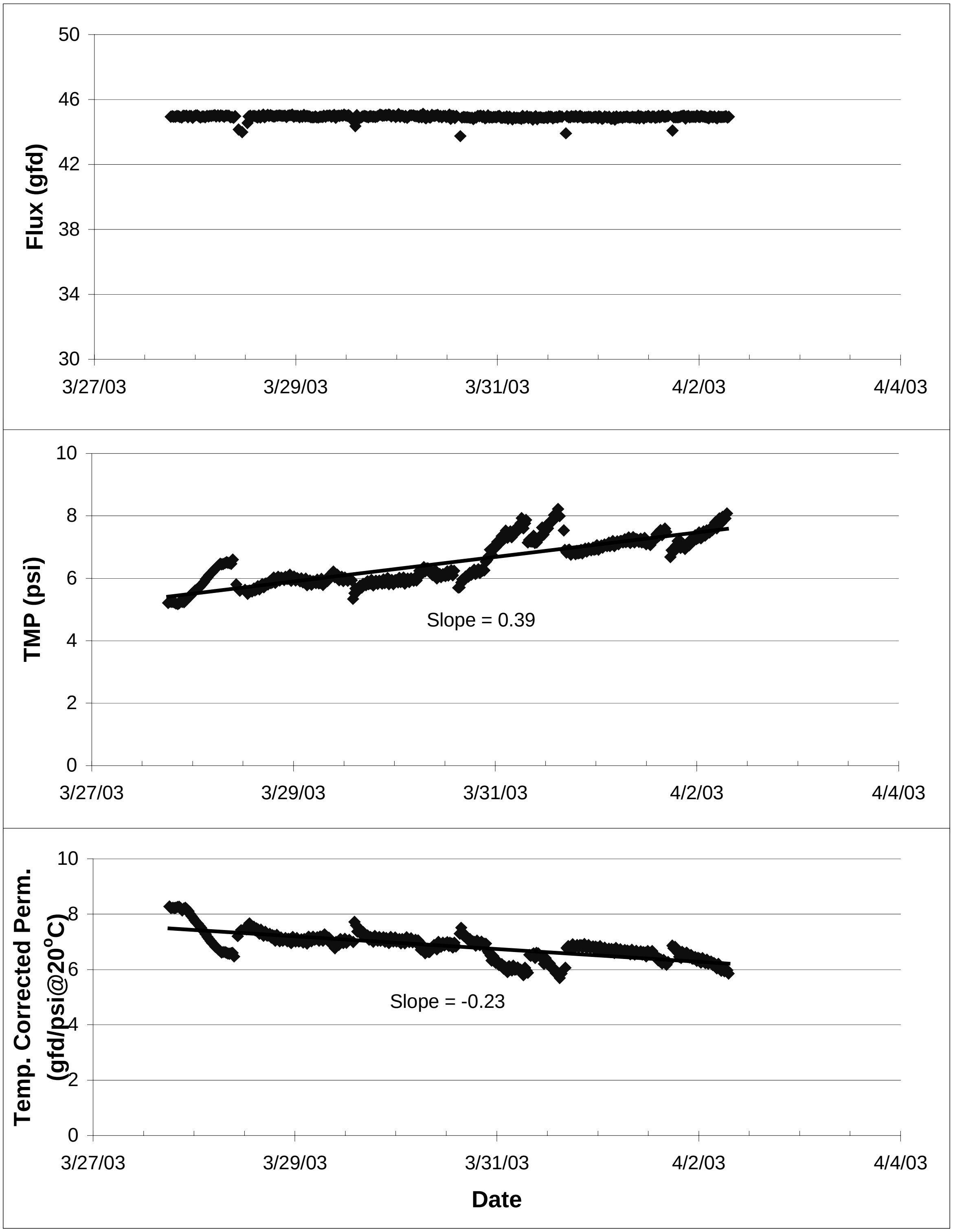


Table 60 summarizes the ferric sulfate dosages for the Actiflo process during the Memcor CMF-S evaluation. All ferric sulfate dosages are reported as pure (100 percent) ferric sulfate. As this table illustrates, the average ferric sulfate dosages for the Actiflo process were 128 mg/L and ranged from 69 mg/L to 289 mg/L.

The average polymer dosage during testing was 0.43 mg/L and ranged from 0.25 mg/L to 0.75 mg/L. Two types of polymer were tested during the evaluation, Cytec® Superfloc® C-1592 PG and Ciba® Magnafloc® LT22S. Both polymers were a medium charge density cationic polymer. Note that cationic polymer can cause membrane fouling. The potential impact of polymer carryover on membrane performance was not directly evaluated during this testing.

The average coagulation pH was 4.2 for testing, resulting in an average soluble iron concentration to the Memcor CMF-S membrane of 1.10 mg/L.

The average apparent color and $UV_{254}$ after clarification were 5 Pt-Co and 0.078, respectively. Turbidity ranged from 0.22 NTU to 2.89 NTU with an average of 0.55 NTU.

**Table 60. Actiflo Clarified Water Quality for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| Ferric Dosage (pure) | (mg/L) | 128 | 289 | 69 | 78 | 0.27 |
| Polymer | (mg/L) | 0.43 | 0.75 | 0.25 | 0.13 | 0.29 |
| Coag pH | | 4.2 | 7.4 | 2.9 | 0.4 | 0.09 |
| Turbidity | (NTU) | 0.55 | 2.89 | 0.22 | 0.29 | 0.52 |
| Iron | (mg/L) | 1.10 | 1.21 | 0.93 | 0.09 | 0.08 |
| Apparent Color | (Pt-Co) | 5 | 22 | 1 | 4 | 0.79 |
| $UV_{254}$ | (abs/cm) | 0.078 | 0.317 | 0.055 | 0.037 | 0.47 |

Table 61 shows that the average permeate turbidity was 0.038 NTU and ranged from a maximum of 0.322 NTU to 0.032 NTU. The maximum turbidity level corresponded with the startup of the pilot system and resulted from either insoluble iron or air in the permeate following startup.

Average particle counts ranged from 0.0 counts/mL to 10.0 counts/mL with an average of 0.6 counts/mL. Again, as with the turbidity, the maximum particle count level corresponded with a startup of the pilot unit and likely resulted from air or insoluble iron in the permeate.

**Table 61. Memcor CMF-S Permeate Water Quality for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| pH | | 7.2 | 7.5 | 6.5 | 0.3 | 0.04 |
| Alkalinity | (mg/L as $CaCO_3$) | 25 | 40 | 3 | 8 | 0.31 |
| Turbidity | (NTU) | 0.038 | 0.322 | 0.032 | 0.012 | 0.33 |
| Particle Counts | (#/ml) | 0.6 | 10.0 | 0.0 | 1.2 | 1.97 |
| Apparent Color | (Pt-Co) | 2 | 5 | 0 | 2 | 1.19 |
| $UV_{254}$ | (abs/cm) | 0.089 | 0.099 | 0.075 | 0.006 | 0.07 |
| Iron | (mg/L) | 0.043 | 0.091 | 0.000 | 0.033 | 0.76 |
| Total $Cl_2$ | (mg/L as $Cl_2$) | 3.713 | 5.450 | 1.100 | 1.439 | 0.39 |

Table 62 presents the average removal of turbidity, apparent color, and $UV_{254}$ by clarification, CMF-S MF, and the combined clarification / MF process.

As Table 62 illustrates, the cumulative turbidity removal was 99.3 percent, the cumulative apparent color removal was 99.4 percent, and the cumulative $UV_{254}$ removal was 90.5 percent. The table suggests an increase in $UV_{254}$ through the ultrafilter following clarification. Average clarified $UV_{254}$ was 0.078 abs / cm and the average filtered $UV_{254}$ was 0.089 abs / cm, a difference of 0.011. However, the clarified average $UV_{254}$ had a standard deviation of 0.037 abs / cm suggesting the difference between clarified and filtered $UV_{254}$ is not statistically significant. Further, the average pH of the Actiflo clarified water was 4.2 and the average pH of the Memcor permeate was 7.2. This increase in $UV_{254}$ could be the result of the higher CMF-S permeate pH, as $UV_{254}$ measurement is pH dependant.

**Table 62. Average Turbidity, Apparent Color, and UV254 Removals for Memcor CMF-S Ultrafiltration Pilot Testing on Actiflo Clarified Effluent**

| Parameter | Units | Averages | | | Removals | | |
|---|---|---|---|---|---|---|---|
| | | Raw | Clarified | Filtered | Raw to Clarified | Clarified to Filtered | Cumulative Removal |
| Turbidity | (NTU) | 5.8 | 0.55 | 0.038 | 90.4% | 93.1% | 99.3% |
| Apparent Color | (Pt-Co) | 263 | 5 | 2 | 98.2% | 69.0% | 99.4% |
| $UV_{254}$ | (abs/cm) | 0.937 | 0.078 | 0.089 | 91.7% | -14.1% | 90.5% |

Table 63 summarizes the average temperature, filtrate particle counts and turbidity, average flux and permeability as well as temperature corrected flux and permeability for the three runs.

Due to the lower temperatures during the first run, the normalized flux was 35.7 gfd compared to an actual flux of 31.6 gfd. The average temperatures during the second and third run were nearly 20 °C; therefore, the normalized flux for these two runs was approximately equal to the actual flux.

**Table 63. Operation Summary for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent**

| Run No. | Date | Temp | TMP | Turbidity | Particle Counts | Flux | | Permeability | |
|---|---|---|---|---|---|---|---|---|---|
| | | (°C) | (psi) | (NTU) | (#/mL) | (gfd) | (gfd$_{20°C}$) | (gfd/psi) | (gfd/psi$_{20°C}$) |
| 1 | 02/04/03-02/12/03 | 14.9 | 4.3 | 0.033 | 1.0 | 31.6 | 35.7 | 7.3 | 8.2 |
| 2 | 02/20/03-03/12/03 | 20.3 | 5.4 | 0.036 | 0.5 | 39.1 | 38.8 | 7.3 | 7.3 |
| 3 | 03/27/03-04/02/03 | 20.7 | 6.5 | 0.044 | 0.6 | 44.9 | 44.2 | 7.0 | 6.8 |

Figures 72, 73, and 74 illustrate changes in filtrate turbidity and particle counts for Run No. 1, 2, and 3, respectively. The figures illustrate the low turbidity and particle counts during Memcor CMF-S testing.

### Membrane Integrity

To assess membrane integrity, pressure decay testing (PDTs) was conducted. At the start of a PDT, the fiber lumens are drained and are statically pressurized with low pressure air to approximately 13.5 psi for 2 minutes, with the feed side open to atmosphere. The rate of decay in pressure is calculated by measuring pressure at the beginning and end of the 2 minute period. A small pressure decay will result if all the membrane pores are filled with water at the start of the test, there are no broken fibers, and there are no O-ring or valve leaks. When these conditions are met, the air flow across the membrane will be by diffusion through the water filled pores or membrane wall. A satisfactory PDT result is in the range of 0.2 psi/min.

**Figure 72. Turbidity and Particle Counts for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent at 30 gfd (Run No. 1)**

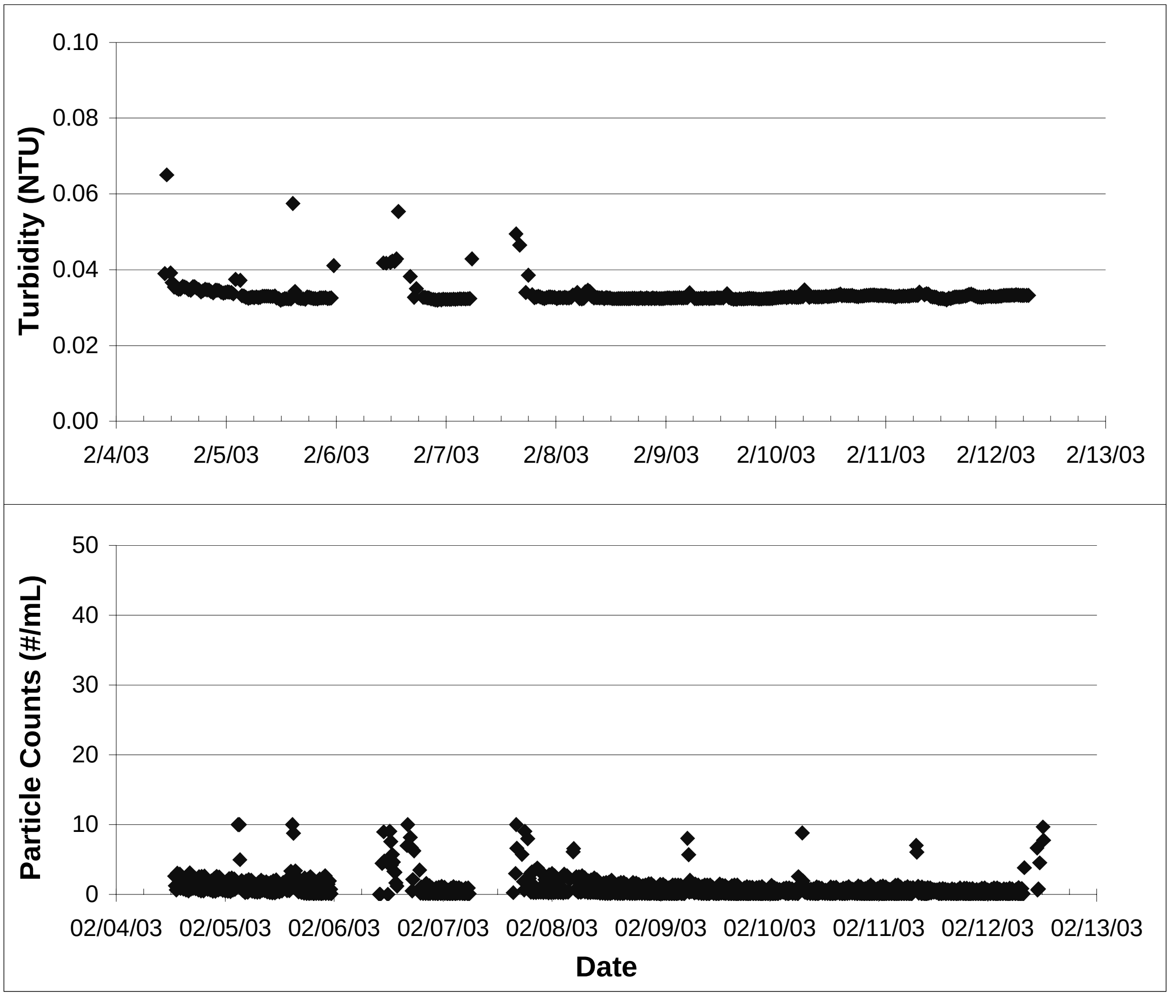


**Figure 73. Turbidity and Particle Counts for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent at 40 gfd (Run No. 2)**

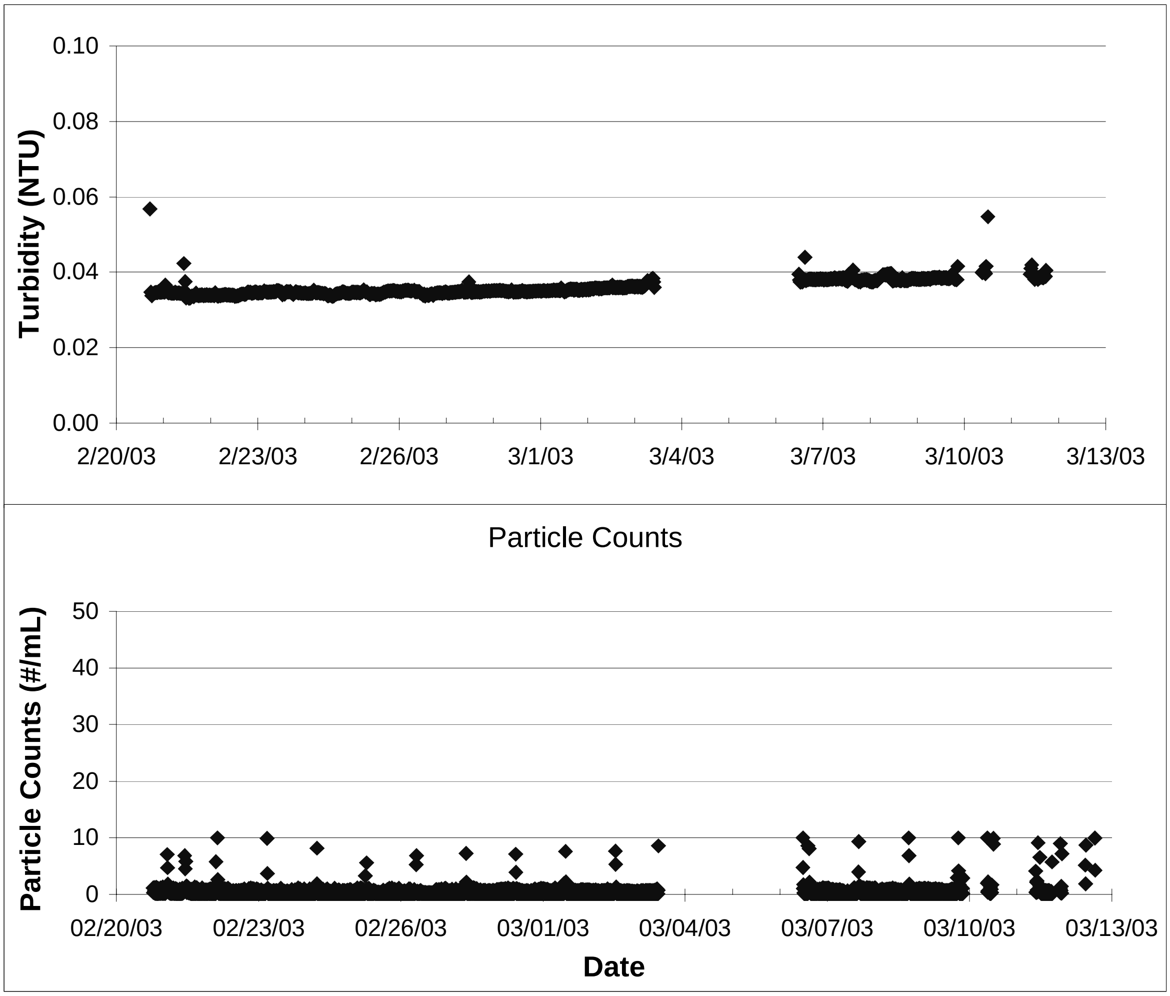
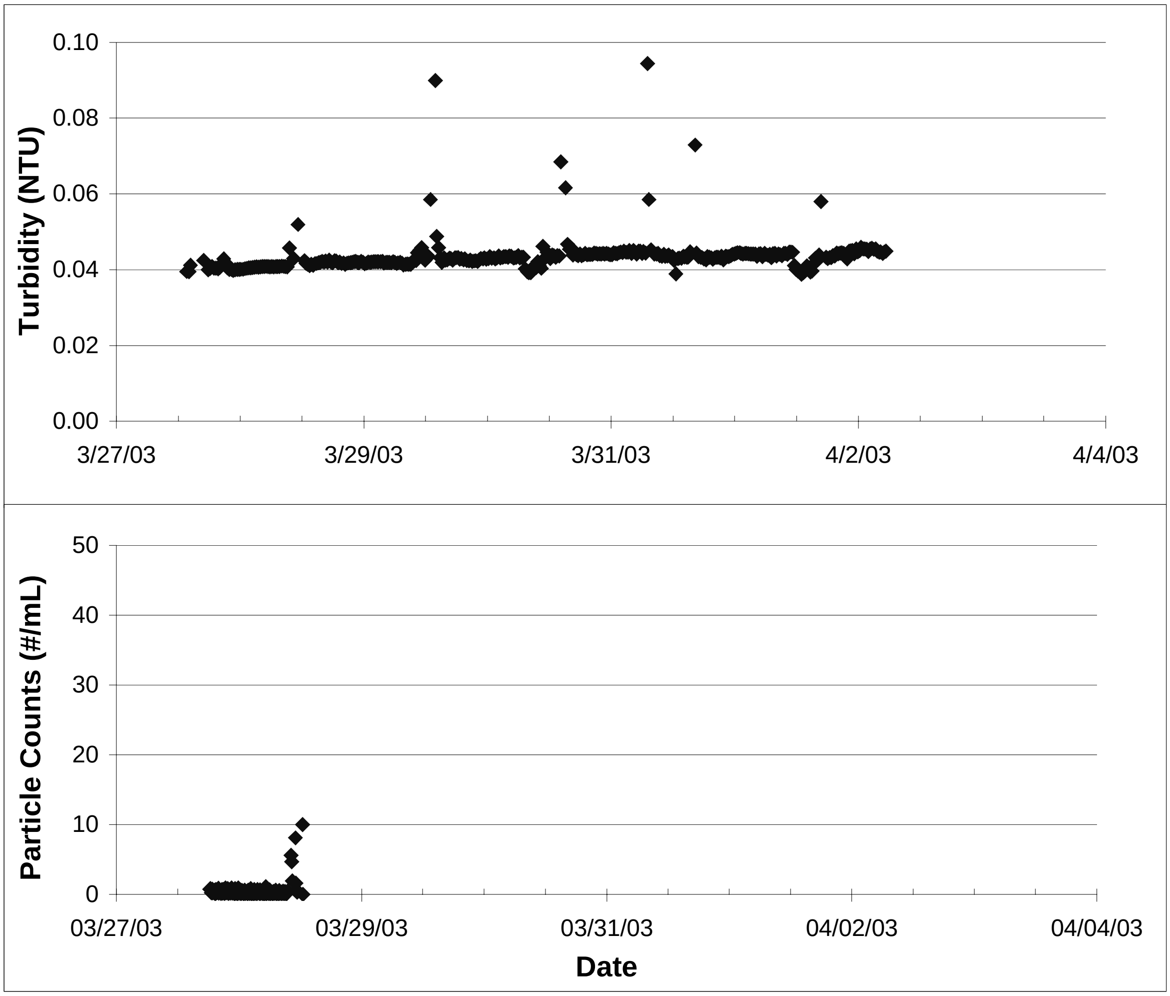


**Figure 74. Turbidity and Particle Counts for Memcor CMF-S Ultrafiltration Testing on Actiflo Clarified Effluent at 45 gfd (Run No. 3)**



Three PDTs were performed during the study. Table 64 illustrates the results of the PDTs and the estimated log removal based on each result. As the table shows, the pressure decay rates ranged from 0.13 psi/min and 0.21 psi/min. Based on the PDT results, the estimated log removal was above 5 for each test.

**Table 64. Pressure Decay Results for Memcor CMF-S Ultrafiltration Testing**

| Date | Starting Pressure (psi) | Ending Pressure (psi) | Pressure Loss (psi/min) | Log Removal |
|---|---|---|---|---|
| 02/12/03 | 13.4 | 13.1 | 0.13 | 5.4 |
| 02/21/03 | 13.3 | 13 | 0.16 | 5.3 |
| 04/02/03 | 13.1 | 12.7 | 0.21 | 5.1 |

### Conclusions

Table 65 summarizes the criteria for the full scale application of Memcor CMF-S for treatment of clarified water, based on the pilot testing results from January 2003 to April 2003.

The CMF-S pilot testing demonstrated that on properly clarified water, a 6 week cleaning interval was possible at a flux of 39 gfd, backwash interval of 30 minutes, and recovery of 94.3 percent. Further, a daily maintenance clean using a chlorinated feed solution of 200 mg/L as $Cl_2$ would be required.

**Table 65. Design Parameters for a Memcor CMF-S Membrane Plant Treating Clarified Water**

| Parameter | Units | CMF-S |
|---|---|---|
| **Instantaneous Flux** | gfd | 39 |
| **Recovery** | % | 94% |
| **Backwash Interval** | Minutes | 30 |
| **Cleaning Interval** | Weeks | > 30 days |
| **Cleaning Strategy** | Backpulse | One Maintance Clean per Day<br>200 mg/L as $Cl_2$ |
| **Recovery Clean - Chlorine** | Concentration | 400 mg/L as $Cl_2$ |
| **Recovery Clean - Citric acid** | Concentration<br>Temperature | 2% Cirtric Acid<br>35-38 $^oC$ |

The polymer required for treatment with Actiflo, was a medium charge density cationic polymer. It was not observed that use of this polymer affected the membrane performance. Although, no direct tests were conducted with polymer and flux rates, all of this flux data used for this recommendation were collected in the presence of polymer. However, in full scale implementation care must be exercised to prevent overdosing of polymer in these units that may cause unacceptable loss of membrane performance. The use of the polymer was carefully monitored during this pilot study. This also holds true for the Zenon 500-C pilot testing conducted on Actiflo clarified water.

## REVERSE OSMOSIS MEMBRANE TESTING

The previous sections have summarized the results and performance of the high rate clarifiers and micro/ultrafilters in removing organics and turbidity.  As mentioned earlier, during this pilot study, these pretreatments continuously provided treated water to the RO membranes for desalting.  The membrane performance data in this section will be summarized from both the single element membrane units as well as the high recovery pilot unit.

This section summarizes the performance of these membranes in treating water provided from these pretreatment processes.  The membrane performance was assessed with regards to differential and net driving pressure, salt passage, and net product flow.  This section will also provide the data and recommendations regarding the most effective method of biofouling control on the membranes.

Testing will also be summarized regarding recommended product recovery and membrane flux rates.  Also, the results of different chemical cleanings will be summarized as well as the resulting membrane recovery after cleaning.

This testing occurred over 19 months with a variety of combinations of the different pretreatments used in this study. Phase 1 A was the only time in which all three pretreatments provided water to the membranes side-by-side.  For the remaining phases, the pretreatment providing water to the membranes depended on schedule and availability.  However, all three pretreatments (Actiflo, SuperP, and Zenon) were able to provide pretreated water to the membranes in during the remaining phases at different times based on availability.  A number of different combinations were evaluated during this phased testing.

Refer to the *Pilot Timeline* section of this report for information regarding which membranes were tested with different pretreatments, dates for the testing, conditions for the testing, as well as process flow schematics for the testing.

Due to the variety of commercially-available nanofiltration (NF) and RO membranes, a selection and screening process was conducted to select the appropriate membranes to treat the water in this study. The membrane screening and selection was conducted by UCF on 25 different membrane types. The 25 membranes tested were selected by UCF using manufacturer provide data.

The RO membranes tested included the following:

- Osmonics SG Brackish Water Membrane
- Hydranautics Low Fouling Composite (LFC1) Membrane
- TriSep X-20 Membrane
- Filmtec BW30FR Membrane
- Filmtec BW30LE Membrane[13]

The first four of the above membranes were selected from the flat sheet testing conducted by UCF as previously discussed. Please refer to the *Flat Sheet Membrane Screening and Selection* section of this report for information on the selection process. The fifth membrane was a conventional low energy fouling resistant membrane. This membrane was added for testing to determine if such a membrane type could be cost effectively operated on the pretreated Lake Monroe water.

## RO Pilot Testing

Table 66 presents the testing dates and field testing tasks previously discussed. Preliminary single element testing using only the X-20 and SG membranes to evaluate RO feasibility on the two pretreatments (high rate clarification / granular media filtration and UF) began on November 9, 2001.

The lead element selection testing using all four membrane types started on April 8, 2002, after the analysis of data from the pretreatment evaluation. The purpose of the lead element evaluation was to test the four single elements selected during flat sheet testing by UCF and rank each based on the performance and response to operation on the two pretreated feeds.

[13] The BW30LE membrane is a conventional (non-fouling resistant membrane) having lower cost and energy consumption compared to the other fouling resistant membranes. This membrane was not selected during the *Flat Sheet Membrane Screening and Selection* previously discussed. Testing was performed on this membrane to determine if such a membrane type could be cost effectively operated on the pretreated Lake Monroe water.

**Table 66. Membrane Field Testing Tasks and Goals Summary**

| Task | Dates | Evaluation Hours | Purpose |
|---|---|---|---|
| Pretreatment Evaluation | 11/09/01-12/19/01 | 850 | Evaluate effect of different pretreatments on reverse osmosis membranes and select pretreatment for further testing. |
| Lead Element Selection | 04/08/02-06/30/02 | 1750 | Evaluate 4 selected membrane types to rank and determine best performing membrane for high recovery testing. Evaluate non-oxiding biofouling inhibitor. |
| Continued Single Element Eval. | 07/01/02-11/08/02 | 2300 | Evaluate four selected membranes for additional runtime to determine long term trends in operation and performance. Evaluate non-oxiding biofouling inhibitor. |
| High Recovery Testing | 07/16/02-12/19/02 | 3050 | Testing of lead element operating in a multielement high recovery system. Also, evaluate conventional non-fouling resistant membrane for comparison. |
| Continued High Recovery Eval. | 01/17/03-04/02/03 | 1300 | Additional testing to evaluate cleaning intervals and long term performance of membranes. |
| Flux Evaluation | 01/28/02-04/02/02 | 1250 | Performance evaluation of new elements and an element with 4800 hours of run time at increased fluxes to compare trends in performance. |

Following element testing and ranking, the single element testing continued to determine membrane response to longer term testing. This testing was important based on the unexpected performance changes that occurred during the first 1,000 hours of operation. These changes, which included increases in both NPF and salt passage, and which were preliminarily attributed to chloramines, resulted in the decision to evaluate a non-oxidizing biofouling control chemical, BioGuard, as an alternative to chloramines.

High recovery testing of the BW30FR at high recovery and X-20, SG, and BW30LE membrane began on July 16, 2002 and continued to December 19, 2002. To study the need for fouling resistant membranes on the source water, a conventional non-fouling resistant membrane was tested. The goal of this testing was to determine if the higher cost/higher pressure, fouling resistant membranes were necessary. During the high recovery testing, BioGuard was again evaluated for controlling biological fouling.

Additional high recovery testing was performed on AF/GF effluent beginning in January 2003. This testing was conducted to deter-mine if higher than expected RO membrane fouling experienced when the large RO unit operated for a short period on AF/GF effluent during the High Recovery Testing period was representative.

The last phase of RO testing included operation of the Filmtec BW30FR membrane in single element units to compare performance at two flux rates using both new and previously-operated elements.

For the purpose of RO membrane data reduction and analysis, normalization equations from ASTM D4516, Standard Practice for Standardizing Reverse Osmosis Performance Data, were used in this report to evaluate changes in membrane element or system product flow and salt passage. The normalized parameters used included NPF and NSP. These directly represented the basic membrane mass transfer water and salt transfer coefficients. Additionally, the pressure drop coefficient (PDC) was used to measure and track changes in the rate at which clogging of the element or system of elements feed-concentrate spacer occurred. The PDC is not defined by the ASTM standard but is, instead, a parameter routinely used by the RO membrane suppliers for this purpose. Definitions for these terms are presented in Appendix C.

RO performance data must be normalized to eliminate the impacts of variations in feed water salinity and temperature as well as variations in RO flux and recovery. By mathematically accounting for these changes, the changes that occur in the fundamental properties of the RO system with time as a result of feed water quality characteristics can be quantified.

### Single Element Membrane Testing

Table 67 provides a summary of the testing schedule for the single element membranes, which included a pretreatment evaluation, a lead element evaluation, continued single element evaluation, and a flux evaluation. The table shows which RO membranes were evaluated in each task and on what pretreatment they were operated.

Only the TriSep X-20 and Osmonics SG were used for the pretreatment evaluation. Single elements were used to compare pretreatment system performance and determine if any of the pretreatments would be eliminated based on poor membrane performance. The membrane part of this evaluation began after the pretreatments were optimized with respect to water quality and filterability. The pretreatment evaluation started on November 11, 2001 and continued to December 19, 2001.

## Table 67. Single Element Testing Schedule

| Task and Pretreatment | Dates | Hours of Testing | Filmtec BW30FR | TriSep X-20 | Osmonics SG | Hydranautics LFC1 |
|---|---|---|---|---|---|---|
| Pretreatment Evaluation | 11/09/01-12/19/01 | | | | | |
| Actiflo-Media Filtration | 11/09/01-12/17/01 | 850 | | XX | XX | |
| SuperP-Media Filtration | 11/09/01-12/19/01 | 850 | | XX | XX | |
| Zenon Ultrafiltration | 11/30/01-12/19/01 | 500 | | XX | XX | |
| Lead Element Selection | 04/08/02-06/30/02 | | | | | |
| SuperP-Media Filtration | 04/10/02-06/30/02 | 1700 | XX | XX | XX | XX |
| Zenon Ultrafiltration | 04/08/02-06/30/02 | 1750 | XX | XX | XX | XX |
| Continued Single Element Eval. | 07/01/02-11/08/02 | | | | | |
| Zenon Ultrafiltration | 07/01/02-10/25/02 | 2050 | XX | XX | XX | XX |
| SuperP-Media Filtration | 07/01/02-09/23/02 | 1500 | XX | XX | XX | XX |
| Actiflo-Media Filtration | 09/23/02-11/08/02 | 800 | XX | XX | XX | XX |
| Flux Evaluation | 01/28/03-04/02/03 | | | | | |
| Actiflo-Media Filtration | 01/28/03-04/02/03 | 1250 | XX | | | |

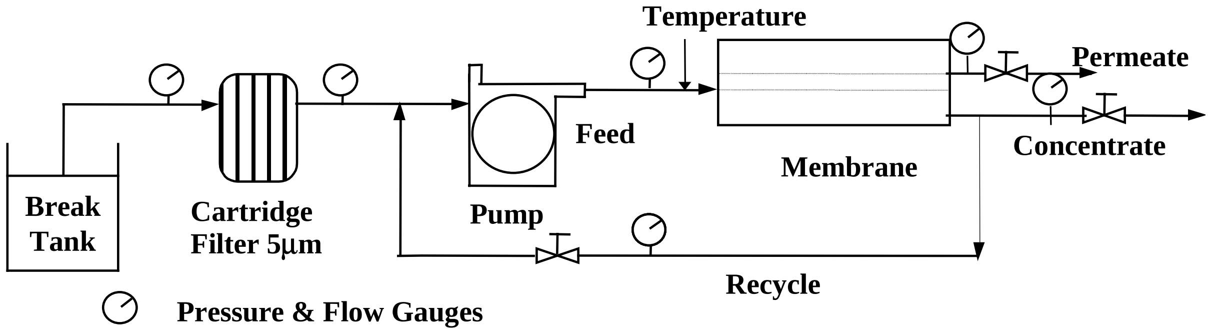
The lead element selection testing was conducted from April 8, 2002 to June 30, 2002. Only the SP/GF and the ZN/UF were used during this phase. Each pretreatment supplied the four single elements. The elements were tested concurrently for a period of approximately 1,700 hours. Data from the element testing was analyzed with respect to the performance parameters described previously and estimated cleaning interval. From this analysis, a single membrane type was selected for further evaluation in the two-stage high recovery system.

Testing with the eight single elements (four membrane types on each pretreatment) continued from July 1, 2002 to November 8, 2002 to gain additional, important information on the longer term impact of pretreated feed water. During this testing, the SP/GF and ZN/UF were again used for pretreatment. SuperP was replaced with Actiflo on August 23, 2002 to further evaluate membrane performance on this high rate clarification process.

The final phase of single element RO testing comprised a flux evaluation from January 28, 2003 to April 2, 2003 using the Filmtec BW30FR membrane type operating on AF/GF effluent only. During this testing period, two new and one previously operated BW30FR elements were operated at the flux rates of 12 gfd (that were used in prior phases) and 15 gfd to assess the impact of flux rate on fouling.

Figure 75 is a flow schematic for the apparatus used for the single element testing. The apparatus included measurement of pressure of the membrane feed, concentrate, and permeate and the differential pressure across the cartridge pre-filter. Feed, permeate, concentrate, and recycle flow and feed water temperature were also measured.

**Figure 75. Single Element Apparatus Process Schematic**




Each single element was operated with the following target conditions: 12 gfd flux, 13 percent element recovery and 70 system recovery[14].

Flux and recovery were controlled using concentrate, permeate and recycle valves.

### Pretreatment Evaluation Phase

#### *Testing Summary*

Figure 76 presents the pretreatment evaluation process schematic. The figure is divided into three sections: one each for Actiflo, SuperP and Zenon, respectively. All pretreatments used ferric sulfate as the coagulant. The SuperP and the Actiflo also required polymer for coagulation/sedimentation. PAC was used with the SuperP for blanket stabilization, taste and odor removal, and additional organics removal. Effluent from SuperP and Actiflo was treated by granular dual media filters for additional particle removal. Effluent from each pretreatment served as feed water to two single element units: one containing the X-20 membrane and the other the SG membrane.

During this phase, the chloramines were dosed to the raw water prior to each pretreatment so as to provide a common chloramines concentration in the influent.

[14] Element recovery is defined as permeate flow divided by feed flow; system recovery is defined as permeate flow divided by the sum of permeate and concentrate flows.

**Figure 76. Pretreatment Evaluation Process Schematic**

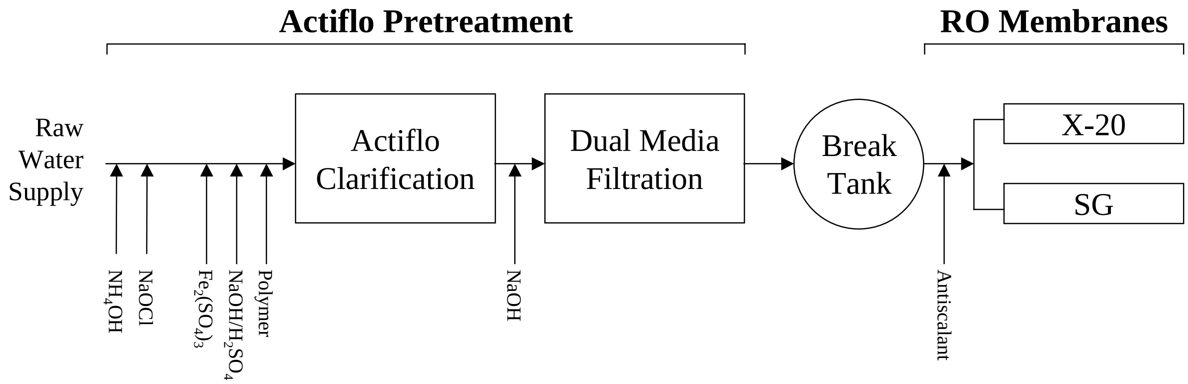



**Figure 76.a**

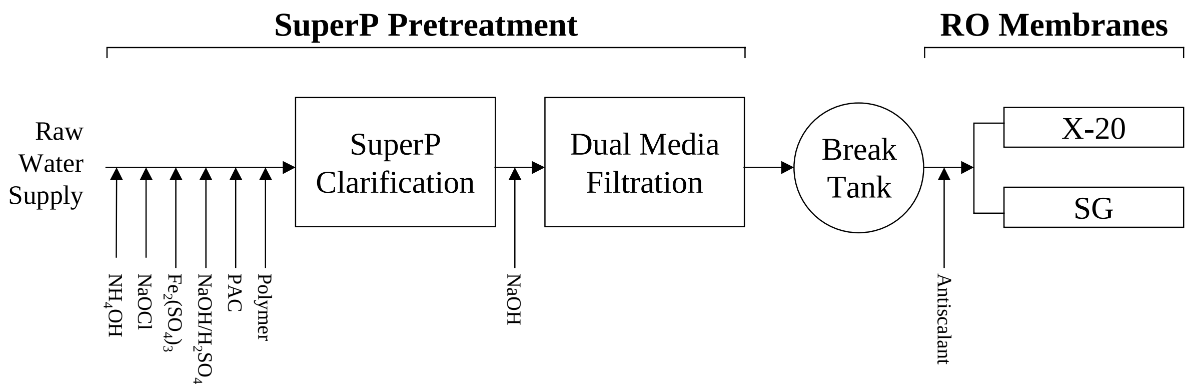



**Figure 76.b**

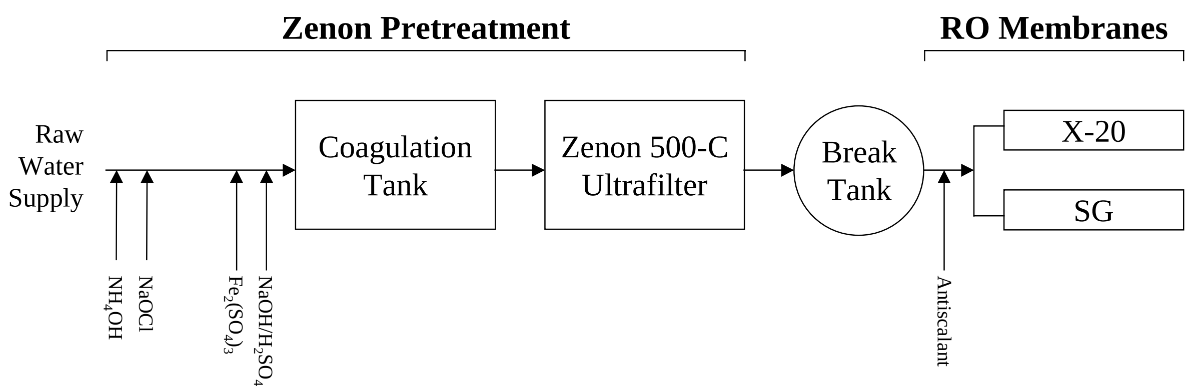



**Figure 76.c**

In order to ensure continuous operation of the RO elements in the event of pretreatment problems, effluent from each pretreatment flowed to a dedicated 3,000 gallon break tank. This prevented shutdown of the RO units when problems with the pretreatment interrupted RO feed water flow.

### *Membrane Performance*

Table 68 compares the treated water quality of the three pretreatment systems. The average turbidity was 0.06 NTU for both the Actiflo and SuperP effluents, and slightly less for the Zenon permeate (0.05 NTU).

The total effluent/permeate chlorine concentrations (as $Cl_2$) averaged 3.3 mg/L for SuperP, 5.6 mg/L for Zenon, and 7.0 mg/L for Actiflo, respectively. The total chlorine concentrations for the SuperP were significantly lower due to chloramine adsorption/neutralization by the PAC.

The addition of PAC to the SuperP also produced lower color and $UV_{254}$ levels compared to the Actiflo. The $UV_{254}$ and color were highest for the Zenon process due to the higher coagulation pH (approximately 5.9). Actiflo and SuperP were able to achieve significantly higher removals of color and $UV_{254}$ due to the lower coagulation pH (approximately 4.5).

The silt density index (SDI) is a surrogate measure for the RO feed water fouling potential, primarily for particle fouling. As expected, Zenon permeate had the lowest average SDI of 3.2, as the UF removes particles down to 0.04 microns. Average SDI's for the SP/GF and AF/GF were less than 4.0. All three pretreatment trains achieved SDI's lower than the RO manufacturer's recommended SDI of 5.0.

**Table 68. Average Effluent/Permeate Quality for Three Pretreatment Systems during Pretreatment Evaluation Phase**

| Process | pH | Turbidity | UV254 | Color | SDI | Iron | Total $Cl_2$ |
|---|---|---|---|---|---|---|---|
| | | (NTU) | (abs/cm) | (Pt-Co) | | (mg/L) | (mg/L as $Cl_2$) |
| Actiflo-Media Filtration | 6.6 | 0.06 | 0.103 | 4 | 3.7 | 0.05 | 7.0 |
| SuperP-Media Filtration | 6.6 | 0.06 | 0.070 | 3 | 3.3 | 0.00 | 3.3 |
| Zenon Ultrafiltration | 6.3 | 0.05 | 0.183 | 10 | 3.2 | 0.05 | 5.6 |

Table 69 summarizes the average flux, system, and element recovery, for single element operation on each pretreatment. The averages for these performance parameters closely matched the target values of 12 gfd, 70 percent and 13 percent, respectively.

**Table 69. Average Single Element Flux, System Recovery, and Element Recovery for Pretreatment Evaluation Phase**

| Process | Flux (gfd) | | | System Recovery (%) | | | Elemental Recovery (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Average | Max | Min | Average | Max | Min | Average | Max | Min |
| Actiflo X-20 | 12.0 | 12.8 | 11.7 | 71% | 72% | 70% | 13% | 14% | 13% |
| Actiflo SG | 12.1 | 12.6 | 11.8 | 71% | 72% | 70% | 13% | 14% | 13% |
| SuperP X-20 | 12.0 | 12.3 | 11.7 | 71% | 72% | 70% | 13% | 13% | 13% |
| SuperP SG | 12.0 | 12.3 | 11.5 | 71% | 72% | 70% | 13% | 13% | 13% |
| Zenon X-20 | 12.0 | 12.4 | 11.6 | 71% | 72% | 69% | 13% | 13% | 12% |
| Zenon SG | 11.9 | 12.3 | 11.2 | 70% | 73% | 69% | 13% | 13% | 12% |

Figure 77 graphically illustrates the flux and system recovery as a function of operating time during this phase. The figure comprises six sub-figures. Figures 77.a and 77.b summarize Actiflo RO membrane data; Figures 77.c and 77.d summarize SuperP RO membrane data; and Figures 77.e and 77.f summarize Zenon RO membrane data. RO operating duration on Zenon pretreatment was less than for SuperP and Actiflo because of later commissioning of the Zenon system. For this and subsequent figures regarding this phase of testing, the initial 200 hours of run data is not presented for the Actiflo and SuperP RO membranes due to pressure gauge malfunctions on the membrane systems. The pressure gauges were replaced with properly functioning gauges after 200 hours of operation.

Flux and recovery were held relatively constant throughout the operating period.

Figure 78 presents the changes in feed pressure and temperature as a function of operating time during the pretreatment evaluation phase. The feed temperature increased gradually during most of the element operation period on SuperP and Actiflo feed waters, which would account for the decreasing feed pressures. However, the feed pressure decline for the Actiflo was much higher than for the SuperP. The Zenon data set starts at a later date than the Actiflo and SuperP data set, and, therefore, cannot be compared without normalization.

There were odd feed pressure trends for the Zenon X-20 membrane, which may suggest calibration problems with the pressure gauge.

## Figure 77. Single Element Flux and Recovery-Pretreatment Evaluation Phase

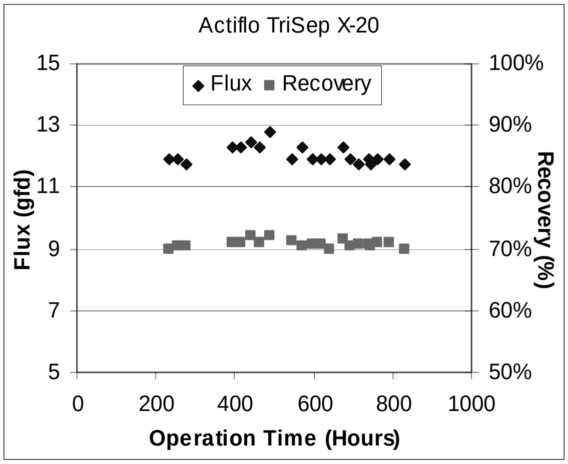



**Figure 77.a**

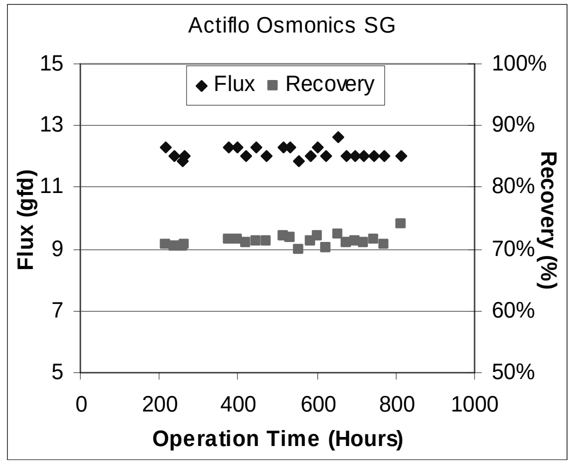



**Figure 77.b**

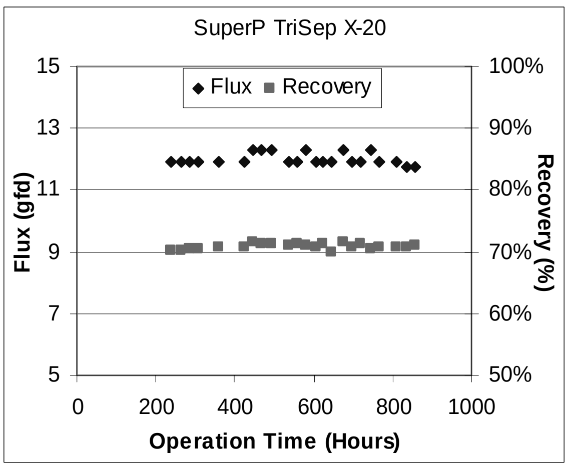



**Figure 77.c**

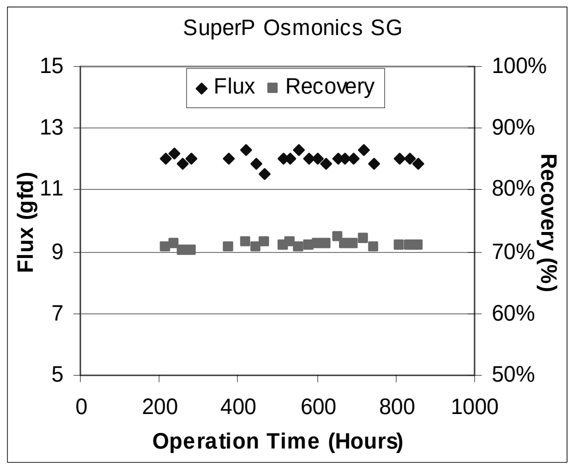



**Figure 77.d**

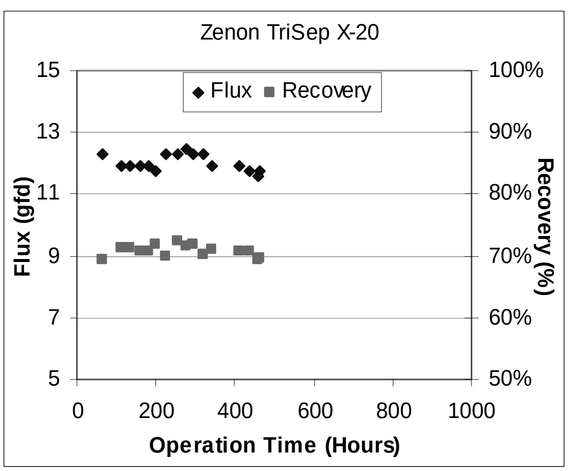



**Figure 77.e**

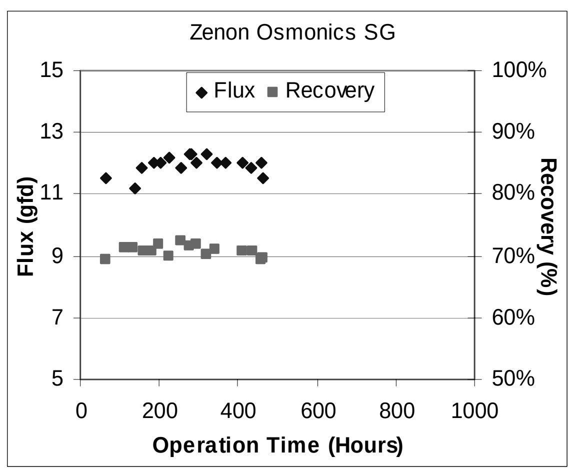



**Figure 77.f**

**Figure 78. Pretreatment Evaluation Single Element Feed Pressure and Temperature**

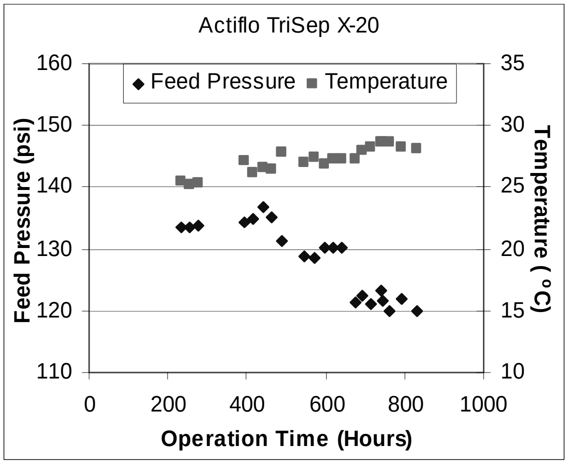



**Figure 78.a**

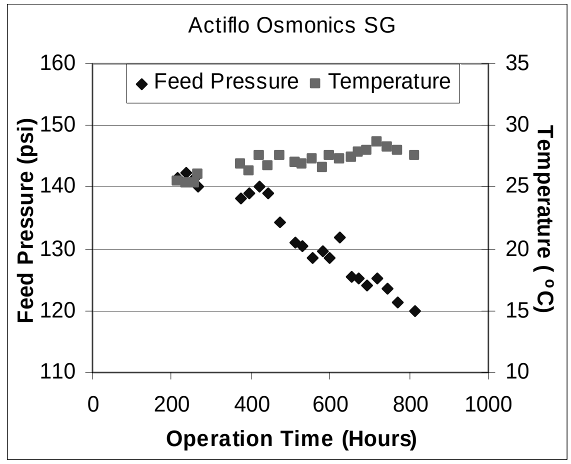



**Figure 78.b**

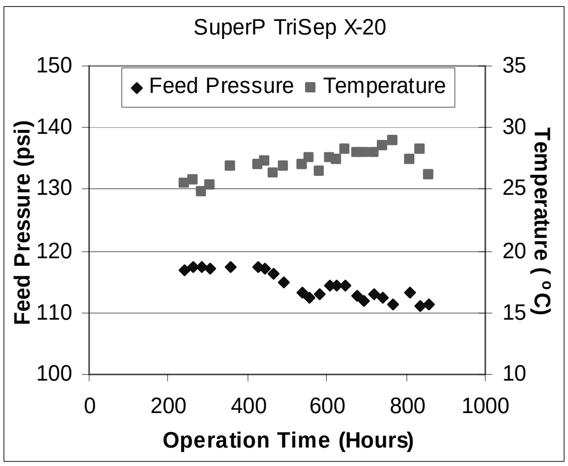



**Figure 78.c**

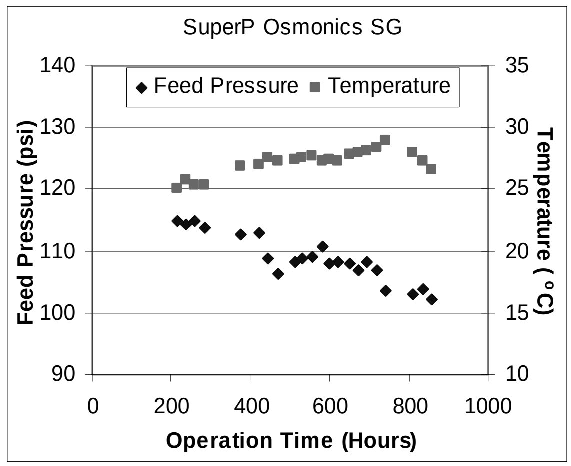



**Figure 78.d**

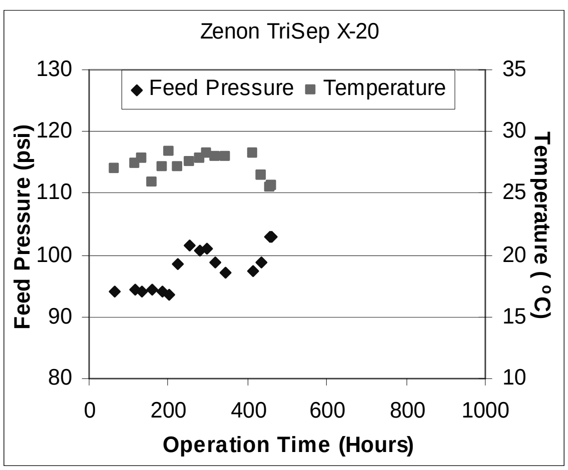



**Figure 78.e**

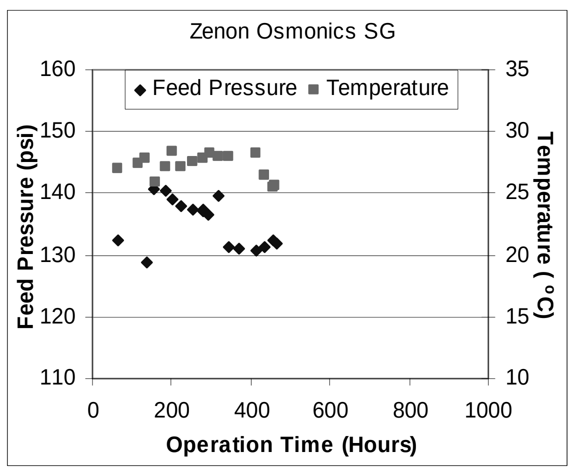



**Figure 78.f**

Figure 79 presents the NPF as a function of operating time for the six single elements. NPF is a direct measure of the membrane water permeability and accounts for fouling (which decreases permeability) and changes in feed pressure, temperature, and TDS (or conductivity).

The NPF increased for both the Actiflo and SuperP X-20 membranes while there was a decrease for the Zenon X-20. The NPF increase for Actiflo X-20 was an order of magnitude higher than that of the SuperP X-20, indicated by the slope of the regression lines.

The only X-20 system with a decline in NPF was the Zenon X-20; however, as Figure 78 suggests, there was a sharp increase in pressure at 200 hours, possibly suggesting a pressure gauge malfunction.

The NPF increased for all of the SG elements. The NPF increase for Actiflo SG was 0.00016 gpm/hr, was 8.7E-05 gpm/hr for SuperP, and 0.00019 gpm/hr for Zenon.

Note that the average chloramine concentration for the Actiflo membranes was 7.0 mg/L as $Cl_2$, the SuperP chloramine concentration was 3.3 mg/L as $Cl_2$, and the Zenon SG elements was 5.6 mg/L as $Cl_2$. By comparing the feed chloramine concentration to the NPF, it would appear that higher chloramine concentration would correlate to increased NPF. This suggests that chloramines directly (oxidative effect) or indirectly (chloramination byproduct) increased the permeability of the RO membranes.

The NPF increase was higher for SG as compared to X-20 elements in all three systems, which may suggest SG is more influenced by chloramines.

Figure 80 presents the change in DPC over time.

There was little if any change in DPC for most of the membranes, indicating there was little particulate deposition or biofilm formation within the feed/concentrate spacer. However, the change in differential pressure was an order of magnitude greater for the Actiflo membrane system.

Figure 81 presents the changes in NSP over time for the six single elements.

Based on linear regressions of the data, all X-20 membranes had a decreasing trend in NSP during testing. The Actiflo and SuperP SG elements had increasing trends in salt passage, while the Zenon SG had a decreasing trend in salt passage.

## Figure 79. Pretreatment Evaluation Single Element Normalized Product Flow

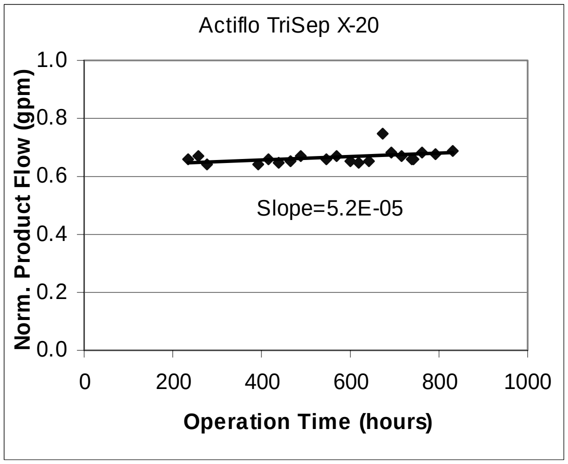



**Figure 79.a**

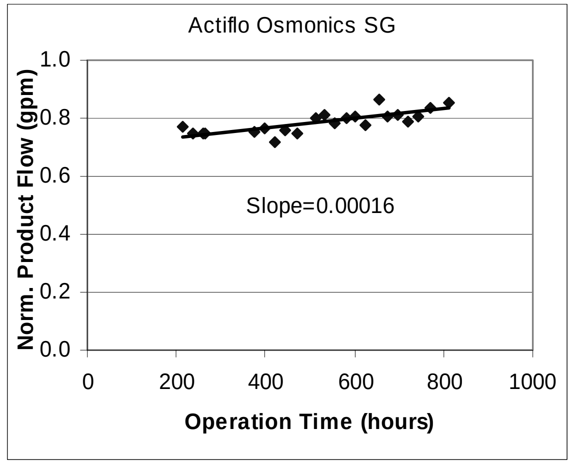



**Figure 79.b**

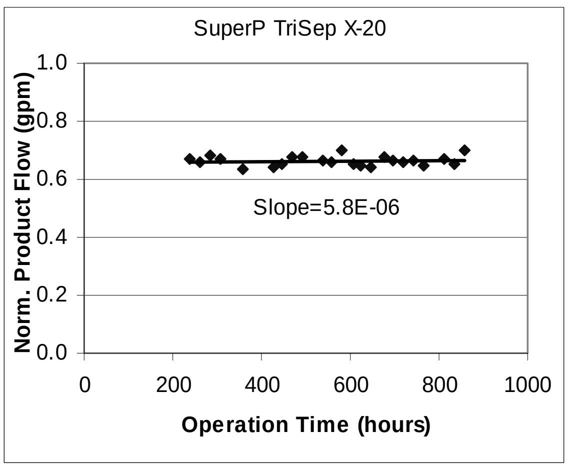



**Figure 79.c**

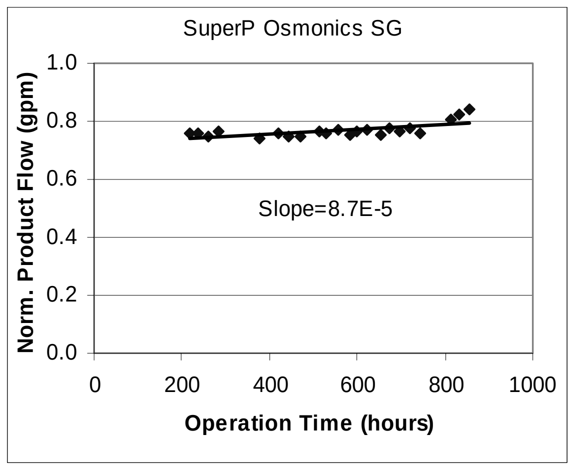



**Figure 79.d**

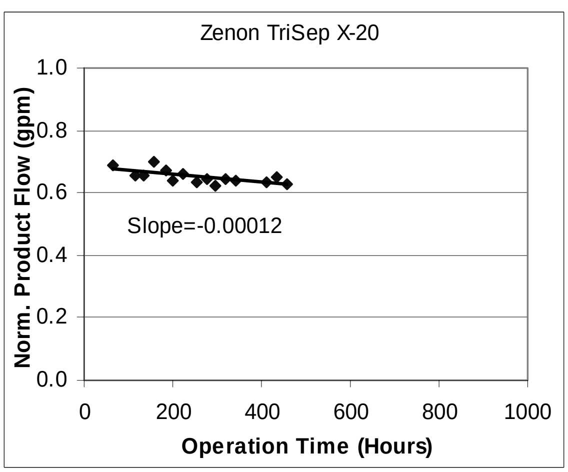



**Figure 79.e**

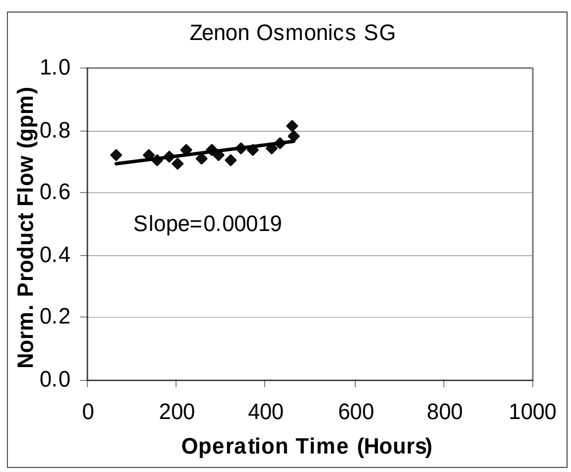



**Figure 79.f**

**Figure 80. Pretreatment Evaluation Single Element Normalized Differential Coefficient Change**

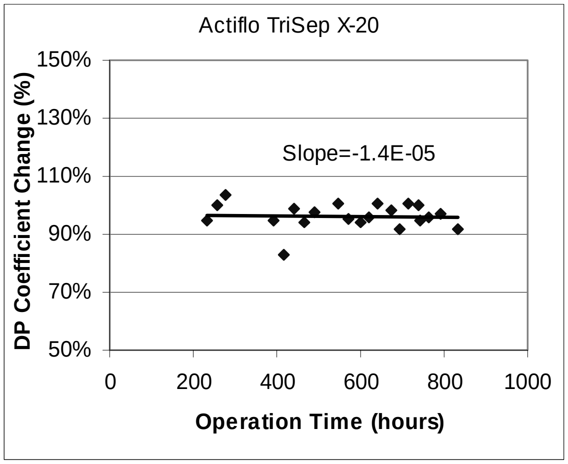



**Figure 80.a**

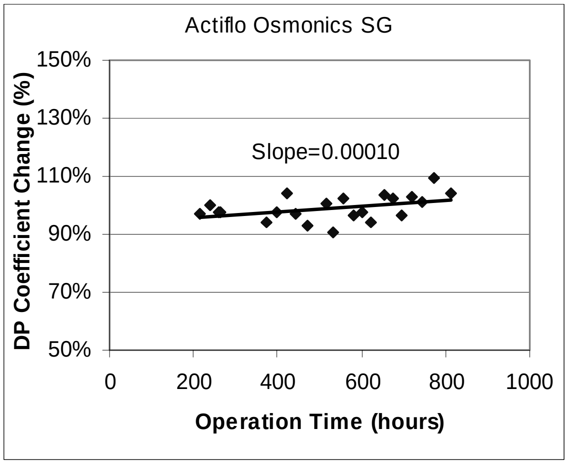



**Figure 80.b**

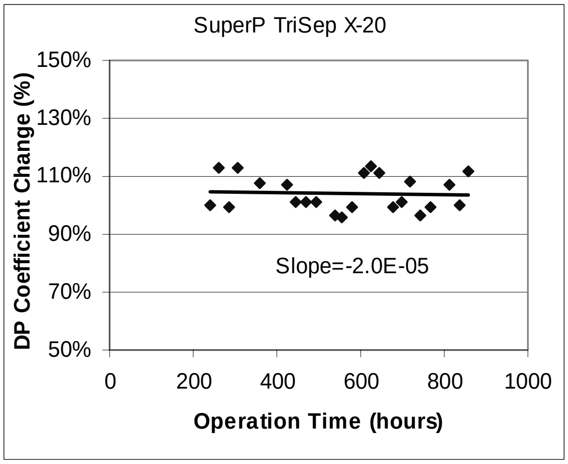



**Figure 80.c**

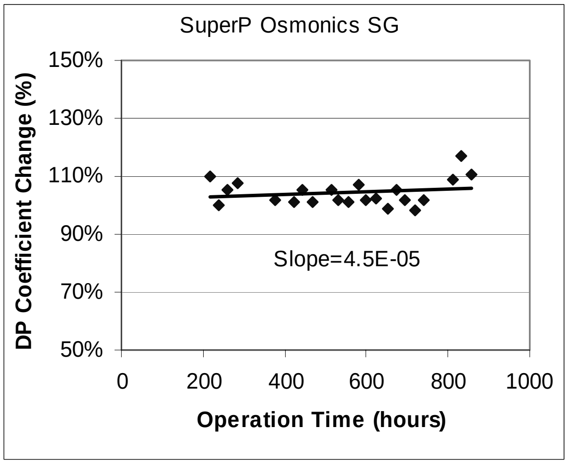



**Figure 80.d**

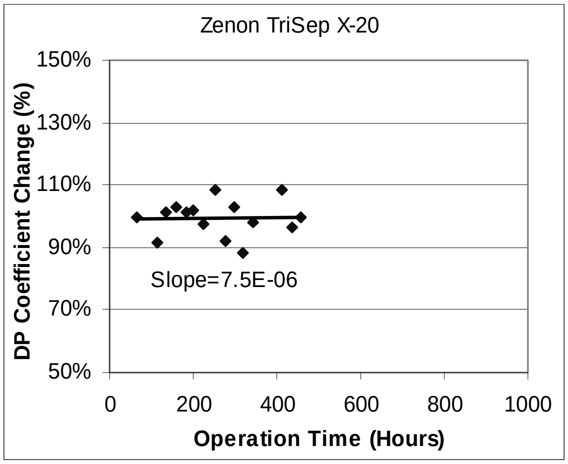



**Figure 80.e**

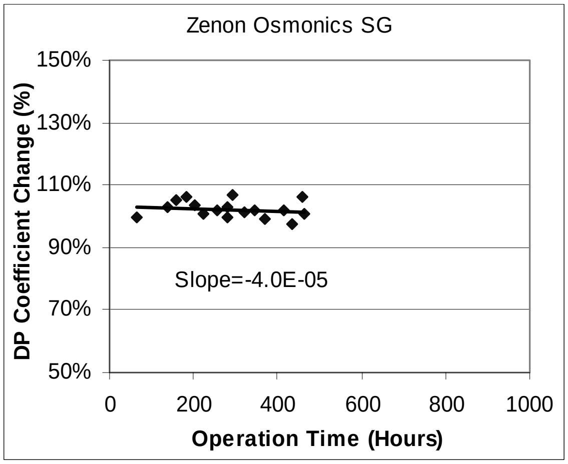



**Figure 80.f**

## Figure 81. Pretreatment Evaluation Single Element Normalized Salt Passage

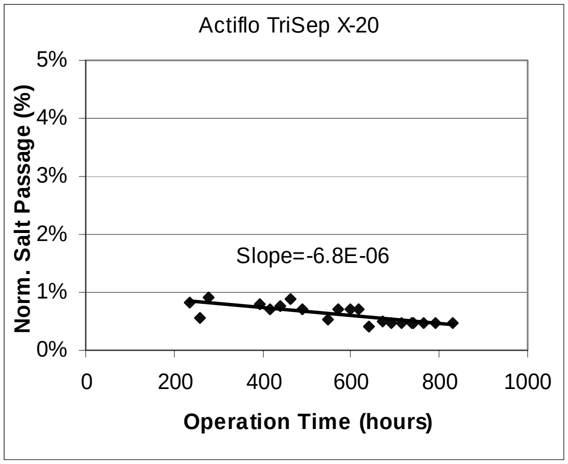



**Figure 81.a**

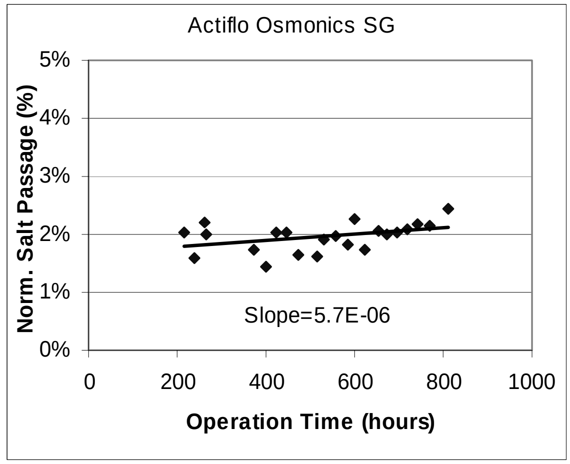



**Figure 81.b**

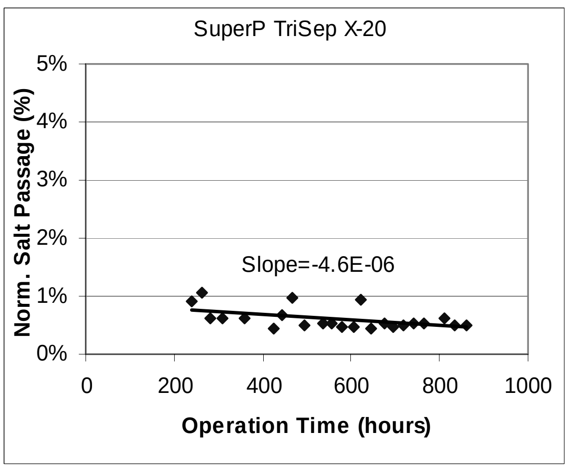



**Figure 81.c**

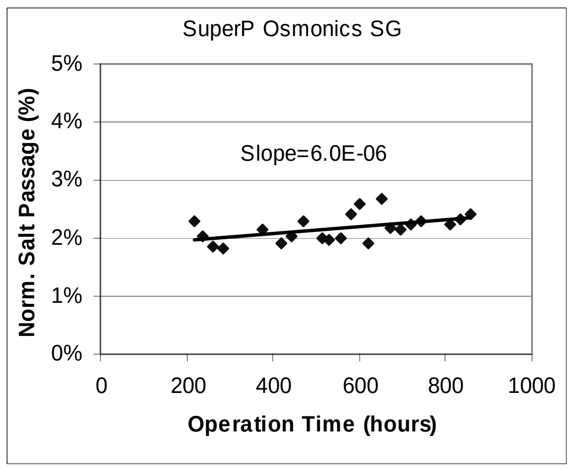



**Figure 81.d**

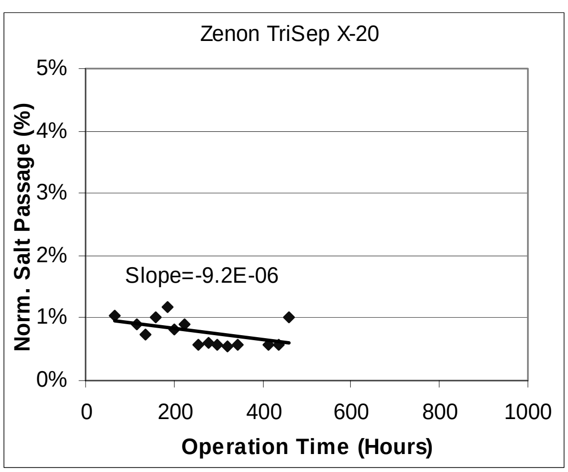



**Figure 81.e**

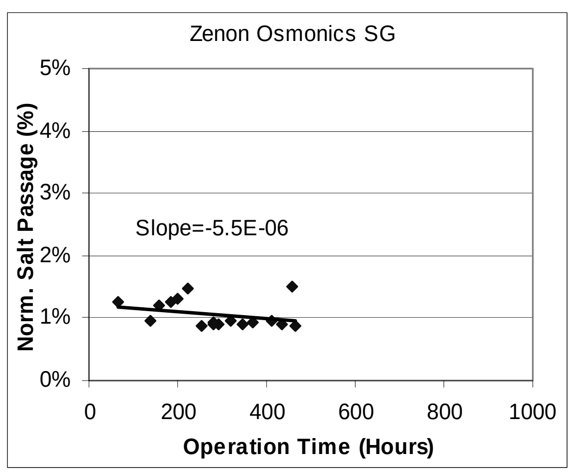



**Figure 81.f**

The increasing trend in salt passage was approximately the same for the SuperP SG and the Actiflo SG elements, losing 0.6 percent of salt rejection every 1,000 hours.

The Actiflo and SuperP SG elements had higher increases/lower decreases in salt passage compared to the X-20 elements, while the Zenon SG had a lower decrease in NSP compared to the X-20 element.

Increasing NSP is undesirable because it indicates higher salt flow through the membrane and higher TDS in the permeate. However, if NPF is increasing as well, the increase in NSP may not cause permeate quality degradation depending on the relative rate of increase of the two parameters. In the case of the X-20, the combined effect of increasing the NPF and decreasing the NSP is very unusual because it would indicate the membrane’s performance was improving significantly (more water flow and less TDS in the permeate with time). The cause of such performance changes is difficult to explain by chloramines oxidative attack. In the case of the SG membranes operated on SuperP and Actiflo pretreatment, increasing NPF and NSP would suggest oxidative attack of the membrane’s polyamide thin film.

#### *Conclusions*

The goal of this testing was to concurrently evaluate RO membrane performance on the three alternative pretreatments to determine their suitability for use in a full-sale integrated membrane system.

Based on the performance of the single RO elements tested during this phase, all three of the pretreatments were able to provide feed water of a quality that produced no or very little RO membrane fouling. The ZN/UF produced the best quality water as measured by SDI; however, this quality improvement did not translate to lower rates of RO membrane fouling.

As anticipated, RO feed water chloramination prevented biological fouling; however, the high chloramine levels used during this phase may have caused the degradation of the polyamide thin film used in the SG membranes and may have also produced the unusual performance changes in the X-20 membrane. To determine if chloramines were responsible for these changes, an additional approach to biofouling control using a non-oxidizing chemical was evaluated in the next phase.

Since all of the pretreatments performed well, all were carried forward during the next phase of single element testing as well as high recovery testing.

### Lead Element Selection and Continued Single Element Evaluation

#### *Testing Summary*

During these testing phases, all four membrane types selected from laboratory testing were operated concurrently as single elements on two pretreatments: SuperP and Zenon or Actiflo and Zenon.

Figure 82 presents process schematics for the two pretreatment/RO element trains (high rate clarification and UF). Figure 82.a illustrates the SuperP-Actiflo-media filter/RO train. During the lead element selection phase, chloramines were dosed to the raw water as in the pretreatment evaluation phase. Because of the significant chloramine demand during clarification, additional chloramines were dosed prior to media filtration. Raw water chloramination on the SP/AF train was stopped after approximately 900 hours of membrane operation but was continued prior to filtration.

Figure 82.b illustrates the Zenon/RO process train. Raw water chloramination was practiced during the lead element selection phase, but was stopped after approximately 950 hours of membrane operation for the evaluation of alternative biofouling control measures as described later in this section.

**Figure 82. Process Schematic; Lead Element Selection and Continued Single Evaluation**

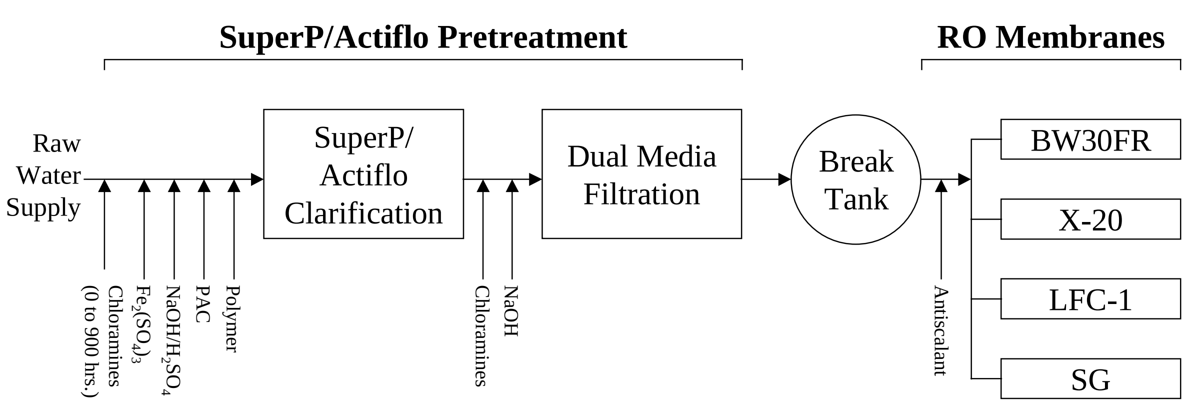



**Figure 82.a**

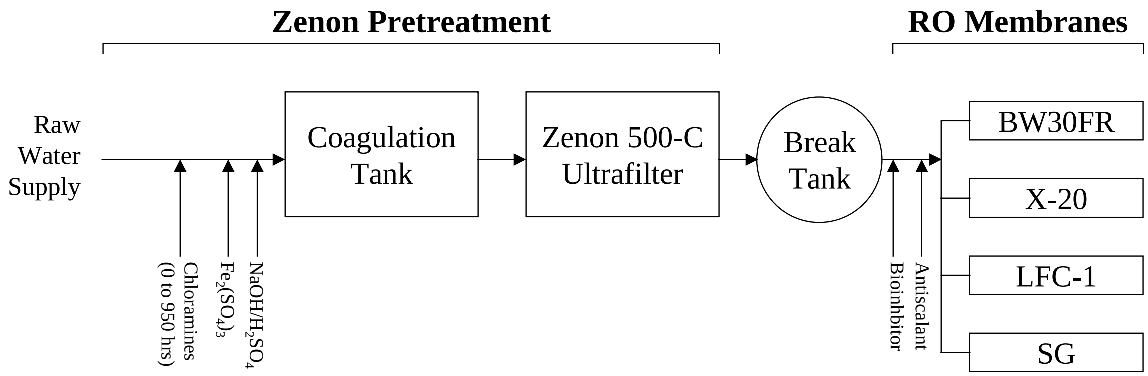



**Figure 82.b**

Tables 70 and 71 presents the SP / AF and Zenon timeline for single element testing conducted during these phases. Listed are events representing significant changes in operation, chemical cleans, and long term shutdowns. For the Zenon system testing with the single elements, testing began in April 2002 and ended in October 2002.

The high rate clarification testing with the single elements began in April 2002 with the SuperP and continued until September 23, 2002 at which time Actiflo was operated for a two-week period. Actiflo testing was again initiated on October 9, 2002 and continued until the end of the follow-on testing phase on November 8, 2002.

**Table 70. Testing Timeline for SP/AF Single Elements; Lead Element Selection and Continued Single Element Evaluation**

| Date | Run Hours | Testing Change Description - SuperP/Actiflo Elements |
|---|---|---|
| 04/10/02 | 0 | Began lead element evaluation with SuperP/media filtration. |
| 05/25/02 | 900 | Stopped raw water chloramination prior to SuperP. Continued clarified chloramination of Super P clarified water. |
| 07/01/02 | 1700 | Continued single element evaluation using SuperP/media filtration pretreatment. |
| 09/06/02 | 2800 | Cleaned all SuperP single elements using permeate at pH 11 (caustic soda for pH adjustment). |
| 09/23/02 | 3100 | Changed from SuperP-media filtration pretreatment to Actiflo-media filtration pretreatment. |
| 10/05/02 | 3300 | Temporarily changed to SuperP-media filtration pretreatment from Actiflo-media filtration pretreatment. |
| 10/09/02 | 3400 | Changed SuperP-media filtration pretreatment to Actiflo-media filtration pretreatment. |
| 11/08/02 | 4000 | Stopped testing of Actiflo single elements. |

As Table 71 suggests, raw water chloramination was used with the ZN/UF pretreatment until 950 hours of RO operation of the lead element selection phase. At that time, BioGuard, a non-oxidizing biodispersent, was dosed to the feed water of the four single elements. This change in biofouling control strategy was made to determine if the observed increases in NSP of the single elements was the result of chloramination. In conjunction with this change, the BW30FR and the LFC1 were replaced to provide a "new element" control for this evaluation. Furthermore, it was decided that one element, the LFC1, would operate with no biofouling control agent.

**Table 71. Testing Timeline for Zenon Single Elements; Lead Element Selection and Continued Single Element Evaluation**

| Date | Run Hours | Testing Change Description - Zenon Elements |
|---|---|---|
| 04/08/02 | 0 | Began lead element evaluation with Zenon |
| 05/25/02 | 850 | Replaced Zenon BW30FR and Zenon LFC1. Stopped chloramine dosing to Zenon. Began evaluation of BioGuard as a biogrowth inhibitor for the single elements. |
| 07/01/02 | 1750 | Continued single element evaluation using Zenon ultrafiltration pretreatment. |
| 10/25/02 | 3800 | Stopped testing of Zenon single elements. |

Table 72 summarizes the biofouling control and scale inhibitor matrix employed with the Zenon single elements after 950 hours of operation. During the initial period of operation, MDC 700 inhibitor was used for scale control. The manufacturer of BioGuard, PWT, could not guarantee that BioGuard would not negatively interact with MDC700. For this reason, MDC700 was replaced with SpectraGuard scale inhibitor, a compatible scale inhibitor also manufactured by PWT for two of the three single elements dosed with BioGuard. For the third element, X-20, MDC700 was continued as a means of evaluating any negative interactions between MDC700 and BioGuard.

The BioGuard/SpectraGuard combination was evaluated on the BW30FR and SG elements. The BioGuard/MDC 700 combination was evaluated on the X-20. As a negative control the LFC1 had no form of biological control. The BioGuard dosage was 5 mg/L and the SpectraGuard dosage was 2.7 mg/L.

**Table 72. Biological Fouling Investigation Dosing Matrix**

| Membrane | Age | Bioinhibitor | | Scale Inhibitor | |
|---|---|---|---|---|---|
| | New/Old | None | BioGuard | SpectraGuard | MDC700 |
| Filmtec BW30FR (ZN) | New | | XX | XX | |
| Hydranautics LFC1 (ZN) | New | XX | | | XX |
| Osmonics SG (ZN) | Old | | XX | XX | |
| TriSep X-20 (ZN) | Old | | XX | | XX |

### *Performance Summary*

Table 73 summarizes the SP/AF membrane feed water quality during the lead element selection and continued single element evaluation phases.

Temperatures during testing ranged from 22.6 to 34.1 °C with an average of 29.2 °C. Average conductivity was 123.1 S/m and ranged from 48.7 to 198.5 S/m.

The average color was 2 Pt-Co for the duration of the evaluation and ranged from 0 Pt-Co to 10 Pt-Co.

As indicated in the table, the average total chlorine during testing was 0.78 mg/L as $Cl_2$ with a range from 2.47 mg/L as $Cl_2$ to 0 mg/L as $Cl_2$. The standard deviation was 0.49 mg/L as $Cl_2$.

**Table 73. Average SP/AF Membrane Feed Water Quality**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **pH** | | 7.1 | 9.8 | 6.1 | 0.6 | 0.08 |
| **Temperature** | **(°C)** | 29.2 | 34.1 | 22.6 | 1.9 | 0.07 |
| **Conductivity** | **(S/m)** | 123.1 | 198.5 | 48.7 | 48.6 | 0.39 |
| **Turbidity** | **(NTU)** | 0.052 | 0.080 | 0.026 | 0.010 | 0.20 |
| **SDI** | | 3.3 | 5.7 | 1.2 | 0.8 | 0.23 |
| **$UV_{254}$** | **(abs/cm)** | 0.058 | 0.105 | 0.013 | 0.022 | 0.39 |
| **Color** | **(Pt-Co)** | 2 | 10 | 0 | 2 | 1.20 |
| **Total Iron** | **(mg/L)** | 0.055 | 0.259 | 0.000 | 0.046 | 0.84 |
| **Total Chlorine** | **(mg/L as $Cl_2$)** | 0.78 | 2.47 | 0.00 | 0.49 | 0.63 |

Table 74 summarizes the Zenon single element membrane feed water quality during the lead element selection and continued single element evaluation.

Temperatures during testing ranged from 22.7 to 34.5 °C with an average of 28.8 °C. Average conductivity was 123.1 S/m. Conductivity ranged from 40.6 to 184.7 S/m. The average color was 6 Pt-Co for the duration of the evaluation and color ranged from 0 Pt-Co to 21 Pt-Co. The Zenon color was significantly higher than the SP/AF color, suggesting significantly higher organic levels in the Zenon pretreated water. Further, based on filtered water sampling during the first 1,500 hours of testing, Zenon NPDOC levels were 6.5 mg/L, compared to SP/AF NPDOC levels of 3.0 mg/L.

The average chlorine concentration was 1.06 mg/L as $Cl_2$ with a range from 2.31 mg/L as $Cl_2$ to 0 mg/L as $Cl_2$ during the initial 950 hours of operation.

**Table 74. Average Zenon Membrane Feed Water Quality**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **pH** | | 6.8 | 8.3 | 5.5 | 0.5 | 0.07 |
| **Temperature** | **(°C)** | 28.8 | 34.5 | 22.7 | 2.0 | 0.07 |
| **Conductivity** | **(S/m)** | 121.3 | 184.7 | 40.6 | 45.4 | 0.37 |
| **Turbidity** | **(NTU)** | 0.044 | 0.077 | 0.035 | 0.007 | 0.17 |
| **SDI** | | 2.5 | 4.2 | 1.5 | 0.6 | 0.23 |
| **$UV_{254}$** | **(abs/cm)** | 0.123 | 0.248 | 0.034 | 0.042 | 0.35 |
| **Color** | **(Pt-Co)** | 6 | 21 | 0 | 5 | 0.83 |
| **Total Iron** | **(mg/L)** | 0.057 | 0.198 | 0.000 | 0.046 | 0.81 |
| **Total Chlorine** | **(mg/L as $Cl_2$)** | 1.06 | 2.31 | 0.03 | 0.38 | 0.36 |

Table 75 summarizes the average single element flux and system and element recoveries for the Zenon and SP/AF single elements. The average flux, system, and element recoveries were approximately equal to the target values for each of these elements; however, flux varied substantially, from a low of 10.3 gfd to a high of 16.6 gfd. Recoveries were more closely controlled.

**Table 75. Average Single Element Flux, System Recovery, and Element Recovery; Lead Element Evaluation and Continued Membrane Evaluation**

| Process | Flux (gfd) | | | System Recovery (%) | | | Elemental Recovery (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Average | Max | Min | Average | Max | Min | Average | Max | Min |
| SP/AF BW30FR | 12.2 | 14.6 | 10.3 | 72% | 76% | 68% | 13% | 15% | 11% |
| SP/AF X-20 | 12.6 | 16.6 | 10.8 | 73% | 77% | 68% | 13% | 16% | 12% |
| SP/AF LFC1 | 12.4 | 14.1 | 11.2 | 72% | 79% | 68% | 14% | 16% | 13% |
| SP/AF SG | 12.4 | 14.1 | 10.7 | 73% | 77% | 68% | 13% | 15% | 12% |
| Zenon BW30FR | 12.4 | 15.5 | 10.7 | 72% | 79% | 66% | 13% | 16% | 12% |
| Zenon X-20 | 12.5 | 16.2 | 10.8 | 71% | 77% | 68% | 13% | 17% | 11% |
| Zenon LFC1 | 12.2 | 14.1 | 11.2 | 73% | 78% | 69% | 13% | 15% | 12% |
| Zenon SG | 12.0 | 13.0 | 10.6 | 70% | 74% | 66% | 13% | 14% | 12% |

Figure 83 through Figure 88 present the data trends for flux, feed pressure and differential pressure for the four elements and the two pretreatments (SP/AF and Zenon). Figure 89 through Figure 94 present normalized data trends on product flow, DPC change, and NSP. The data in the latter set of figures are used to reach conclusions for selection of elements which perform most effectively.

Figure 83 illustrates the changes in flux and system recovery for the SP/AF single elements. The figure is separated into four segments. Figure 83.a summarizes the SP/AF BW30FR; Figure 83.b summarizes the X-20; Figure 83.c summarizes the LFC1; and Figure 83.d summarizes the SG.

*At approximately 2,800 hours, a high pH caustic clean was performed on each element. The solid vertical line represents this clean. For the high pH clean, RO permeate was adjusted to a pH of 11 using sodium hydroxide.* The solution was fed to the single element until the concentrate pH stabilized at pH 11, at which point the feed pump was stopped and the membrane was allowed to soak for 30 minutes. This process was repeated three times and the unit was then put back into operation.

*The dashed line represents the change from SuperP to Actiflo for pretreatment. This change occurred at approximately 3,100 hours.* To simplify the graphs, the change back to SuperP at 3,300 hours and the subsequent change to Actiflo again at 3,400 hours is not labeled on the figure.

**Figure 83. SuperP Single Element Flux and Recovery, Lead Element Selection**

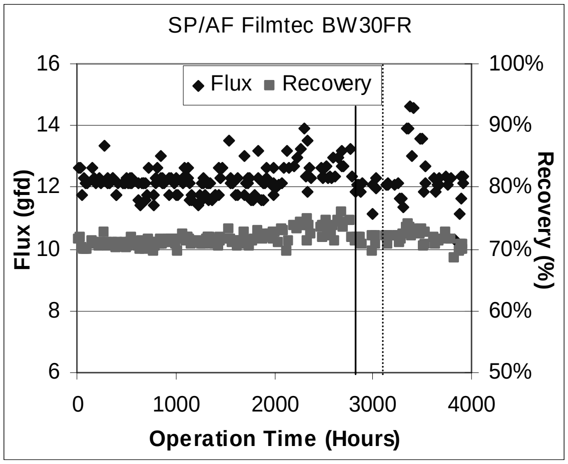



**Figure 83.a**

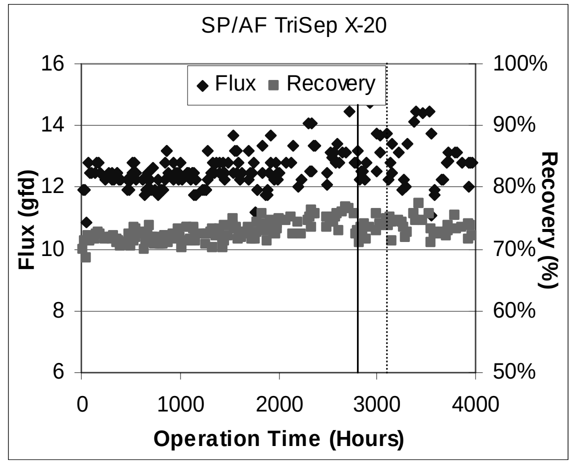



**Figure 83.b**

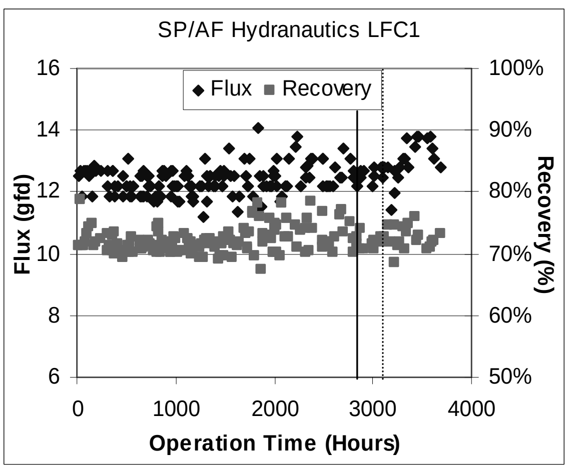



**Figure 83.c**

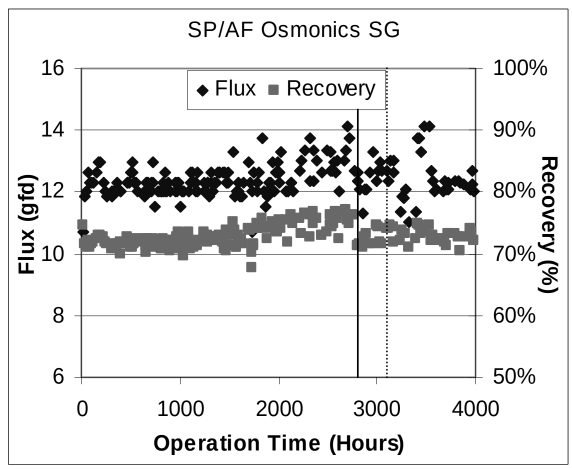



**Figure 83.d**

Figure 84 illustrates the flux and system recovery for the Zenon single elements. The figure is separated into four segments. Figure 84.a summarizes the Zenon BW30FR; Figure 84.b summarizes the X-20; Figure 84.c summarizes the LFC1; and Figure 84.d summarizes the SG.

The solid lines on the plots represent the termination of chloramine dosing to the Zenon system. This line in Figure 84.a and Figure 84.c also represents the replacement of the BW30FR and LFC1, respectively. These lines were placed to divide the data set to allow better illustration of data trends based on these changes in operation.

**Figure 84. Zenon Single Element Flux and Recovery, Lead Element Selection**

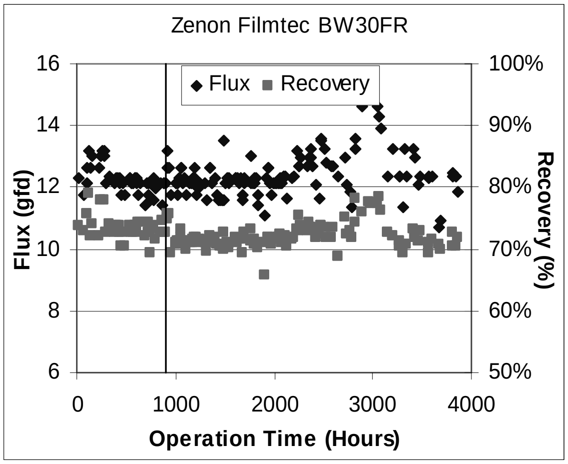



**Figure 84.a**

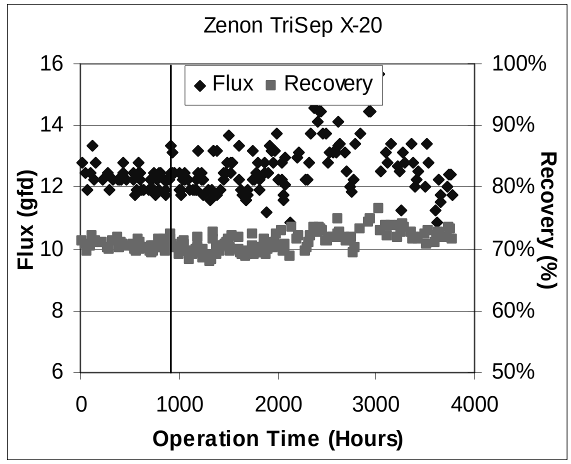



**Figure 84.b**

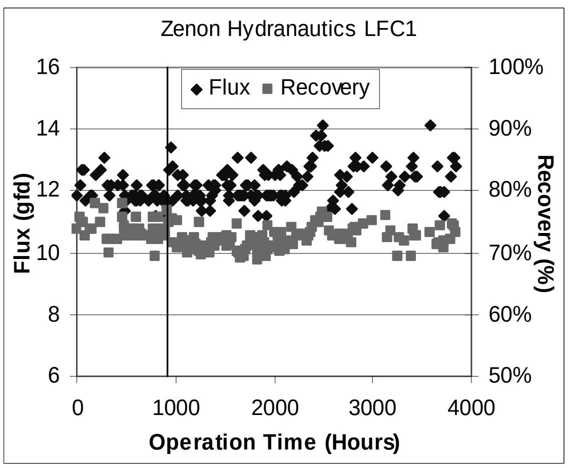



**Figure 84.c**

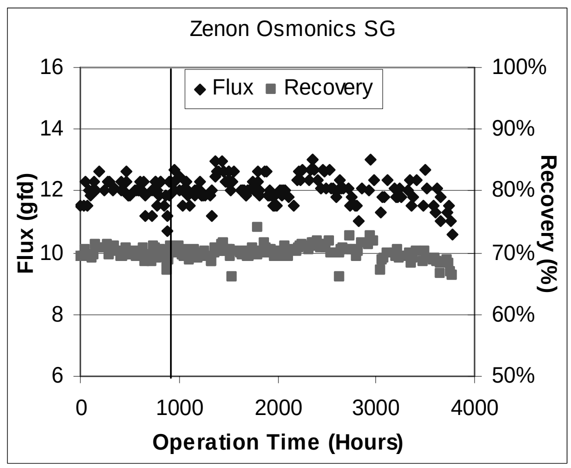



**Figure 84.d**

Figure 85 summarizes feed pressure and temperature as a function of operating time for single elements operating on SP / AF pretreatment. All elements were cleaned using sodium hydroxide / permeate at a solution pH of 11 for approximately 2,800 hours.

Initial feed pressures ranged from approximately 100 psi for the LFC1 to 140 psi for the SG membrane. Both the BW30FR and X-20 had an initial feed pressure requirement of 120 psi. Feed pressure declined steadily for the BW30FR, SG, and X-20 element during the first 2,500 hours of operation, after which time pressures increased. The cleaning at 2,800 hours appeared to have no impact on feed pressure. In contrast, LFC1 feed pressure declined until the cleaning after which it increased dramatically and in step fashion and then continued to increase through the remainder of the operating period.

The changes in feed pressure during the first 3,100 hours were not related to changes in the feed temperature, as the temperature remained relatively constant. Temperature decreased by approximately 8° C during the remaining 900 hours, which would cause feed pressures to rise. As noted previously, pretreatment changed from SuperP to Actiflo at 3,100 hours, indicated by the dotted line in the figures.

**Figure 85. SP/AF Single Element Feed Pressure and Temperature, Lead Element Selection**

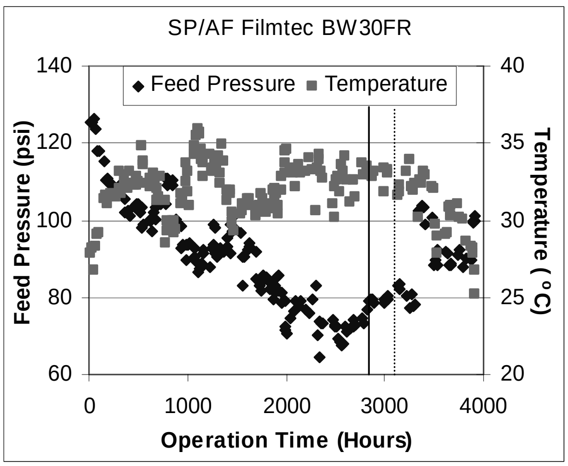



**Figure 85.a**

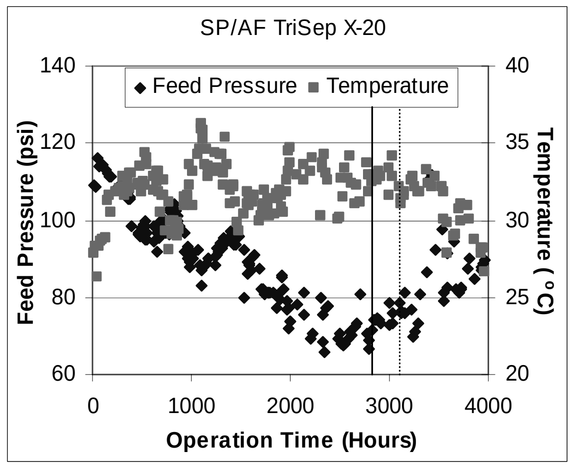



**Figure 85.b**

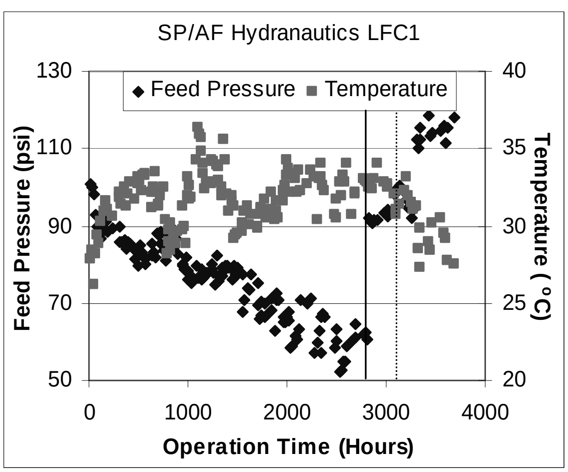



**Figure 85.c**

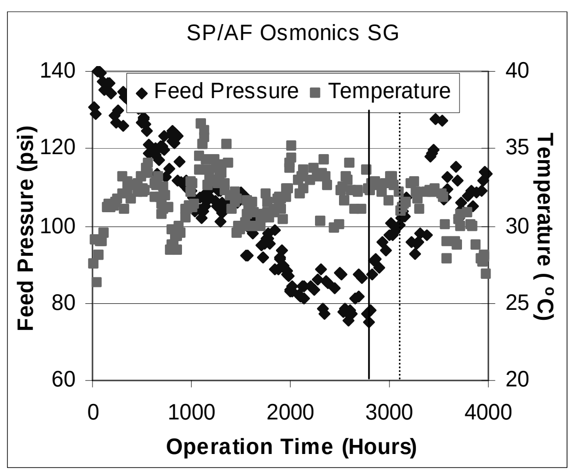



**Figure 85.d**

Figure 86 illustrates feed pressure and temperature as a function of operating time for the single elements operating on the Zenon pretreatment. As with the SP/AF SG, the Zenon SG element had the highest initial feed pressure requirement. The three other Zenon elements had initial feed pressure requirements of 120 psi. Unlike operation on the SP/AF pretreatment, feed pressures for all elements showed more variable changes that correlated somewhat better with changes in feed temperature during the initial 1,500 to 2,000 hours. However, the feed pressure increases observed for the SG and X-20 during the latter 2,000 hours cannot be explained by temperature changes.

**Figure 86. Zenon Single Element Feed Pressure and Temperature, Lead Element Selection**

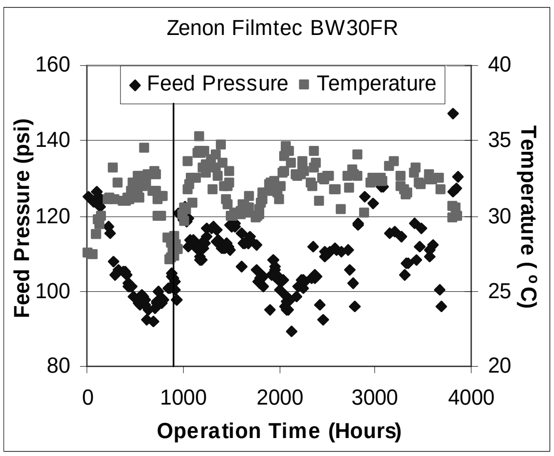



**Figure 86.a**

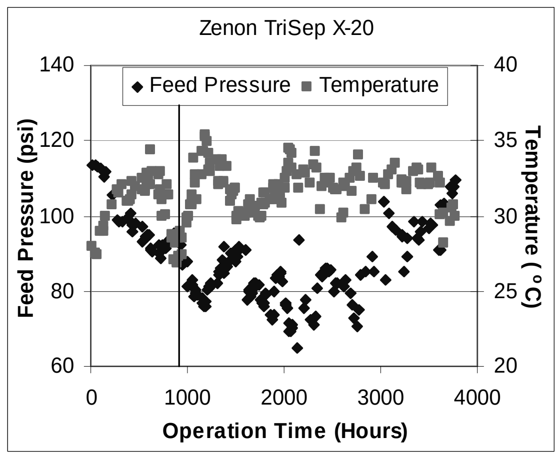



**Figure 86.b**

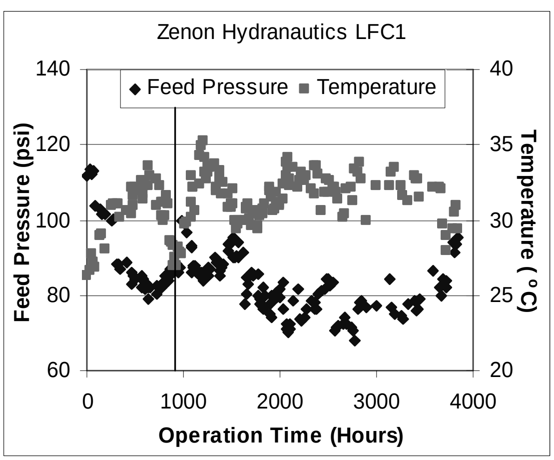



**Figure 86.c**

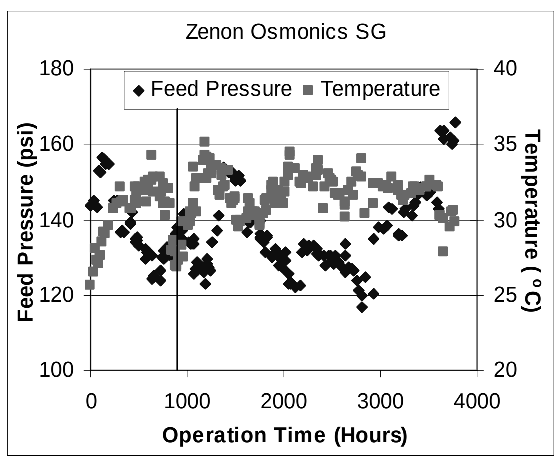



**Figure 86.d**

Figure 87 presents the differential pressure as a function of operating time for the single elements operated on the SP/AF pretreatment. Further, two linear regressions were performed on the differential pressure data to determine the hourly change in differential pressure. The first regression is from 0 to 2,800 hours corresponding to operation prior to the chemical clean. The solid line at 2,800 hours represents this clean. The second regression is from 2,800 hours (the high pH clean) until the end of testing at 4,000 hours.

Prior to the clean, the differential pressure loss was lowest for the BW30FR and LFC1 and highest for the X-20 and SG. Following the clean, all of the elements continued to show increases in differential pressure. However, the LFC1 and the SG had much higher rates of increase loss while the X-20 and BW30FR had rates only slightly higher than prior to the clean. The BW30FR had a low rate of pressure loss throughout the testing. The higher rates of fouling for the SG and LFC-1 membranes after the chemical clean suggest higher rates of spacer fouling and possibly biofouling.

**Figure 87. SuperP Single Element Differential Pressure, Lead Element Selection**

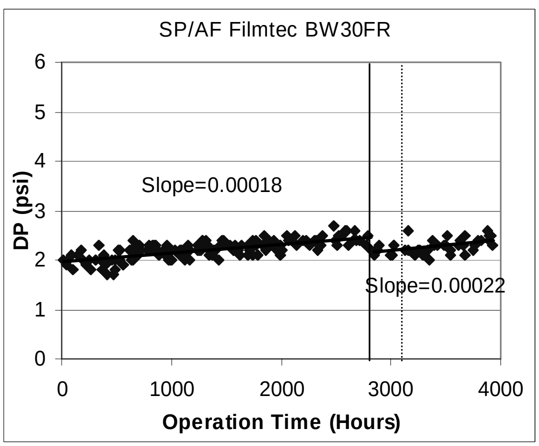



**Figure 87.a**

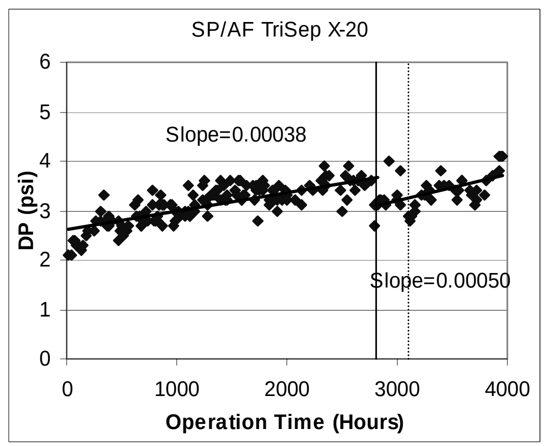



**Figure 87.b**

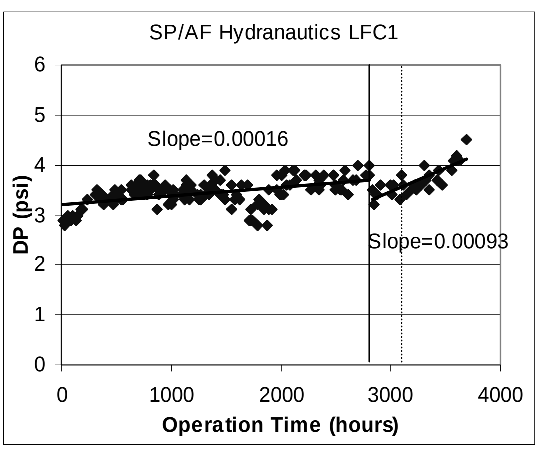



**Figure 87.c**

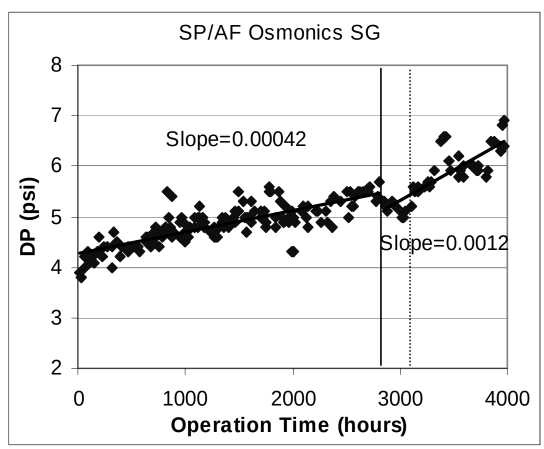



**Figure 87.d**

Figure 88 illustrates the differential pressure for the Zenon single element during this phase of testing. Again, two linear regressions were performed on the differential pressure data to determine the change rate in differential pressure. The first regression is from 0 to 950 hours corresponding to the period of feed water chloramination. The second regression is from 950 to 3,000 hours. This regression period does not include data after 3,000 hours as there was an exponentially increasing rate of fouling. The accelerated rate of differential pressure increase observed for all elements after 3,000 hours is characteristic of biofilm formation on the membrane surface and feed/concentrate spacer that has become established and has had a more rapid rate of bioactivity, particularly secretion of exopolymeric substances.

During chloramination from 0 to 950 hours, all elements except the X-20 had a decline in differential pressure. This decrease can be explained, in part, by the lower viscosity of the feed water resulting from increased feed temperature during this period. However, some membranes, such as the LFC1, had higher declines, which would not be accounted for by temperature change alone since all elements saw the same feed water.

For the period of operation beginning 950 hours, all elements except the LFC1 received feed water dosed with BioGuard; the LFC1 element received no biofouling control agent. During this period, the SG showed the highest rate of differential pressure increase (1.7 psi/khr), the BW30FR the lowest (0.0095 psi/khr) and the LFC1 the next highest (0.92 psi/khr). This very large difference indicates that the susceptibility to feed/concentrate spacer fouling, most likely was due to biofilm formation, and was a function of element and membrane type rather than use or non-use of BioGuard.

Table 76 summarizes the membrane feed spacer thickness. The BW30FR has the largest feed spacer thickness while the X-20 had the second largest feed spacer. The SG and LFC1 had smaller feed spacer thicknesses. Generally, this feed spacer thickness correlated with the rate of differential pressure increase (between 950 and 3,000 hours), in that, a larger feed spacer resulted in a lower rate of differential pressure increase.

**Table 76. Membrane Feed Spacer Thickness**

| Membrane | BW30FR | X-20 | SG | LFC1 |
|---|---|---|---|---|
| Feed Spacer Thickness | 34 mm | 31mm | 28mm | 26mm |

**Figure 88. Zenon Single Element Differential Pressure, Lead Element Selection**

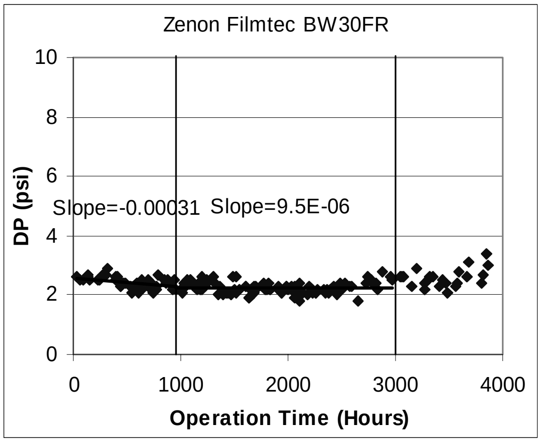



**Figure 88.a**

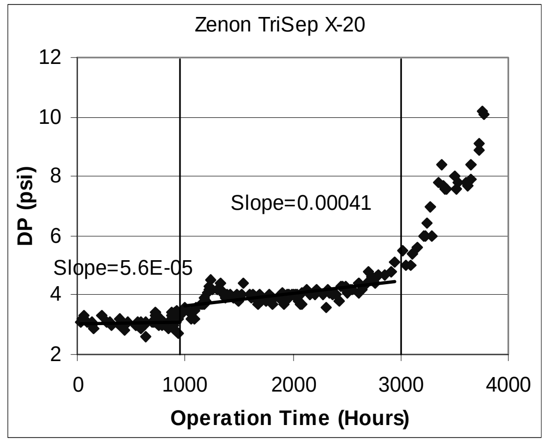



**Figure 88.b**

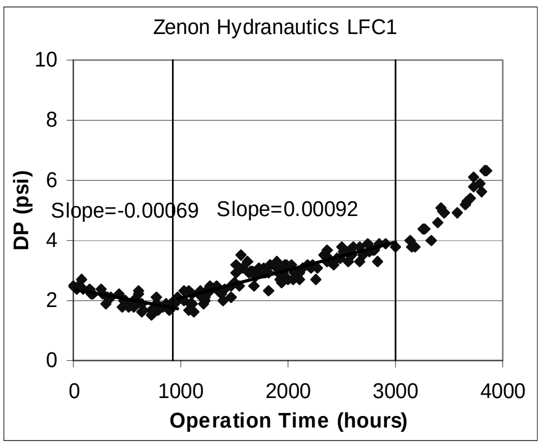



**Figure 88.c**

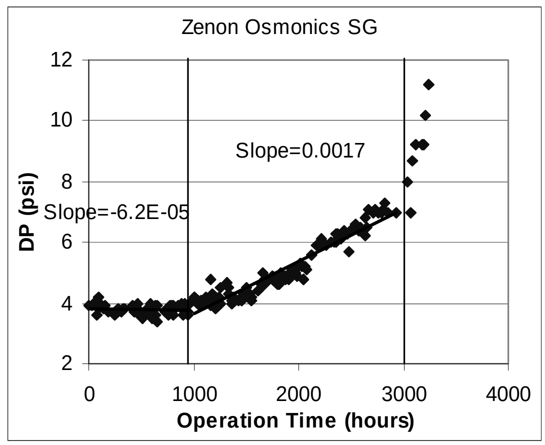



**Figure 88.d**

Figure 89 illustrates NPF data as a function of operating time for the single elements operating on SP / AF pretreatment.

All elements had steady increases in NPF during the first 2,800 hours of operation; however the SG had a significantly higher rate of increase when compared to the other three elements. The increase in NPF indicates that water transfer across the membrane at a given applied pressure is increasing, a beneficial effect.

Following the chemical clean and the change from SuperP to Actiflo pretreatment, NPF for all elements declined, although the rate of decline varied by membrane type. The decrease in NPF is most likely correlated to the change in pretreatment, not by chloramination, which remained consistent during this period, both in point of application and in level. As illustrated in Figure 90, the combined chlorine levels in the feed to the single elements remained relatively constant before and after the chemical clean.

**Figure 89. SP/AF Single Element Normalized Product Flow, Lead Element Selection**

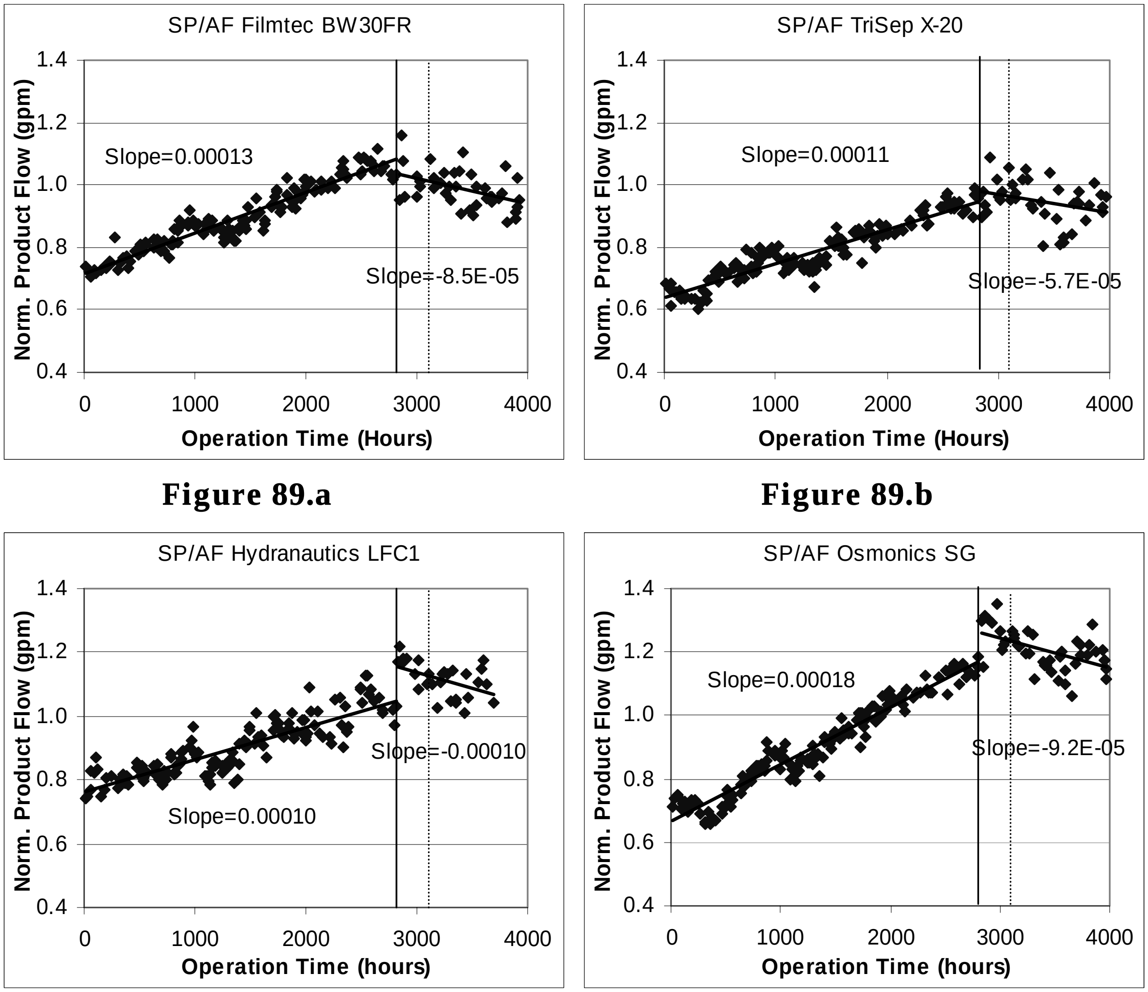



**Figure 89.a** **Figure 89.b**

**Figure 89.c** **Figure 89.d**

**Figure 90. SP/AF Single Element Feed Chlorine Concentration; Lead Element Selection and Continued Membrane Evaluation**

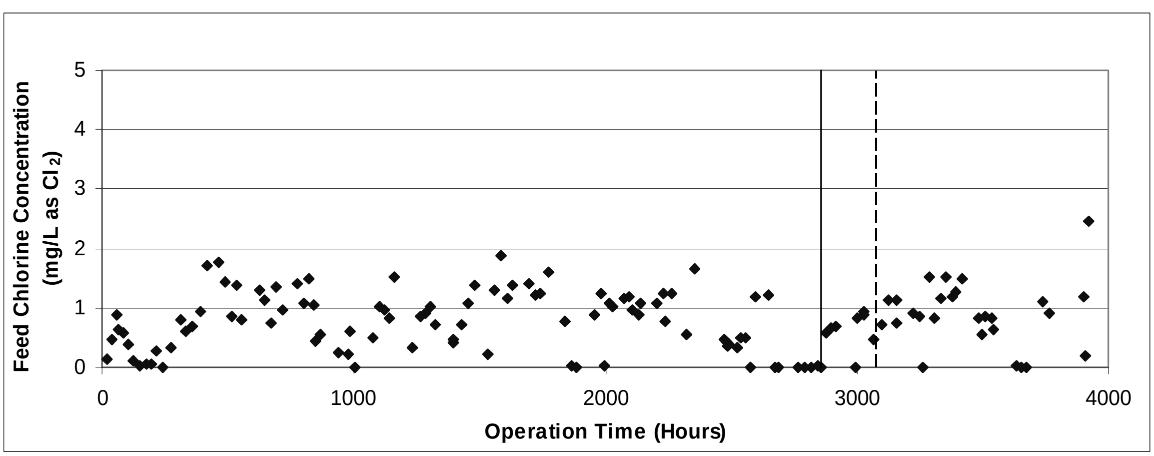


Figure 91 illustrates the changes in NPF, shown as a function of operating time for the single elements operating on Zenon pretreatment.

During the initial 950 hours of operation, all elements had a rapid increase in NPF. This increase correlates to the use of raw water chloramination for biofouling control.

At 950 hours, the BW30FR and LFC1 elements were replaced, chloramination was terminated, and BioGuard dosing was initiated for all membranes but the LFC1. Between 950 and 3,000 hours, NPF for all elements was much more stable, with some showing slight increases and some a decline. Following 3,000 hours, all elements had NPF declines. These declines, when considered along with the rapid differential pressure increases during this period, suggests increased fouling with particles and biofilms.

**Figure 91. Zenon Single Element Normalized Product Flow, Lead Element Selection**

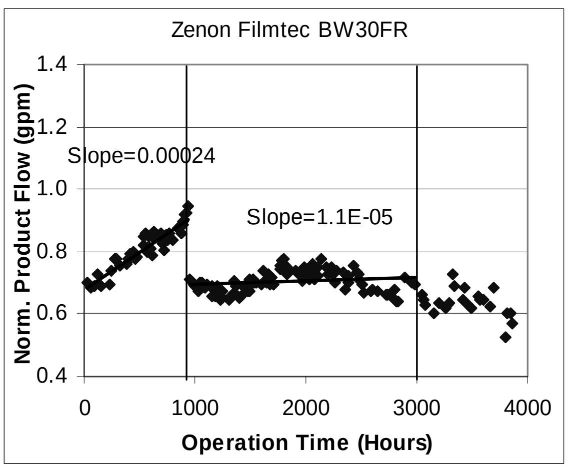



**Figure 91.a**

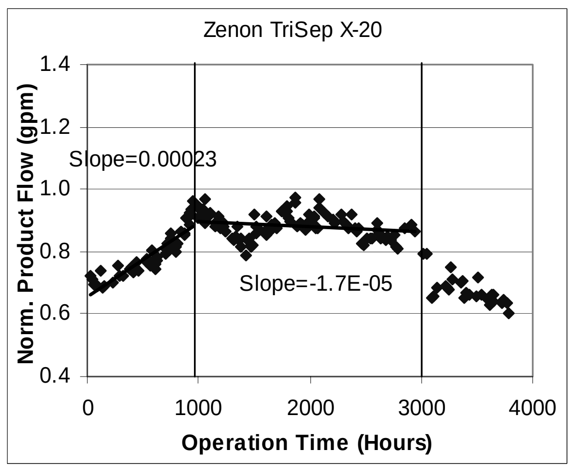



**Figure 91.b**

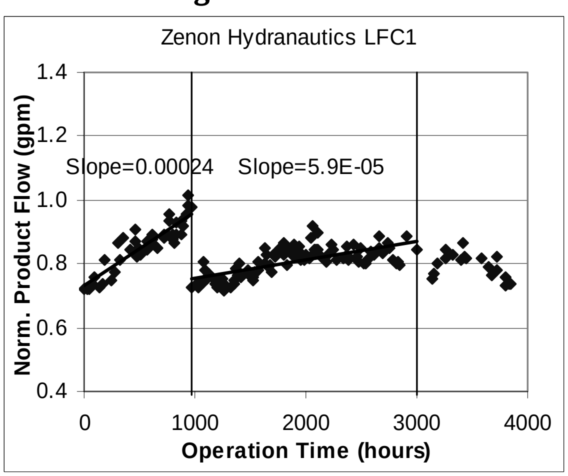



**Figure 91.c**

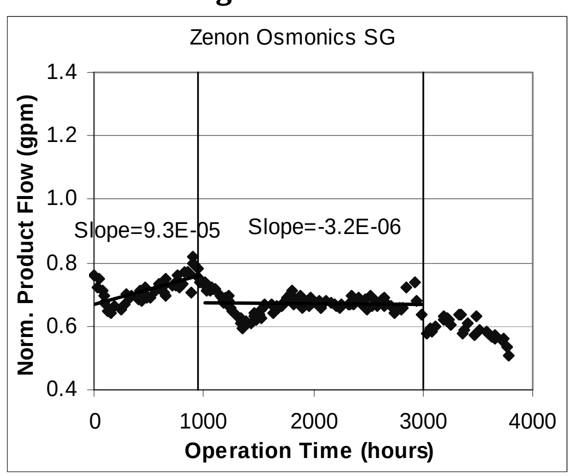



**Figure 91.d**

Figure 92 shows the changes in DPC for the single elements operated on the SP / AF pretreatment. Prior to the clean at 2,800 hours, the BW30FR and LFC1 had the lowest rates of DPC increase, while the X-20 and the SG had the highest. This is similar to what was previously reported for differential pressure.

The rates of fouling did not appear to correlate to feed spacer thickness during this testing, except that the BW30FR had the lowest overall increase (during 4,000 hours of testing) in DPC for the testing (BW30FR had the largest feed spacer thickness).

After the clean, there was a decrease in DPC for all elements, clearly indicating that the caustic solution removed particulate matter from the feed spacer and membrane surface. After the clean at 2,800 hours, the coefficient rate of increase of the BW30FR and X-20 was approximately the same as prior to the clean. The SG and LFC1 had higher rates of increase possibly related to the change from SuperP to Actiflo pretreatment.

**Figure 92. SuperP Single Element Normalized Differential Pressure Coefficient Change, Lead Element Selection**

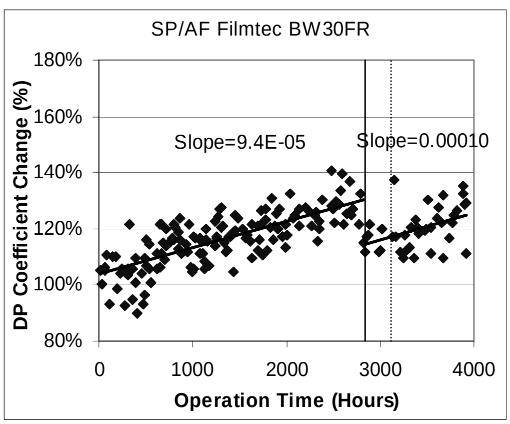



**Figure 92.a**

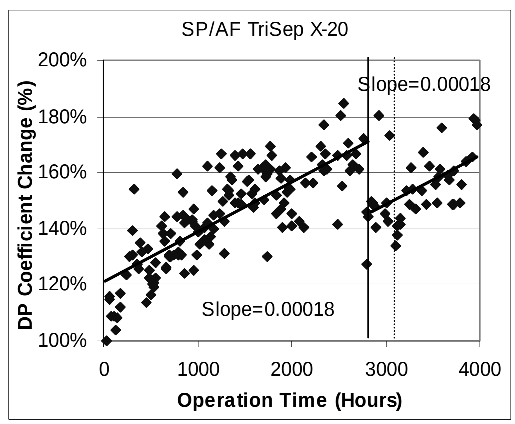



**Figure 92.b**

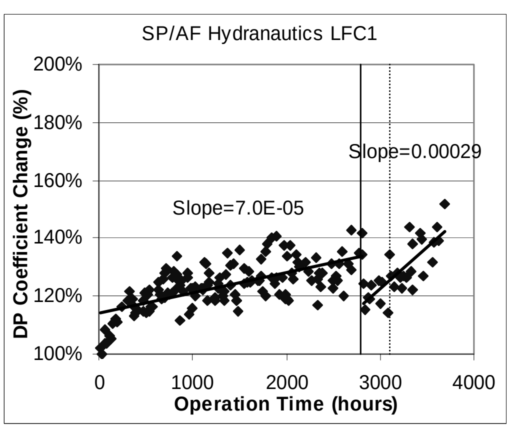



**Figure 92.c**

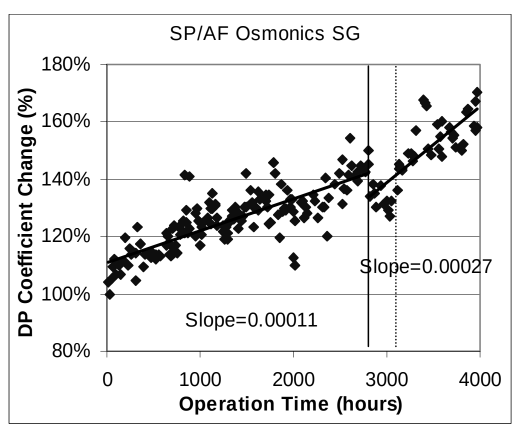



**Figure 92.d**

Figure 93 summarizes the Zenon single element DPC change. As the figure suggests, all of the elements had a decreasing trend in DPC prior to the change in operation at 950 hours. As the figure suggests, the LFC1 and BW30FR had the highest rate of decline. The X-20 had the lowest rate of decline.

Following the change in operation, the DPC for the BW30FR was stable while that for the other elements increased indicating that spacer fouling was not correlated to use or non-use of BioGuard. The DCP increase did correlate with feed spacer thickness, in that a larger feed spacer thickness would suggest a lower rate of DCP increase (BW30FR and X-20) and a smaller feed spacer thickness would suggest a higher rate of DCP increase (LFC1 and SG).

The rate of increase in DPC accelerated during the last 1,000 hours of operation, indicating increasing fouling with particulate matter and biofilms.

**Figure 93. Zenon Single Element Normalized Differential Pressure Coefficient Change, Lead Element Selection**

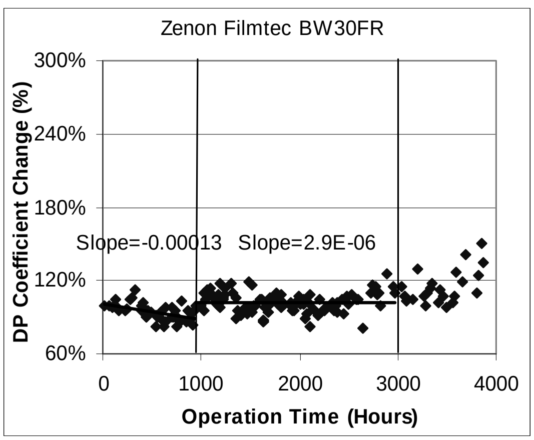



**Figure 93.a**

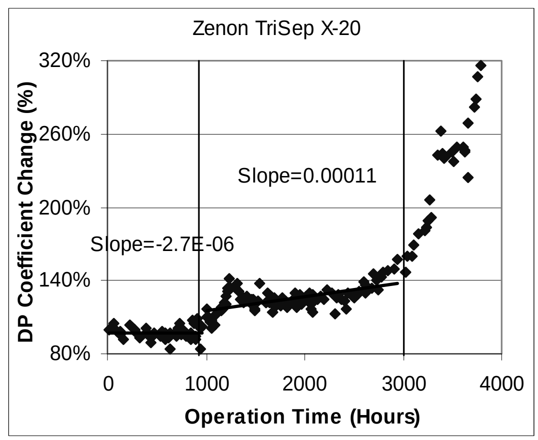



**Figure 93.b**

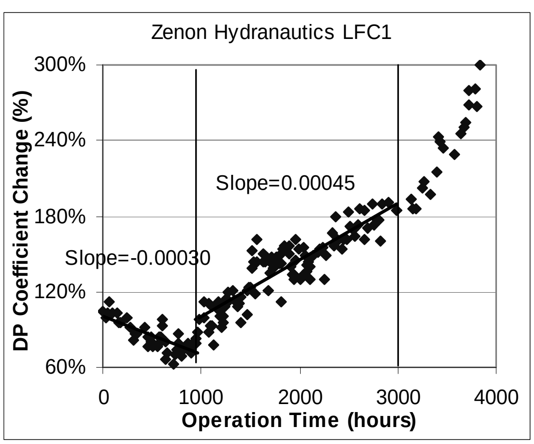



**Figure 93.c**

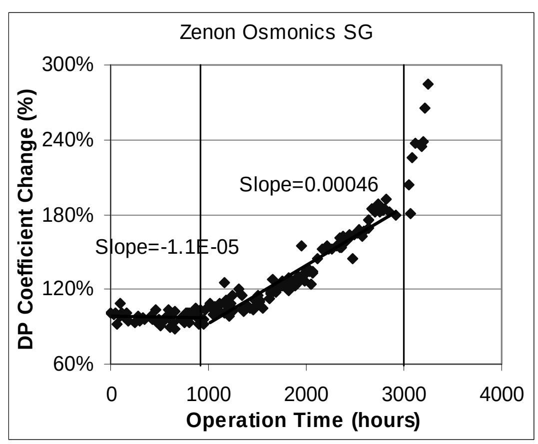



**Figure 93.d**

Figure 94 summarizes the NSP for the SP / AF single elements. During the entire 4,000 hour operating period, the BW30FR NSP was the most stable, showing only a small increase. Prior to the clean, the highest increase in salt passage occurred with the SG and LFC-1, with the X-20 intermediate. The SG had the highest rate of salt passage increase, losing 0.36 percent every 1,000 hours. The BW30FR had very stable salt passage, having a salt passage increase of 0.08 percent loss in removal every 1,000 hours or 0.7 percent every year.

The LFC1 data would suggest a low increase in salt passage overall; however, NSP increased dramatically during operation on chloramines and Actiflo pretreatment.

**Figure 94. SP/AF Single Element Normalized Salt Passage, Lead Element Selection**

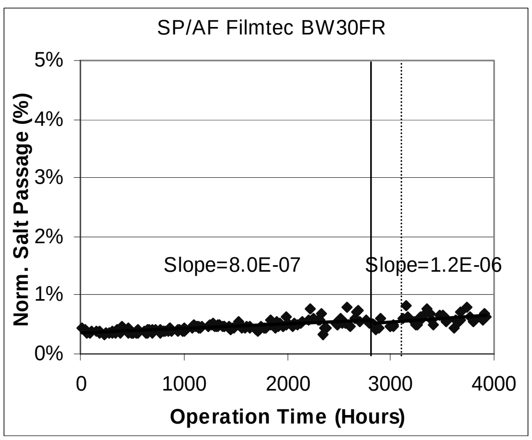



**Figure 94.a**

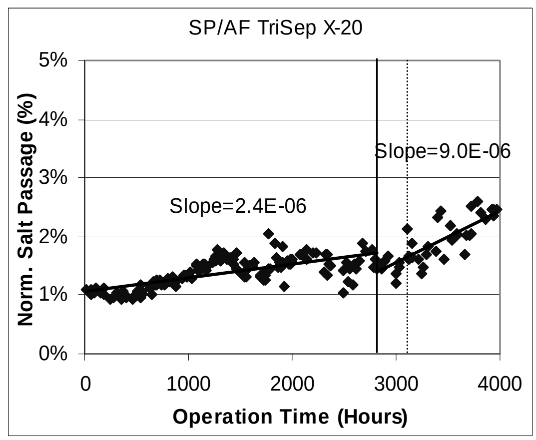



**Figure 94.b**

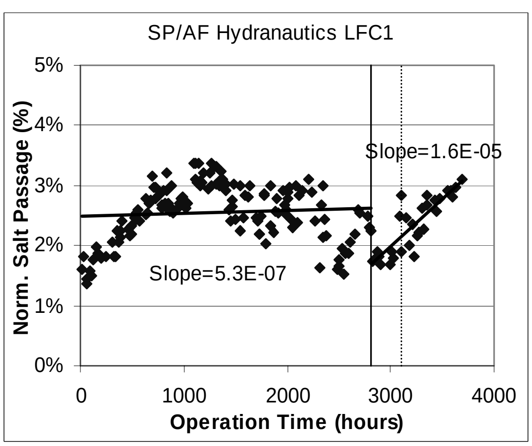



**Figure 94.c**

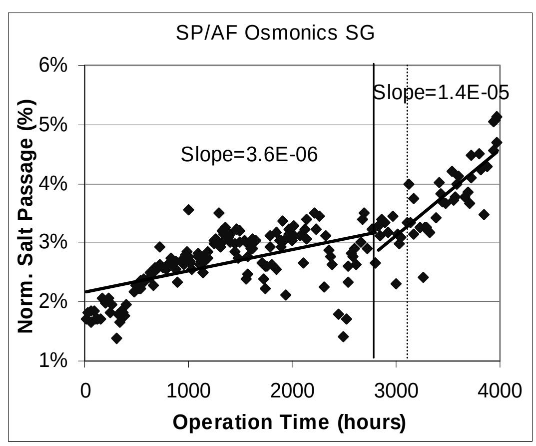



**Figure 94.d**

Following the change from SuperP to Actiflo pretreatment, the NSP for all elements increased at a significantly greater rate. This change correlates positively with higher rate of NPF decrease and DPC increase, and suggests that membrane fouling increased following this change. The BW30FR still had a much lower rate than the other elements possibly due to the larger feed spacer thickness used with this element.

Table 77 summarizes the NSP for the elements. The initial NSP was lowest for the BW30FR as was the increase during the first 2800 hours of operation. During the initial 2,800 hours, the SG NSP increased to 3.12 percent from 1.75 percent, an increase of 1.37 percent.

Following the clean, the SG NSP was higher than prior to the clean, while the other three elements had a decrease in the NSP. From 2,800 to 4,000 hours, the BW30FR again had the lowest increase in NSP and the SG had the highest NSP increase.

The overall increase was again lowest in the BW30FR (0.23 percent) and highest for the SG (2.86 percent). Both the X-20 and LFC1 had approximately a 1.3 percent increase.

**Table 77. SP/AF Normalized Salt Passage Increase Summary; Lead Element Selection and Continued Single Element Evaluation**

| Membrane | Prior to Clean (0-2800 hrs) | | | Following Clean (2800-4000 hrs) | | | Overall (0-4000 hrs) |
|---|---|---|---|---|---|---|---|
| | Initial NSP | NSP before Clean | NSP Increase | NSP after Clean | Final NSP | NSP Increase | Overall NSP Increase |
| **BW30FR** | 0.38% | 0.61% | 0.23% | 0.48% | 0.61% | 0.13% | 0.23% |
| **X-20** | 1.07% | 1.69% | 0.62% | 1.54% | 2.40% | 0.85% | 1.33% |
| **LFC1** | 1.63% | 2.42% | 0.79% | 1.78% | 2.91% | 1.13% | 1.29% |
| **SG** | 1.75% | 3.12% | 1.37% | 3.13% | 4.61% | 1.48% | 2.86% |

Assuming a linear increase in salt passage for the BW30FR, and assuming a 0.7 percent/yr increase, the salt passage for the BW30FR would increase from 0.38 percent to 3.9 percent after 5 years of operation (0.38 percent + 0.70 percent/yr * 5 yrs). For comparison, the X-20 NSP would increase to 12 percent after 5 years (1.07 percent + 2.1 percent/yr * 5 yrs).

Figure 95 summarizes the NSP for the Zenon single elements. All elements except the BW30FR had rapid increases in NSP during the first 950 hours of testing when chloramines were used for biological fouling control.

During the period 950 to 3,000 hours, the NSP declined for all elements, in most cases to near or less than initial levels. Thereafter, the NSP increased. This increase is most likely the result of biofouling.

**Figure 95. Zenon Single Element Normalized Salt Passage, Lead Element Selection**

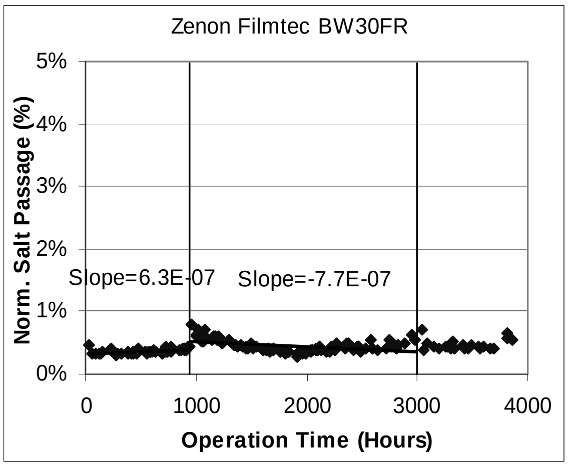



**Figure 95.a**

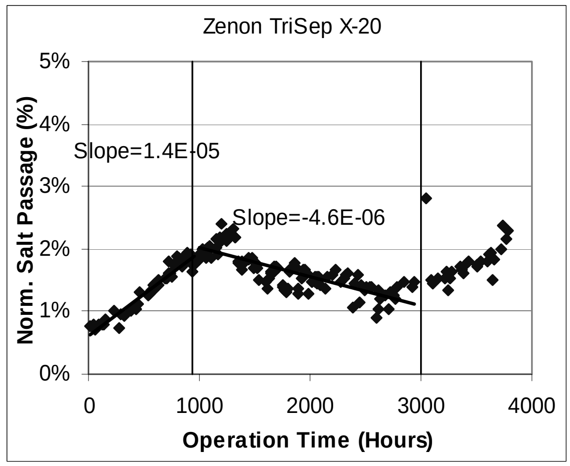



**Figure 95.b**

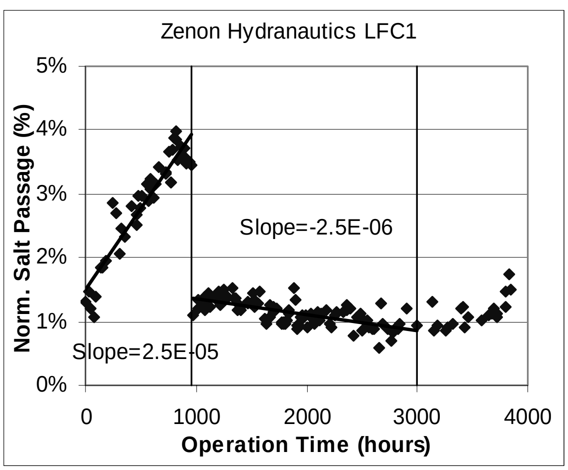



**Figure 95.c**

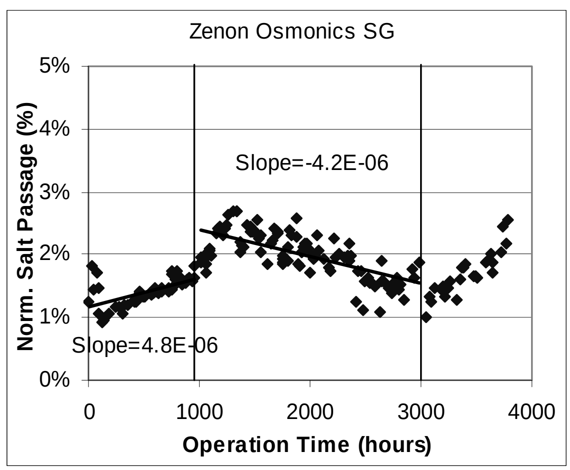



**Figure 95.d**

## Conclusions

The purpose of the testing conducted in these two phases was to evaluate all four pre-selected RO membrane types to determine, on high rate clarification and UF pretreatments, which elements perform most effectively and to confirm that both pretreatments are suitable for use in a full-scale integrated membrane system.

The results indicated that the BWFR30 was the best performing membrane, based on the smallest changes in all three performance parameters: NPF, DPC and NSP, when operated on either pretreated feed water. The membrane displaying the next best performance was the X-20, although it's performance was considerably less stable than the BW30FR. The LFC1 and SG membranes encountered the most dramatic changes in NSP, when operated on chloraminated feed, and were also the most sensitive to fouling, most likely because of the smaller feed spacer used with these two elements.

The unusual increases in NPF for all elements during operation on chloraminated feed are difficult to explain. When combined with increases in NSP, it is consistent with oxidative degradation of the thin film, particular when NPF stabilized after chloramination was stopped (post-950 hours on Zenon pretreatment). However, the decline in NSP for all elements upon cessation of chloramine feed is not consistent with oxidative attack. If oxidation of the thin film occurred, no decrease in NSP would have been anticipated.

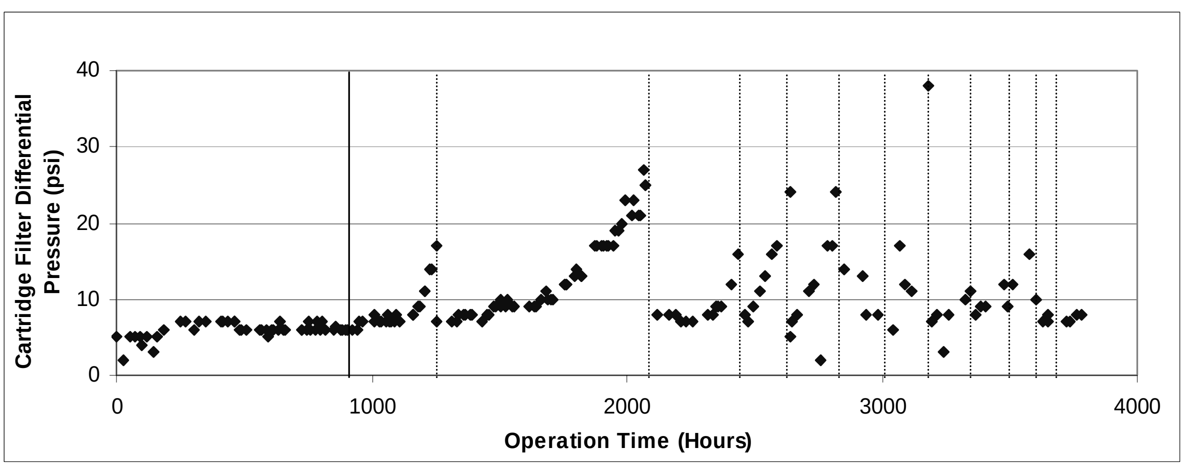
Two possible explanations for the reversing of NSP (or temporary increase) could be considered. First, chloramination of the raw water at relatively high levels could have formed a chloro-organic compound(s) that diffused into the thin film and changed their salt (and water) transport characteristics. When chloramination was stopped (with the Zenon pretreatment), this compound(s) diffused out of the thin film with the associated impact dissipating. Secondly, chloramines could have caused a reversible change in the transport properties of the thin film. As described at the end of this section, the analysis of membrane swatches removed from BW30FR elements that were autopsied at the end of field testing provides evidence to support the latter hypothesis.

The element performance on Zenon pretreated feed indicated that chloramines are necessary to control biofouling. The use of BioGuard was not effective in controlling the adverse performance impacts that biofouling produce. BioGuard is the only NSF-approved chemical currently available, that is not an oxidizing disinfectant, that can be used in a drinking water RO plant to control biofouling. To confirm that biofouling was the causative agent of performance impacts (and not inorganic or organic fouling) during BioGuard use, changes in the differential pressure across the cartridge filters located ahead of the single element feed pumps were examined during periods of chloramination and BioGuard use. An example is provided for the Zenon BW30FR element in Figure 96. Chloramines were applied to the Zenon feed water (and carried through the cartridge filter to the single element) during the initial 950 hours. This time, chloramines were stopped and BioGuard was applied (solid line indicates change). The dashed lines represent replacement of the cartridge filters, which occurred when the differential pressure across the filter increased by approximately 10 psi.

The cartridge filter differential pressure was stable during the 950-hour period of chloramination. Once BioGuard dosing began, the differential pressure increased within 200 hours, and with continued operation, increased at a more rapid rate resulting in more frequent filter changes.

Further, upon removal of the cartridge filters during operation with BioGuard, it was found that the filters were coated with a black, slimy material and had an earthy, musty odor suggesting biological growth was occurring within and on the cartridge filters.

**Figure 96. Cartridge Filter Replacement Frequency; ZN BW30FR Single Element**



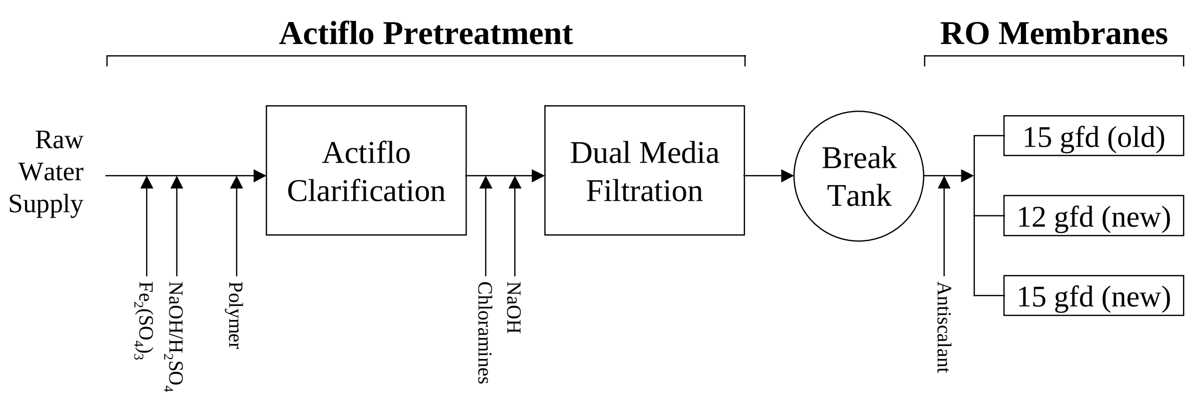
### Flux Evaluation Phase

#### *Testing Summary*

A flux evaluation was done to determine if the preferred membrane, the BW30FR, could be operated at higher flux without a significant increase in fouling or increase in salt passage. An increased flux is desirable because it reduces the capital cost of the RO system (fewer elements and pressure vessels, smaller train footprint) and reduces membrane replacement costs. During testing, the target element and system recoveries were 13 percent and 70 percent, respectively. Both a new BW30FR element and the BW30FR element used in the SP/AF pretreatment testing for the lead element and continued single element evaluation phases were operated at 15 gfd to confirm that performance changes were not related to duration of feed water exposure. The old BW30FR single element had been in operation for approximately 4,800 hours of run time at a flux of 12 gfd, a system recovery of 70 percent, and an elemental recovery of 13 percent. In addition, a new BW30FR element was also operated at 12 gfd to provide a control.

Figure 97 illustrates the process flow diagram for the flux evaluation. The three BW30FR single element membranes were operated on effluent from the AF/GF train with chloramines fed to the clarified water. The target combined chlorine concentration, as measured in the RO feed, was 1.5 mg/L as $Cl_2$.

**Figure 97. Process Flow Diagram for Single Element Testing; Flux Evaluation**




#### *Performance Summary*

Table 78 summarizes the feed water quality during the single element flux evaluation.

The temperatures during testing ranged from 13.6 °C to 25.0 °C with an average of 19.4 °C. The average conductivity during the flux evaluation was 72.6 S/m. The conductivity ranged from 60.8 S/m to 79.0 S/m. The average color was 0 Pt-Co for the duration of flux evaluation and ranged from 0 Pt-Co to 1 Pt-Co.

As the table suggests, the average total chlorine during testing was 1.8 mg/L with a range from 2.2 mg/L as $Cl_2$ to 0 mg/L as $Cl_2$. The standard deviation was 0.5 mg/L as $Cl_2$ but the coefficient of variance was 0.27 suggesting moderate variability in total chlorine concentration.

**Table 78. Single Element Feed Water Quality; Flux Evaluation**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **pH** | | 6.9 | 7.4 | 6.3 | 0.3 | 0.04 |
| **Temperature** | **(°C)** | 19.4 | 25.0 | 13.6 | 3.6 | 0.19 |
| **Conductivity** | **(S/m)** | 72.6 | 79.0 | 60.8 | 3.9 | 0.05 |
| **Turbidity** | **(NTU)** | 0.043 | 0.050 | 0.039 | 0.004 | 0.09 |
| **SDI** | | 3.4 | 4.6 | 2.8 | 0.5 | 0.14 |
| **$UV_{254}$** | **(abs/cm)** | 0.072 | 0.085 | 0.062 | 0.006 | 0.09 |
| **Color** | **(Pt-Co)** | 0 | 1 | 0 | 0 | 1.61 |
| **Total Iron** | **(mg/L)** | 0.007 | 0.025 | 0.000 | 0.008 | 1.20 |
| **Total Chlorine** | **(mg/L as $Cl_2$)** | 1.8 | 2.2 | 0.0 | 0.5 | 0.27 |

Table 79 lists the average, maximum and minimum values for flux, and system and element recoveries during the flux evaluation phase. All elements were operated at 70 percent system recovery, as used in prior testing phases.

Average values were close to the target values for all elements.

**Table 79. Average Single Element Flux, System Recovery, and Elemental Recovery; Flux Evaluation**

| Membrane | Flux (gfd) | | | System Recovery (%) | | | Elemental Recovery (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Average | Max | Min | Average | Max | Min | Average | Max | Min |
| Original BW30FR @ 15gfd (After 4828 hours) | 15.0 | 15.5 | 14.3 | 70% | 72% | 69% | 13% | 13% | 12% |
| Original BW30FR @ 12gfd (Initial 1248 hours) | 12.1 | 13.3 | 9.9 | 71% | 73% | 66% | 13% | 14% | 11% |
| New BW30FR @ 15 gfd | 15.0 | 15.5 | 14.6 | 71% | 74% | 69% | 13% | 13% | 13% |
| New BW30FR @ 12 gfd | 12.5 | 15.0 | 11.9 | 71% | 74% | 69% | 14% | 16% | 13% |

Figure 98 illustrates the flux and system recovery during the flux evaluation. The figure is divided into four subfigures labeled Figure 98.a to 98.d to illustrate the performance of the four elements.

As the figure suggests, the flux and recovery were maintained at the target values for the 1,250 hours of flux evaluation testing.

**Figure 98. Single Element Flux and Recovery; Flux Evaluation**

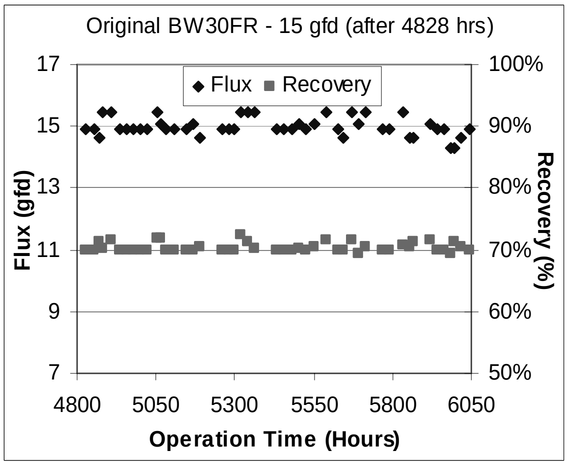



**Figure 98.a**

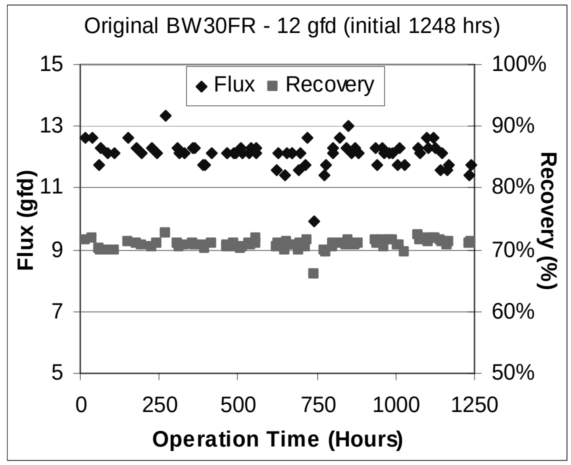



**Figure 98.b**

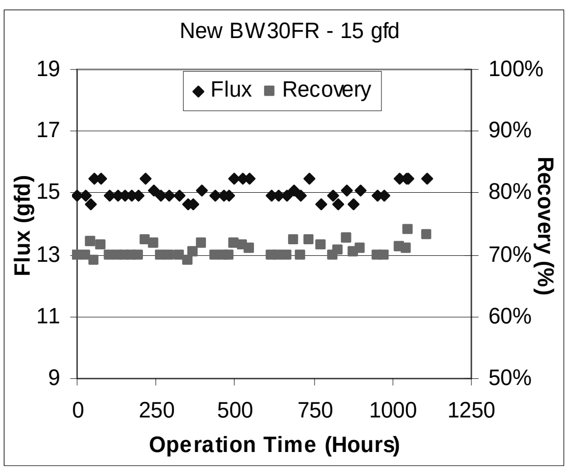



**Figure 98.c**

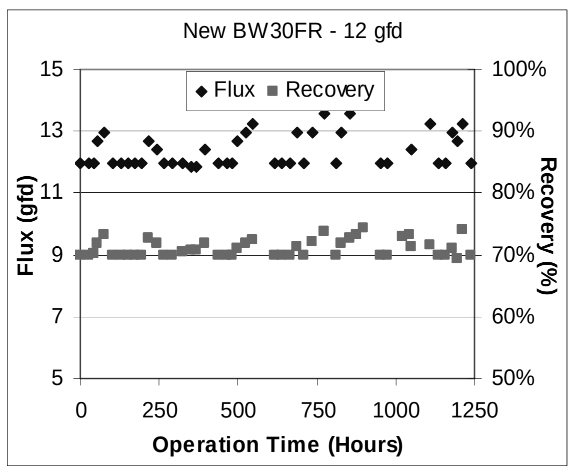



**Figure 98.d**

Figure 99, divided into subfigures for each element, summarizes the feed pressure and temperature for the flux evaluation.

As shown in Figures 99.a and 99.c, feed pressure for the new element at 15 gfd was 60 psi higher than for the old element after 4,828 hours of operation (or the start of the flux evaluation). The lower pressures for the old element correlates with the increased NPF observed during the prior two phases on SP / AF pretreatment. The feed pressure for the new element at 12 gfd was also higher than for the original element at the same flux when initially operated (Figures 99.b and 99.d); however, the feed temperature for the original element was significantly higher.

All three membranes showed decreases in feed pressure during the flux evaluation period; however, most of the decrease could have been due to increasing feed temperatures.

**Figure 99. Single Element Pressure and Temperature, Flux Evaluation**

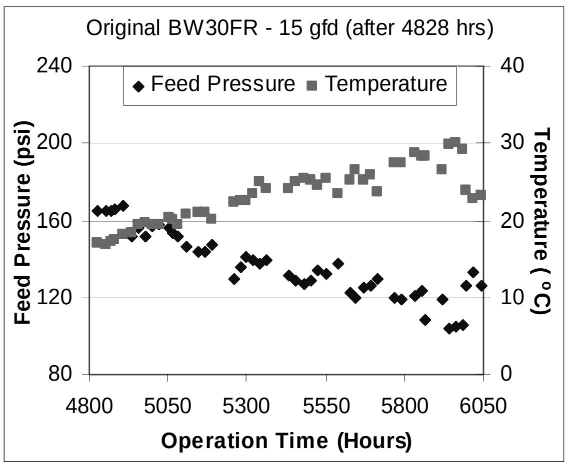



**Figure 99.a**

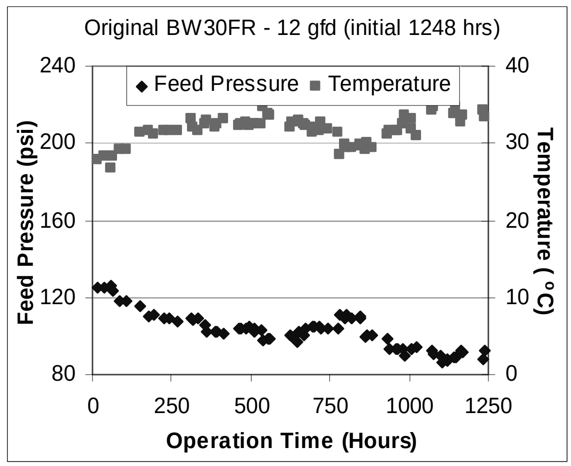



**Figure 99.b**

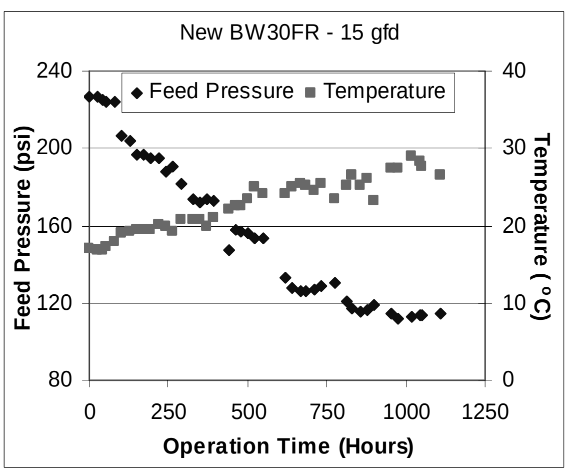



**Figure 99.c**

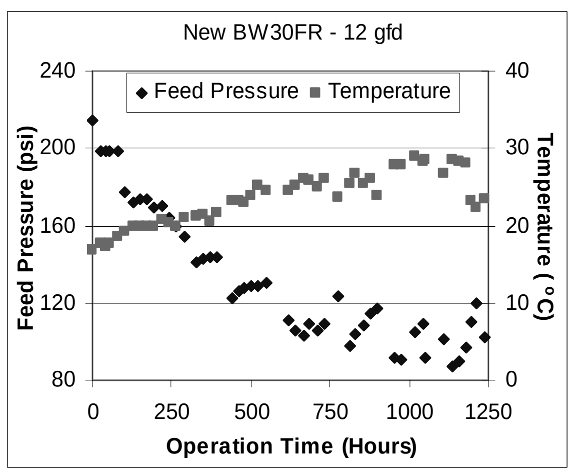



**Figure 99.d**

Figure 100 summarizes the differential pressure for the single element during the flux evaluation testing. Linear regressions were performed on the differential pressure to determine the hourly rate of change in differential pressure.

To illustrate the difference in the rate of differential pressure increase between the old element and the new element at 15 gfd, the rate of increase in Figure 100.a (0.00023 psi/hr) was compared to 0.00011 psi/hr in Figure 100.c. This suggests that the rate of increase was twice as high on the old element compared to the new element. The higher rate of fouling could be attributed to the impact of fouling that had occurred on the old element during the previous operation.

The differential pressure for the new BW30FR at 12 gfd declined slightly during the test period, indicating no fouling had occurred.

**Figure 100. Single Element Differential Pressure, Flux Evaluation**

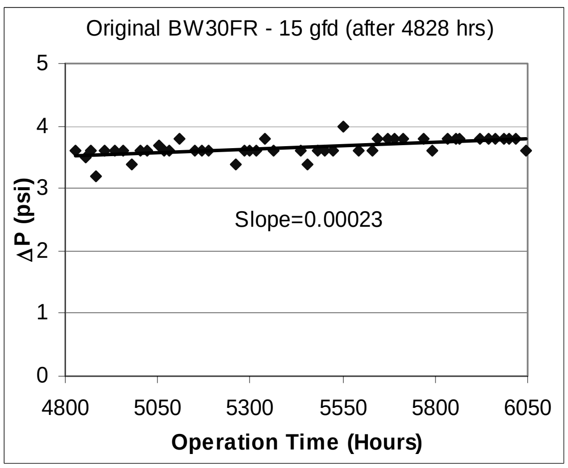



**Figure 100.a**

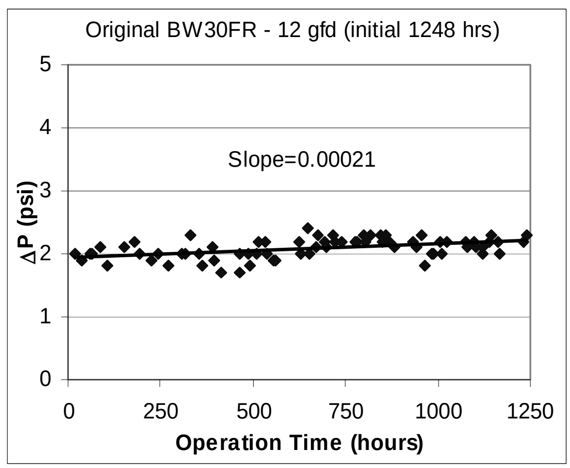



**Figure 100.b**

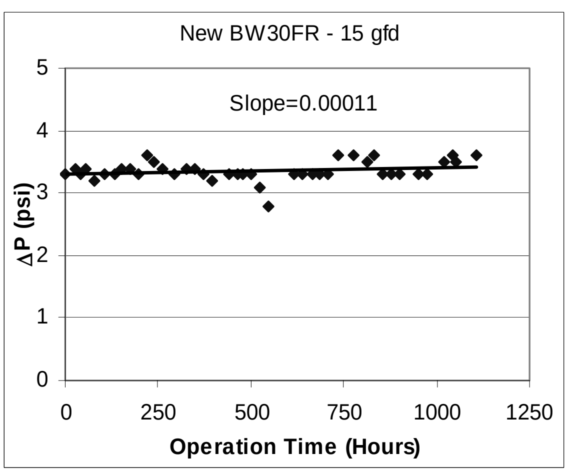



**Figure 100.c**

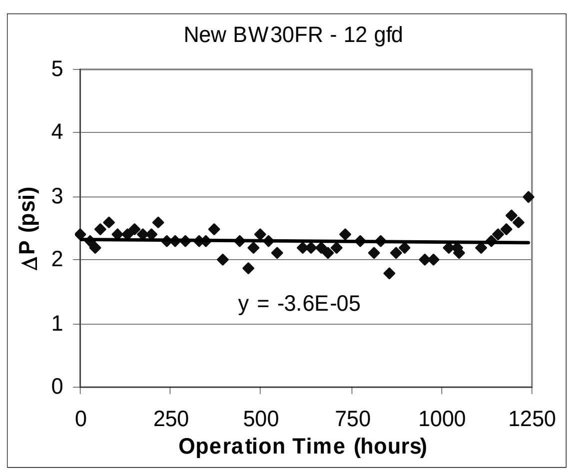



**Figure 100.d**

Figure 101 illustrates the NPF for the flux testing. The old BW30FR at 15 gfd had a low increase in NPF (Figure 101.a). Both new single elements had a more rapid increase of approximately 0.00046 gpm/hr (Figures 101.c and .d), similar to, but greater than, that for the old element during initial testing (Figure 101.b). This suggests that chloraminated feed water impacts are more significant during initial membrane operation.

Average chlorine concentrations during the initial 12 gfd testing were 0.74 mg/L as $Cl_2$, while average chlorine concentrations during the new 12 gfd element testing were 1.76 mg/L as $Cl_2$, 2.4 times higher than the original testing. The higher chloramines loading could explain the higher rate of increase in NPF, due to chloramine degradation.

**Figure 101. Single Element Normalized Product Flow, Flux Evaluation**

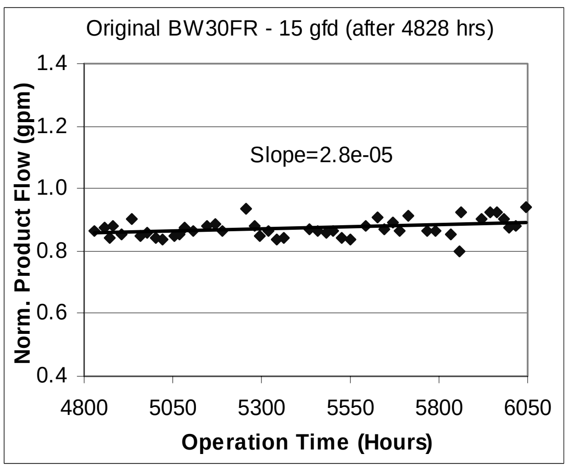



**Figure 101.a**

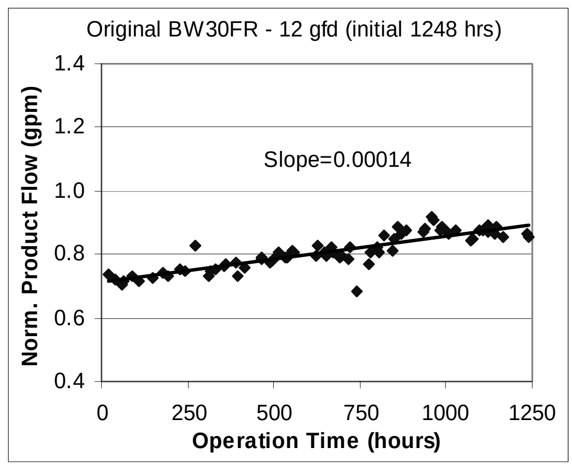



**Figure 101.b**

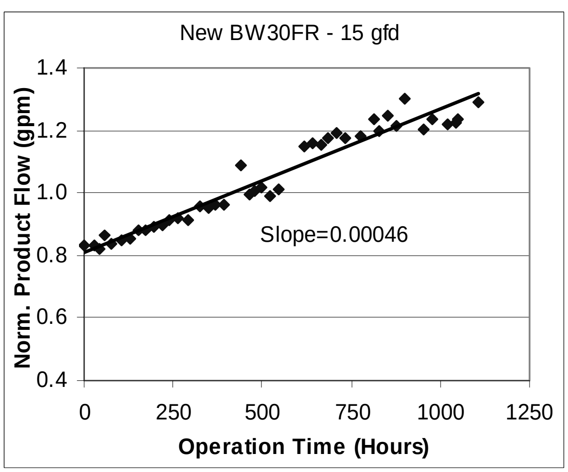



**Figure 101.c**

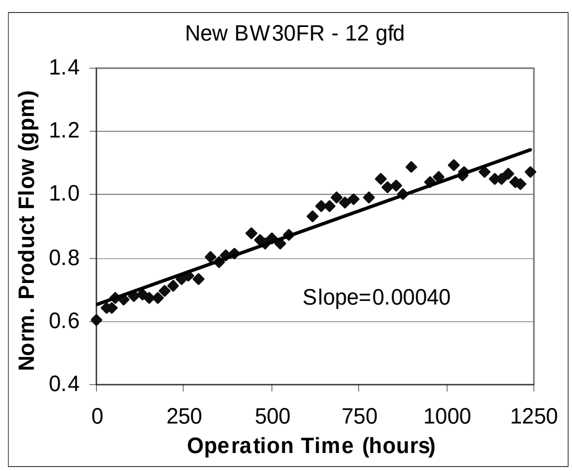



**Figure 101.d**

Figure 102 summarizes the DPC change. Initial operation of the original BW30FR resulted in a DPC increase of 0.00012 percent/ day compared to the testing of the new BW30FR at 12 gfd which had a decline in DPC. Again, the original BW30FR-15 gfd had a higher rate of DPC when compared to the new BW30FR-15 gfd.

**Figure 102. Single Element Normalized Differential Pressure Coefficient Change, Flux Evaluation**

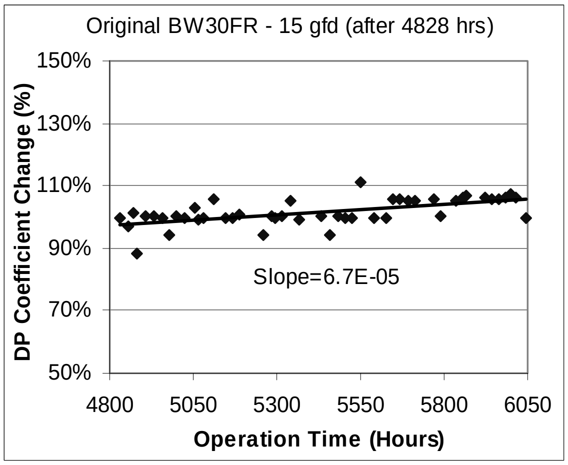



**Figure 102.a**

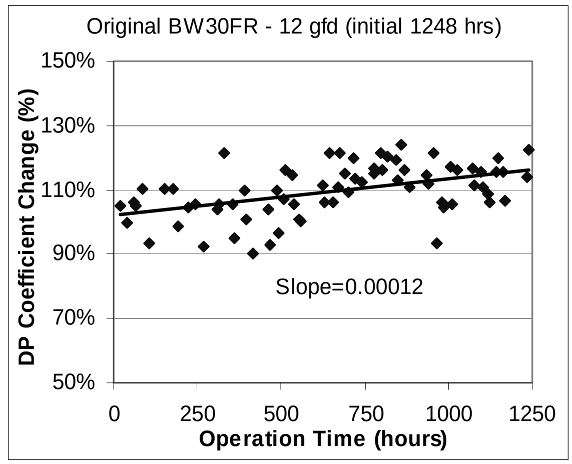



**Figure 102.b**

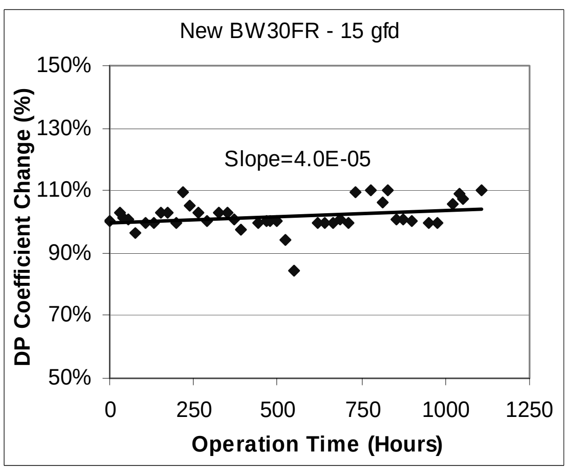



**Figure 102.c**

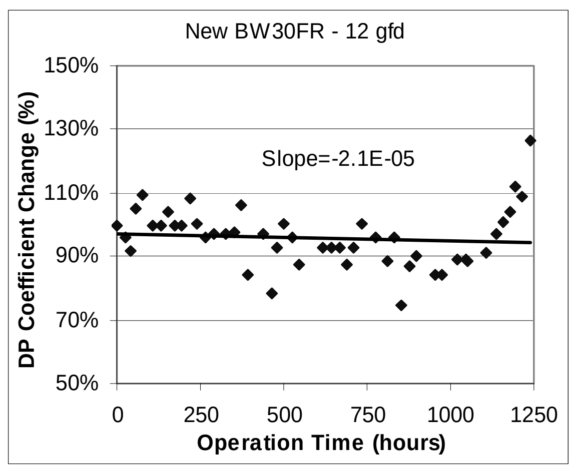



**Figure 102.d**

Figure 103 summarizes the NSP for the single elements during the flux evaluation. The highest increase in salt passage occurred on the previously operated BW30FR at 15 gfd. From approximately 4,800 hours to 6,050 hours, the rate of salt passage increase was 2.3E-06 percent/ hr, or 0.23 percent every thousand hours (2.1 percent every year). During the entire 6,050 hours of operation of the original BW30FR, the increase rate was 8.4E-07 percent/hr or 0.75 percent per year, indicating that the rate of NSP increase for this element was higher at higher flux.

Both of the new elements had a NSP increase of approximately 9E-07 percent/hr or approximately 0.8 percent every year, indicating that the rate of increase in NSP was not a function of membrane flux. In comparison, during the first 1,250 hours of testing of the original BW30FR, the salt passage increase was 7.2E-07 percent/hr or 0.63 percent per year. The lower rate for the original element may result from the lower chloramine concentrations.

**Figure 103. Single Element Normalized Salt Passage, Flux Evaluation**

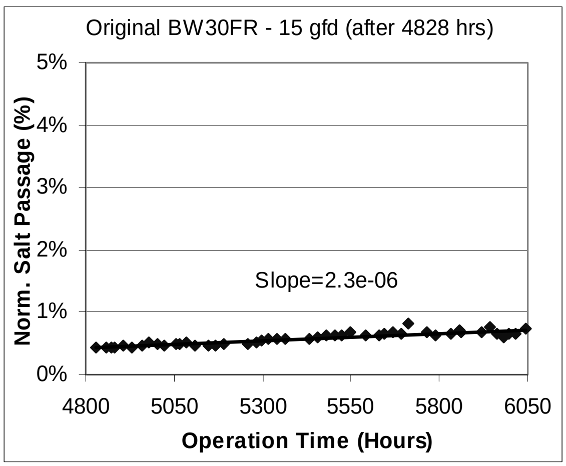



**Figure 103.a**

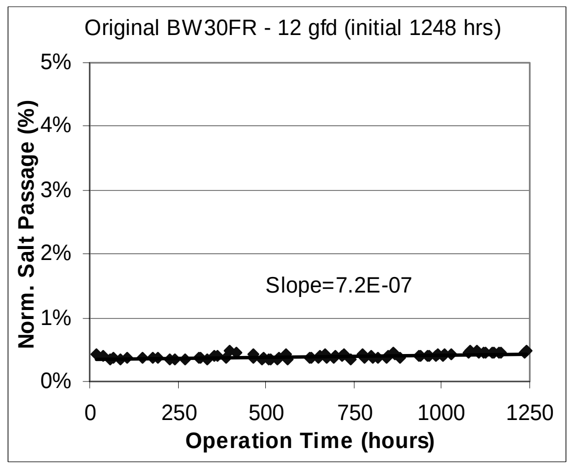



**Figure 103.b**

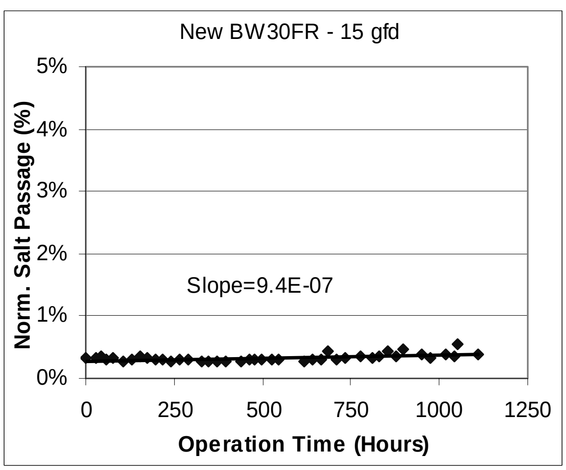



**Figure 103.c**

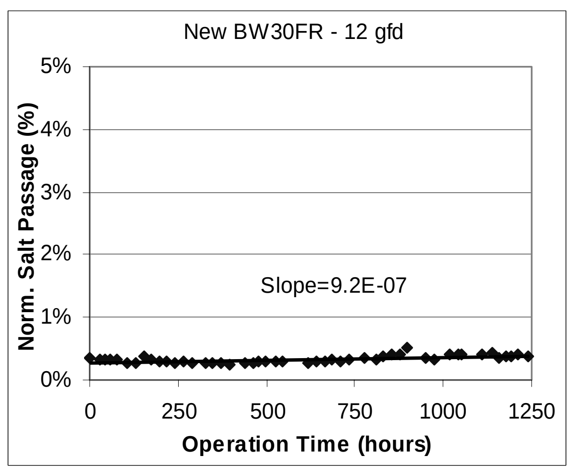



**Figure103.d**

### Conclusions

Based on the results of this testing, it appears that a flux of 15 gfd is feasible. The differences in both NPF and NSP between the new BW30FR elements operated at 12 and 15 gfd were not statistically significant.

Based on the comparison between the old element at 12 gfd and the new element at 12 gfd, there was a higher rate of salt passage increase and NPF increase for the new element; however, the difference in chloramines concentration of the feed water to the elements could account for these differences. The average total chlorine feed concentration for the old 12 gfd element was 0.74mg/L as $Cl_2$, compared to a concentration of 1.76 mg/L as $Cl_2$ for the new element at 12 gfd. This suggests that lower chloramine concentrations would result in less membrane damage and extended membrane life.

Based on these data, optimization could be conducted to further evaluate lower chloramine levels to offset membrane degradation and increased salt passage. Lower chloramine dosages (below the 0.74 mg/L level tested in this study) could be evaluated to determine if effective biofouling control could be maintained at a lower dose. However, the incremental reduction in NSP that may be realized from lower chloramine levels below 0.74 mg/L should be assessed relative to the ability to effectively and consistently control the residual at those low levels.

### High Recovery/Low Recovery Multi-Element Testing

In order to further evaluate the different membrane types, testing in a multi-element high recovery system was done. Based on single element testing, the BW30FR was selected for evaluation in this system. Further, to evaluate the need for fouling resistant membranes on this water source, a conventional non-fouling resistant membrane, Filmtec BW30LE, was also tested. The following membranes were evaluated in the high recovery/low recovery testing system:

- Filmtec BW30FR (high recovery)
- Filmtec BW30LE (low recovery)
- TriSep X-20 (low recovery)
- Osmonics SG (low recovery)

Due to poor performance during the single element testing, the Hydranautics LFC1 was not evaluated in the high recovery system.

### Testing Summary

Table 80 summarizes the pretreatment and membranes tested during the high recovery testing. Testing started on July 16, 2002 with SuperP-media filtration as pretreatment and was changed to Actiflo-media filtration on August 23, 2002. As the table suggests, during the initial high recovery testing, all four membranes were evaluated using both SuperP and Actiflo as pretreatments.

Based on the results of the initial high recovery testing, additional testing was necessary. This next step in the evaluation started on January 17, 2003 and continued until April 2, 2003. Testing of the SG membrane was stopped due to poor performance in single element testing and the initial high recovery evaluation.

**Table 80. High Recovery Testing Summary**

| Task and Pretreatment | Dates | Filmtec BW30FR | Filmtec BW30LE | TriSep X-20 | Osmonics SG |
|---|---|---|---|---|---|
| High Recovery Evaluation | 07/16/02-12/19/02 | | | | |
| SuperP-Media Filtration | 07/16/02-09/23/02 | XX | XX | XX | XX |
| Actiflo-Media Filtration | 09/23/02-12/19/02 | XX | XX | XX | XX |
| Continued Evaluation | 01/17/03-04/02/03 | | | | |
| Actiflo-Media Filtration | 01/17/03-04/02/03 | XX | XX | XX | |

Figure 104 illustrates the process flow diagram for high recovery testing. The pretreatment system supplied a 3,000 gallon break, which allowed extended membrane run time when upsets and shutdowns in the pretreatment system occurred. Antiscalant (and BioGuard for the first 1,285 hours) was added prior to the pretreated membrane feed.

**Figure 104. Process Flow Diagram for High Recovery Testing**

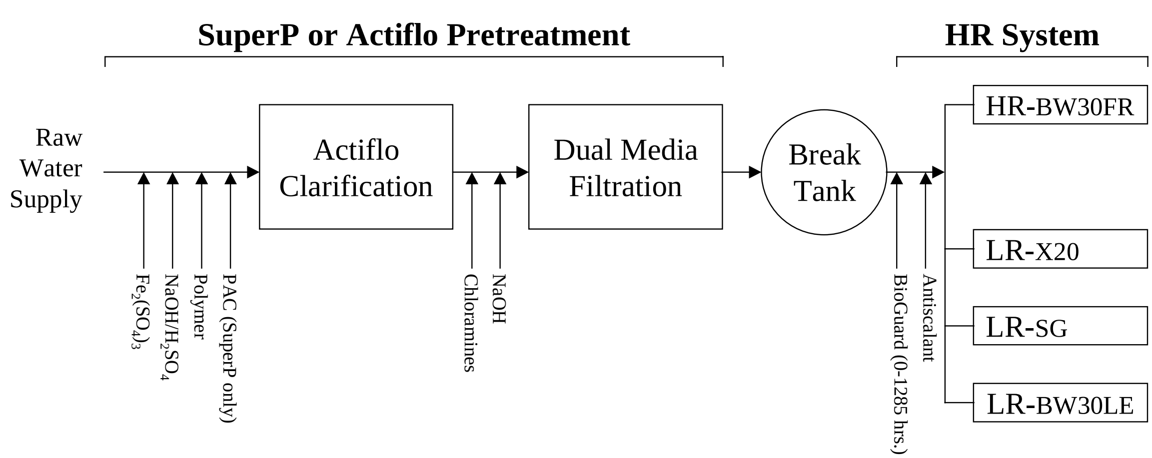


Figure 105 presents a flow diagram of the high recovery membrane system. The drawing illustrates the high recovery system and the three low recovery vessels. The high recovery system was configured in a 2-1 array. As the figure suggests, the first stage had four vessels, while the second stage had two vessels. Each vessel contained three elements with a total of 18 elements for the entire high recovery system. The BW30FR was the element used in the high recovery system.

The other three membrane types were used in the low recovery vessels, which simulate the lead vessel of Stage 1 in the high recovery system. The BW30LE was contained in vessel LR1, the X-20 was contained in vessel LR2, and the SG was contained in LR3.

**Figure 105. High Recovery Process Flow Diagram**

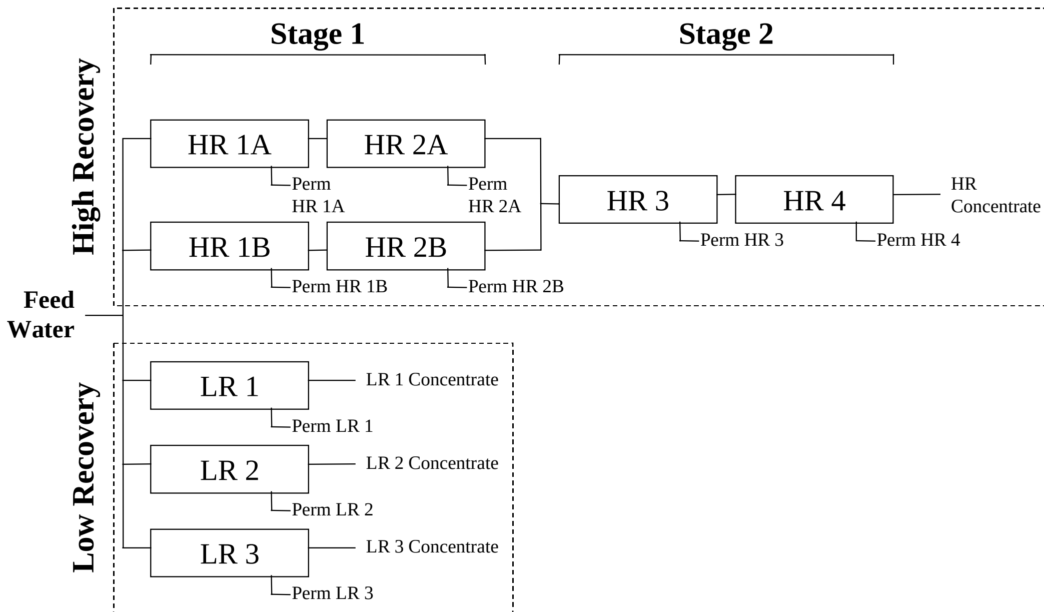



Table 81 summarizes the significant events that occurred during the high recovery testing. The table summarizes system startups, changes in operation, cleanings, and system shutdowns.

As the table indicates, the system was started on July 16, 2002 using SuperP-media filtration as pretreatment. At startup, BioGuard was applied to the system at a dosage of 5 ppm to control biological fouling.

High pH caustic cleans were performed at 620 hours, 1,150 hours, and 1,950 hours. A caustic clean was performed by adding sodium hydroxide to RO permeate until a solution pH 11 was reached. Low pH acid cleans followed by high pH sodium hydroxide cleans were performed at 2,370 hours, 2,820 hours, 3,080 hours, and 4,170 hours.

The cleans were performed using pH 11 sodium hydroxide / RO permeate solutions and pH 2 hydrochloric acid / RO permeate solutions. The given solution was applied to the membranes under low pressure until the pH of the concentrate was at the same pH as the cleaning solution. The membranes were allowed to soak for 30 minutes, and were flushed with the solution. This was repeated three times.

As the table shows, the X-20 was replaced at 2,370 hours. This was done to evaluate the X-20 membrane both before and after chloramines were applied to the system for biological fouling control.

Testing of the SG was discontinued at 1,285 hours, based on the performance of the SG in the single element systems and the high recovery system.

Testing was stopped at 3,050 hours and the membranes were preserved using sodium bisulfite. Testing resumed approximately one month later and was completed on April 2, 2003 at 4,330 hours.

**Table 81. High Recovery Testing Timeline**

| Date | Run Hours | Description |
|---|---|---|
| 07/16/02 | 0 | Began high recovery testing using SuperP-media filtration pretreatment. BioGuard for biofouling control. |
| 08/16/02 | 580 | Stopped Bio-Guard dosing to the system. |
| 08/19/02 | 620 | Cleaned SG and X-20 low recovery membranes using pH 11 NaOH soln. |
| 09/01/02 | 860 | Restarted Bio-Guard dosing to the system at 10 ppm. |
| 09/16/02 | 1150 | Cleaned all membranes using pH 11 NaOH soln. |
| 09/23/02 | 1260 | Changed SuperP-media filtration pretreatment to Actiflo-media filtration pretreatment. |
| 09/25/02 | 1285 | Stopped Bio-Guard dosing to the system. Started chloramines. |
| 09/25/02 | 1285 | Stopped Osmonics SG testing. |
| 10/05/02 | 1500 | Changed pretreatment to SuperP/media filtration. |
| 10/09/02 | 1590 | Changed pretreatment to Actiflo/media filtration. |
| 10/19/02 | 1780 | Stopped chloramine dosing. |
| 10/25/02 | 1900 | Restarted chloramine dosing. |
| 10/28/02 | 1950 | Cleaned all membranes using pH 11 NaOH soln. |
| 11/20/02 | 2370 | Replaced TriSep X-20 membranes in low recovery vessel. |
| 11/20/02 | 2370 | Cleaned all membranes using pH 11 NaOH soln. followed by pH 2 HCl soln. |
| 12/09/02 | 2820 | Cleaned all membranes using pH 11 NaOH soln. followed by pH 2 HCl soln. |
| 12/19/02 | 3050 | Cleaned all membranes using pH 11 NaOH soln. |
| 12/19/02 | 3050 | Stopped operation of system. Membranes preserved using sodium bisulfite. |
| 01/17/03 | 3060 | Restarted testing. Upset in treatment by Actiflo system resulting in poor feed water to system. |
| 01/18/03 | 3080 | Cleaned all membranes using pH 2 HCl soln. followed by pH 11 NaOH soln. followed by pH 2 HCl soln. |
| 03/25/03 | 4170 | Cleaned all membranes using pH 2 HCl soln. followed by pH 11 NaOH soln. |
| 04/02/03 | 4330 | Stopped testing. |

### Feed Water Quality Summary

Table 82 summarizes the feed water quality during the high recovery testing. The table presents the average, maximum, minimum, standard deviation, and CV for the water quality parameters.

As the table suggests, the average temperature during testing was 24.3°C with a maximum of 32.0°C and a minimum of 10.9°C. The average color during testing was 2 Pt-Co and the average pH during testing was 6.9. SDI's ranged from 5.2 to 2.1 with an average of 3.2.

**Table 82. High Recovery System Feed Water Quality**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| pH | | 6.9 | 8.5 | 6.0 | 0.4 | 0.06 |
| Temperature | (°C) | 24.3 | 32.0 | 10.9 | 5.8 | 0.24 |
| Conductivity | (S/m) | 73.0 | 105.8 | 41.6 | 10.0 | 0.14 |
| Turbidity | (NTU) | 0.048 | 0.084 | 0.026 | 0.011 | 0.23 |
| SDI | | 3.2 | 5.2 | 2.1 | 0.7 | 0.22 |
| $UV_{254}$ | (abs/cm) | 0.071 | 0.105 | 0.028 | 0.015 | 0.22 |
| Color | (Pt-Co) | 2 | 7 | 0 | 2 | 0.92 |
| Total Iron | (mg/L) | 0.064 | 0.197 | 0.000 | 0.055 | 0.86 |
| Total Chlorine | (mg/L as $Cl_2$) | 1.8 | 5.0 | 0.0 | 1.2 | 0.65 |

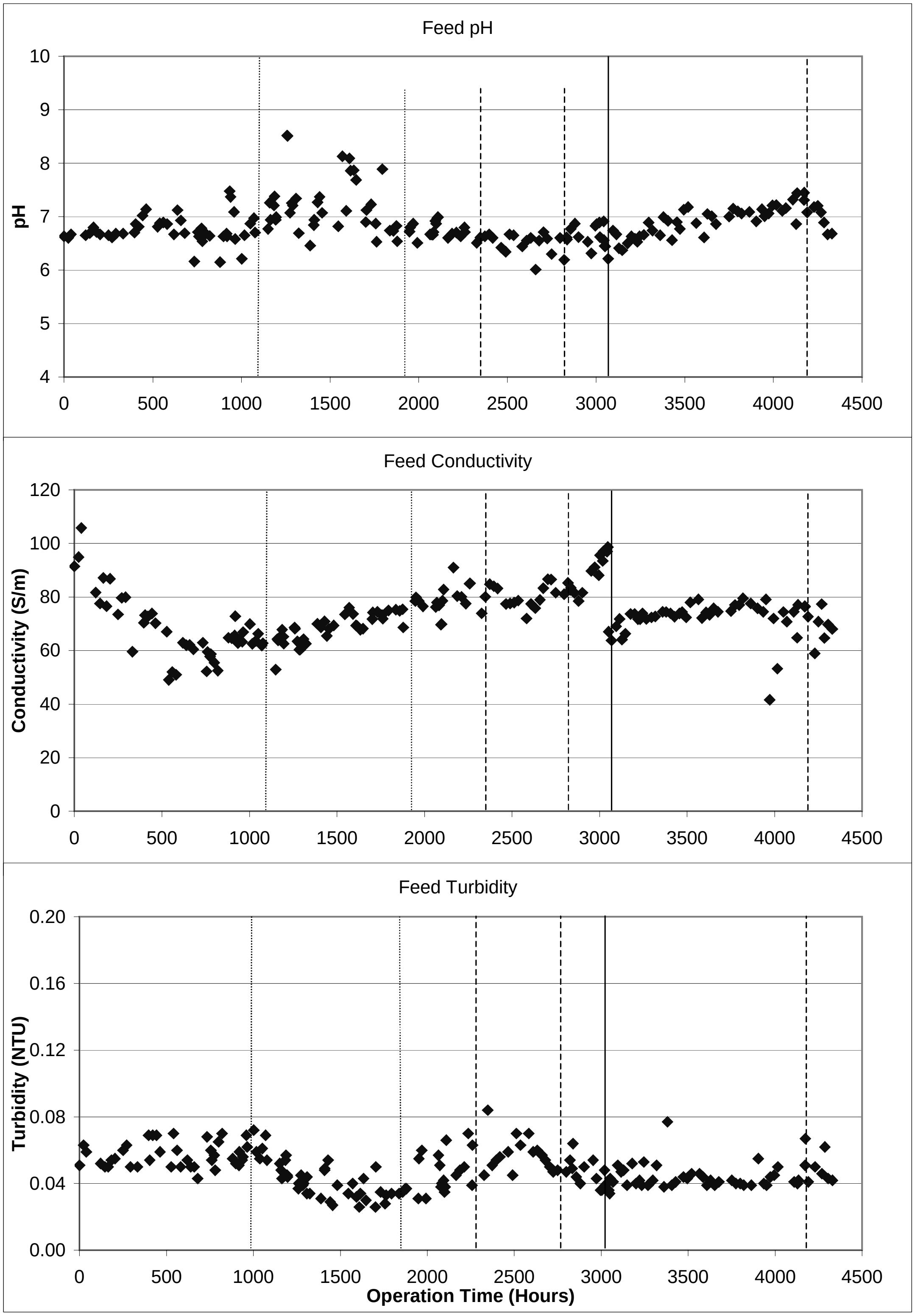
Figure 106 summarizes the high recovery feed pH, conductivity, and turbidity during testing. As Table 82 suggests and Figure 106 illustrates, the average turbidity during testing was 0.048 NTU and with a range from 0.084 NTU to 0.026 NTU.

Figure 107 illustrates the feed total chlorine, $UV_{254}$, absorbance, and iron during high recovery testing. As the figure indicates, chlorine was not dosed until after approximately 1,300 hours of membrane operation.

Grab samples were taken monthly and analyzed by personnel at the UCF. Table 83 summarizes the rejections of various water quality parameters by the BW30FR tested at high recovery. Further, the BW30LE and X-20 results are also summarized. The average levels and percentage rejections are provided. No samples were taken from the SG prior to discontinuing testing.

The average feed TDS during high recovery testing was 352.3 mg/L. All of the systems were able to achieve more than 97 percent removal of this parameter. The average feed NPDOC was 3.9 mg/L with approximate rejections of 90 percent. Feed bromide levels were 0.34 mg/L, while permeate bromide levels were below detectable limit (0.1 mg/L).

**Figure 106. High Recovery Feed pH, Conductivity, and Turbidity**



# Figure 107. High Recovery Feed pH, Conductivity, and Turbidity

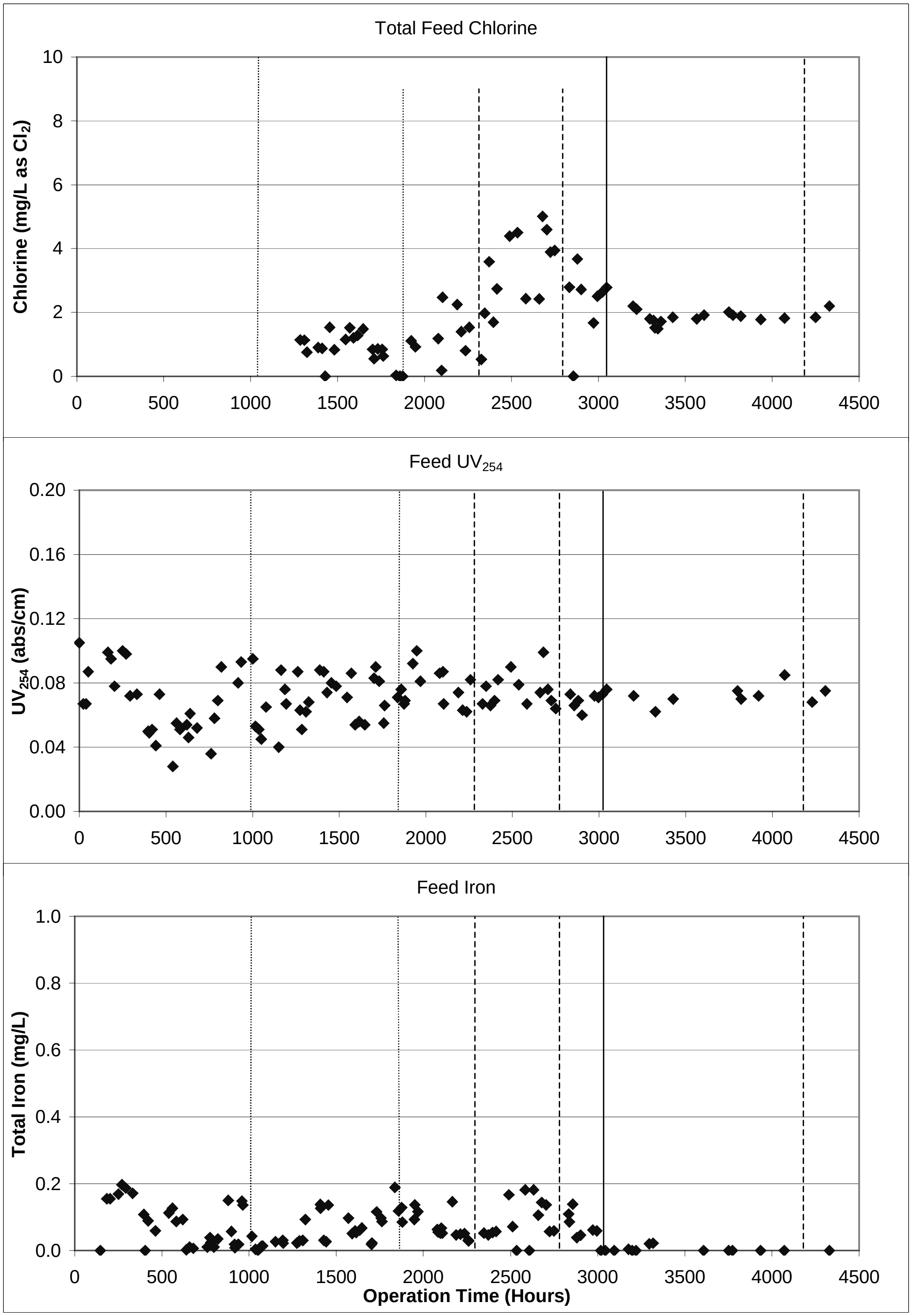


**Table 83. Average Water Quality Parameter Removals; UCF Lab Data**

| Parameter | Units | Feed | BW30FR | | BW30LE | | X-20 | |
|---|---|---|---|---|---|---|---|---|
| | | Avg. | Avg. | % Rej. | Avg. | % Rej. | Avg. | % Rej. |
| NPDOC | (mg/L) | 3.9 | 0.4 | 90.4% | 0.3 | 91.0% | 0.4 | 89.8% |
| TDS | (mg/L) | 352.3 | 9.6 | 97.3% | 10.2 | 97.1% | 6.0 | 98.3% |
| Ca | (mg/L) | 36.3 | 0.2 | 99.6% | 0.2 | 99.5% | 0.2 | 99.3% |
| Mg | (mg/L) | 9.9 | BDL | > 99.0% | BDL | > 99.0% | BDL | > 99.0% |
| Na | (mg/L) | 92.2 | 1.3 | 98.6% | 2.6 | 97.2% | 0.9 | 99.1% |
| SiO2 | (mg/L) | 6.0 | BDL | > 83.3% | BDL | > 83.3% | BDL | > 83.3% |
| Br | (mg/L) | 0.34 | BDL | > 70.3% | BDL | > 70.3% | 0.1 | > 70.3% |
| Cl | (mg/L) | 116.0 | 3.0 | 97.4% | 4.3 | 96.3% | 2.9 | 97.5% |
| SO4 | (mg/L) | 125.0 | BDL | > 99.9% | BDL | > 99.9% | BLD | > 99.9% |
| Color | (Pt-Co) | 4 | 2 | 42.9% | 3 | 40.5% | 3 | 34.5% |
| Alkalinity | (mg/l as $CaCO_3$) | 23 | 4 | 80.3% | 4 | 83.9% | 4 | 84.5% |

## Membrane Performance

### *High Recovery Membrane Performance*

Table 84 summarizes the flux and recovery for the high recovery system. Further, the first and second stage of the high recovery system are summarized. Flux and recovery is different from the first to the second stage due to increasing osmotic pressure loss through the system.

As the table suggests, the average flux of the system was 11.9 gfd compared to a flux of 13.4 gfd in the first stage and a flux of 8.9 gfd in the second stage. The maximum and minimum flux in the first stage was 15.8 gfd and 12.3 gfd, respectively, while the maximum and minimum flux in the second stage was 11.4 gfd and 4.1 gfd.

**Table 84. Average High Recovery Interstage Flux and Recovery**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| System Flux | (gfd) | 11.9 | 12.5 | 10.8 | 0.2 | 0.02 |
| System Recovery | % | 85% | 88% | 82% | 1% | 0.01 |
| Stage 1 Flux | (gfd) | 13.4 | 15.8 | 12.3 | 0.6 | 0.05 |
| Stage 1 Recovery | % | 64% | 74% | 15% | 5% | 0.07 |
| Stage 2 Flux | (gfd) | 8.9 | 11.4 | 4.1 | 1.3 | 0.15 |
| Stage 2 Recovery | % | 58% | 67% | 39% | 4% | 0.07 |

Figure 108 illustrates the system flux and recovery during testing. The top of the figure summarizes the cumulative flux and recovery, the middle of the figure illustrates Stage 1 flux and recovery, and the bottom of the figure illustrates Stage 2 flux and recovery.

The perforated lines on the figure represent caustic cleans, dashed lines represent caustic/acid cleans, and the solid line represents the temporary shutdown of the system at 3,050 hours, at which time an acid/caustic/acid clean was performed.

As the figure illustrates, the flux of Stage 1 is higher than the flux of Stage 2. This is due to the lower conductivity in the first stage and the decrease in pressure through the system due to pressure loss in the system. Further, the flux was not balanced between the stages through the use of valves.

The cumulative flux and recovery was maintained at a constant level during testing and had a coefficient of variance of 0.02. As expected, during the initial stages of operation (0 - 1,150 hours) as the Stage 2 flux and recovery decreased, the Stage 1 flux increased and recovery increased.

Figure 109 summarizes both the system and the Stage 2 feed pressure. The top of the figure illustrates the cumulative feed pressure and the bottom of the figure illustrates the stage 2 feed pressure.

During the first 1,150 hours and prior to the first clean, there was a rapid increase in feed pressure in the first stage. Following the first clean, the initial feed pressure significantly decreased and again increased rapidly until the second clean at 1,950 hours. After this clean, the pressure recovered and again increased rapidly; however, the temperature was also declining during this period.

Figure 110 shows the differential pressure for the entire system, the Stage 1 differential pressure, and the Stage 2 differential pressure. Linear regressions were performed on the data to determine the hourly pressure loss rate for the membranes between cleans.

***Stage 1.*** As the figure suggests, there was a rapid increase in the differential pressure. Based on the increase in differential pressure, a high pH clean using sodium hydroxide was performed at 1,150 hours. As the figure illustrates, the differential pressure was not recovered to the initial differential pressure of approximately 10 psi.

# Figure 108. Flux and Recovery; High Recovery System Interstage Comparison

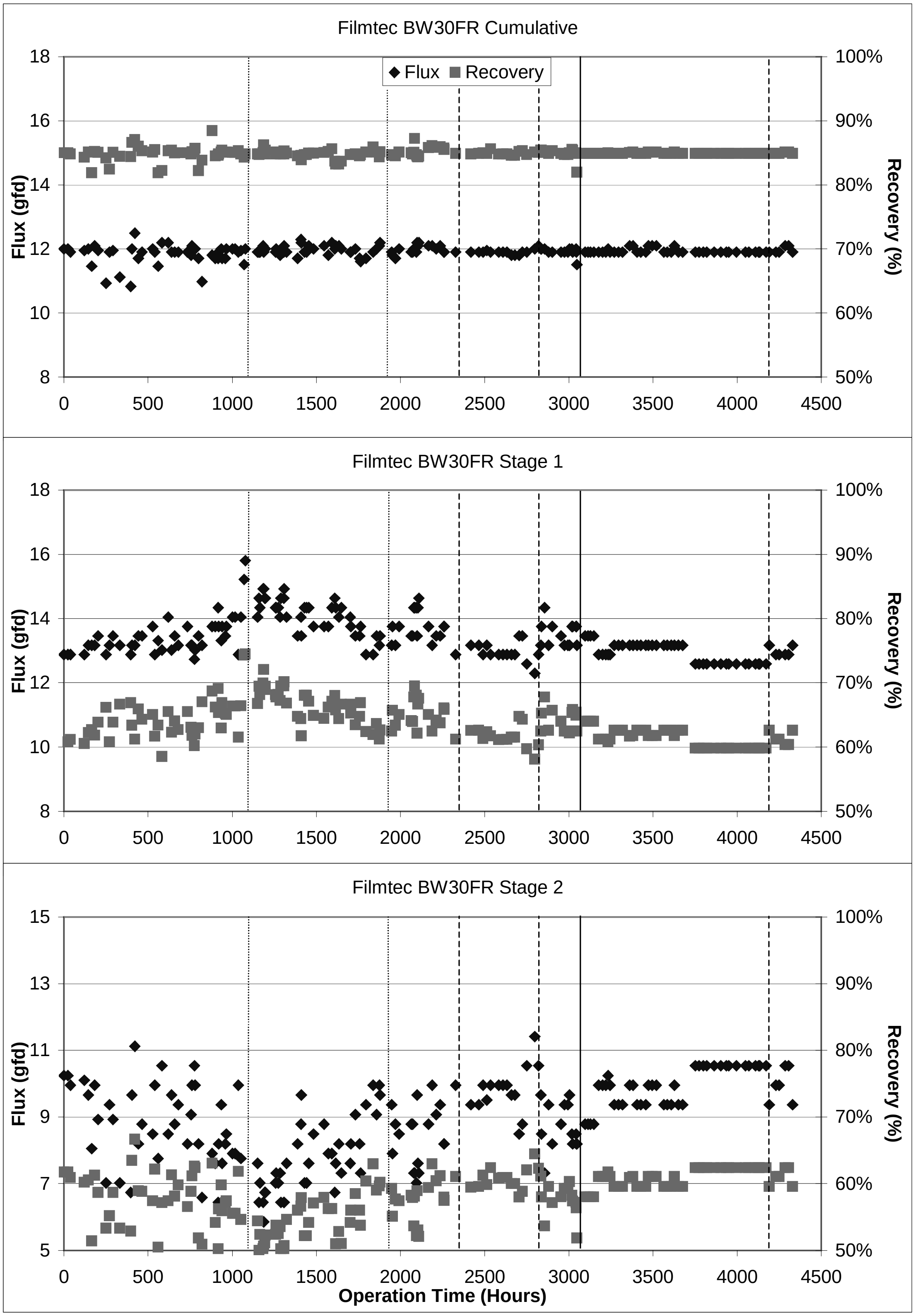
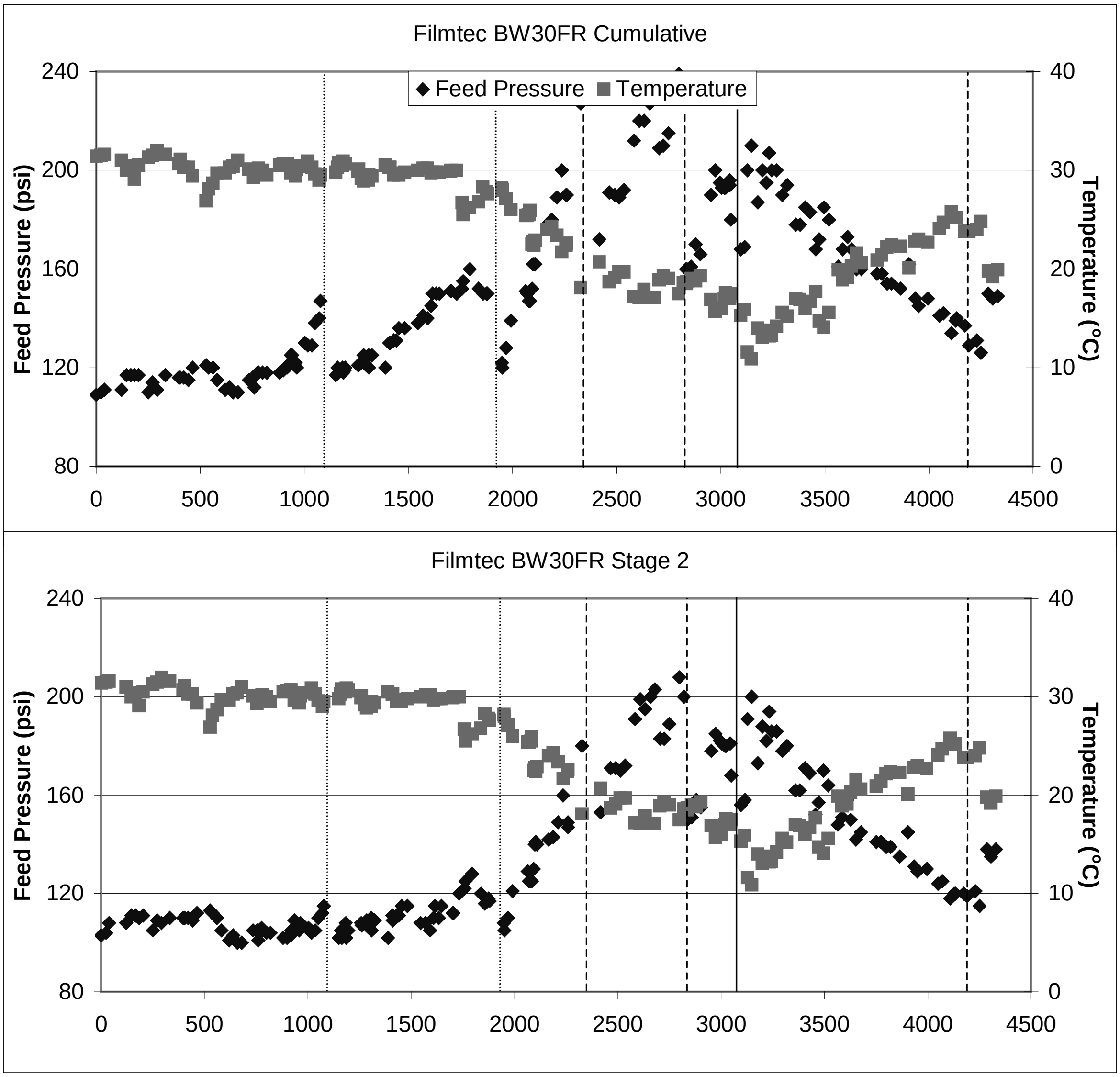


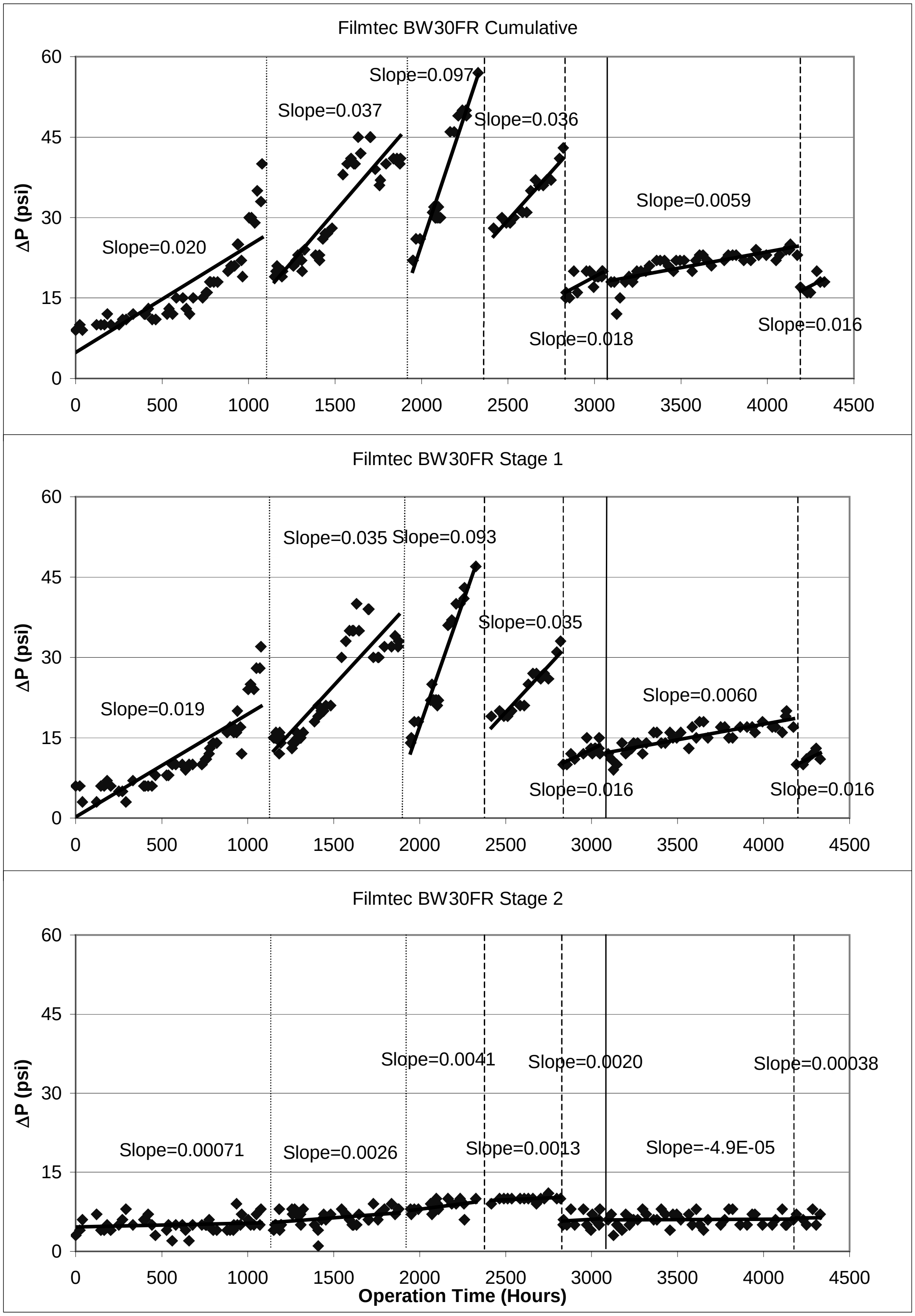
**Figure 109. Feed Pressure and Temperature; High Recovery System Interstage Comparison**




Following this clean, the rate of differential pressure loss was approximately twice as high. Based on this rate of fouling, the BioGuard dosing was halted and chloramine dosing began. This change did not seem to have an effect on differential pressure.

Based on the differential pressure, another high pH clean was performed at 1,950 hours. After this clean, the rate of differential pressure increase was approximately 2.6 times higher than the previous rate.

**Figure 110. Differential Pressure; High Recovery System Interstage Comparison**



Because of these increasing rates of fouling, a high pH clean was performed followed by a low pH clean at 2,370 hours. Generally, high pH cleans will remove organic fouling on the membranes while low pH cleans will remove iron fouling on the membranes. The clean conducted at 2,370 hours resulted in a decreased rate of fouling. The high pH/low pH clean at 2,820 hours again resulted in a lower rate of fouling.

The membrane system was shutdown at 3,050 hours, cleaned at high pH, and preserved with sodium bisulfite. The system was restarted approximately one month later. An upset in the treatment and a malfunction with the pretreatment control systems occurred at 3,060 hours, directly after startup. This resulted in poorly treated water at a low pH and high iron concentration being supplied to the system at a high pH.

Due to this upset, a thorough clean of the system was initiated. The clean consisted of a low pH clean, followed by high pH clean, followed by a low pH clean. Following this clean, the membrane had the lowest rate of fouling during testing, with a differential pressure loss rate of 6 psi every 1,000 hours of operation.

Finally, prior to the end of testing, a low pH/high pH clean was done at 4,170 hours. The data suggest a rapid increase in differential pressure; however, the previous runs showed a similar rapid increase in differential pressure following the clean a stabilized rate of differential pressure loss occurred after approximately 100 hours of operation.

***Stage 2.*** The Stage 2 differential pressure was very stable except for small increases that occurred during the operating period from 1,780 to 2,370 hours. A dramatically higher rate of feed/concentrate spacer fouling in the first stage of a multi-stage RO system is characteristic of biofouling, where bacterial colonization and growth occurs preferentially in the first stage because of higher rates of nutrient delivery to the membrane surface (higher flux). This differential pressure trend exhibited by the high recovery system, is consistent with the results of the lead element selection and continued single element testing phases, clearly indicating that biofouling was occurring while the high recovery system was receiving feed dosed with BioGuard. Biofouling is generally difficult to control and, after restart of chloramination, required an aggressive cleaning regime to control the continued impact on differential pressure.

Figure 111 presents NPF data as a function of operating time for the system and individual stages. As with the differential pressure, the NPF was progressively worse following every caustic clean. Once low pH cleans were combined with high pH cleans, the loss rate in NPF became progressively better.

The lowest rate of NPF loss was observed during testing from 3,080 to 4,170. Further, the NPF increased in Stage 2 during this time.

The most important finding from the NPF data is that once the biofouling was brought controlled using chloramination and a cleaning regime using both high and low pH solution was employed, NPF was restored to start-up levels and the rate of decline in NPF was significantly reduced.

Figure 112 illustrates the DPC change, which accounts for changes in flow rate. The trends in DPC were consistent with those observed and described earlier for differential pressure based on only minor differences in Stage 1 and Stage 2 feed/concentrate flow rates during the operating period.

Figure 113 illustrates the NSP for the high recovery system.

The NSP showed significant increases through 2,300 hours of operation. Most of this increase occurred in the first stage and is attributed to biofouling occurring from BioGuard use and the absence of chloramines during the initial 1,300 hours of operation. Biofouling is most pronounced in the first stage of a two-stage system and the impact on RO performance continues even after further growth in arrested. The NSP also increased, although less dramatically, in Stage 2. The cause of the increase is not clear, but could be attributed to minor fouling by iron oxides or iron/organic complexes or a combination.

During the testing from 3,060 hours to 4,170 hours, the rate of salt passage increase was 3.7E-06 percent/hr or a 3.2 percent increase every year.· The lowest rate of increase was in Stage 1 with the highest rate occurring in Stage 2. This indicates that biofouling was not the primary cause of the salt passage increase, but is the cause of some other form of fouling related to an increase in the concentration of foulant in the system. The primary fouling was potentially iron-based (iron becomes less soluble at higher concentration and at the higher pH occurring in the second stage), perhaps in association with organics. The beneficial impact of low pH cleanings conducted beginning at 2,370 hours further supports iron-based fouling.

**Figure 111. Normalized Product Flow; High Recovery System Interstage Comparison**

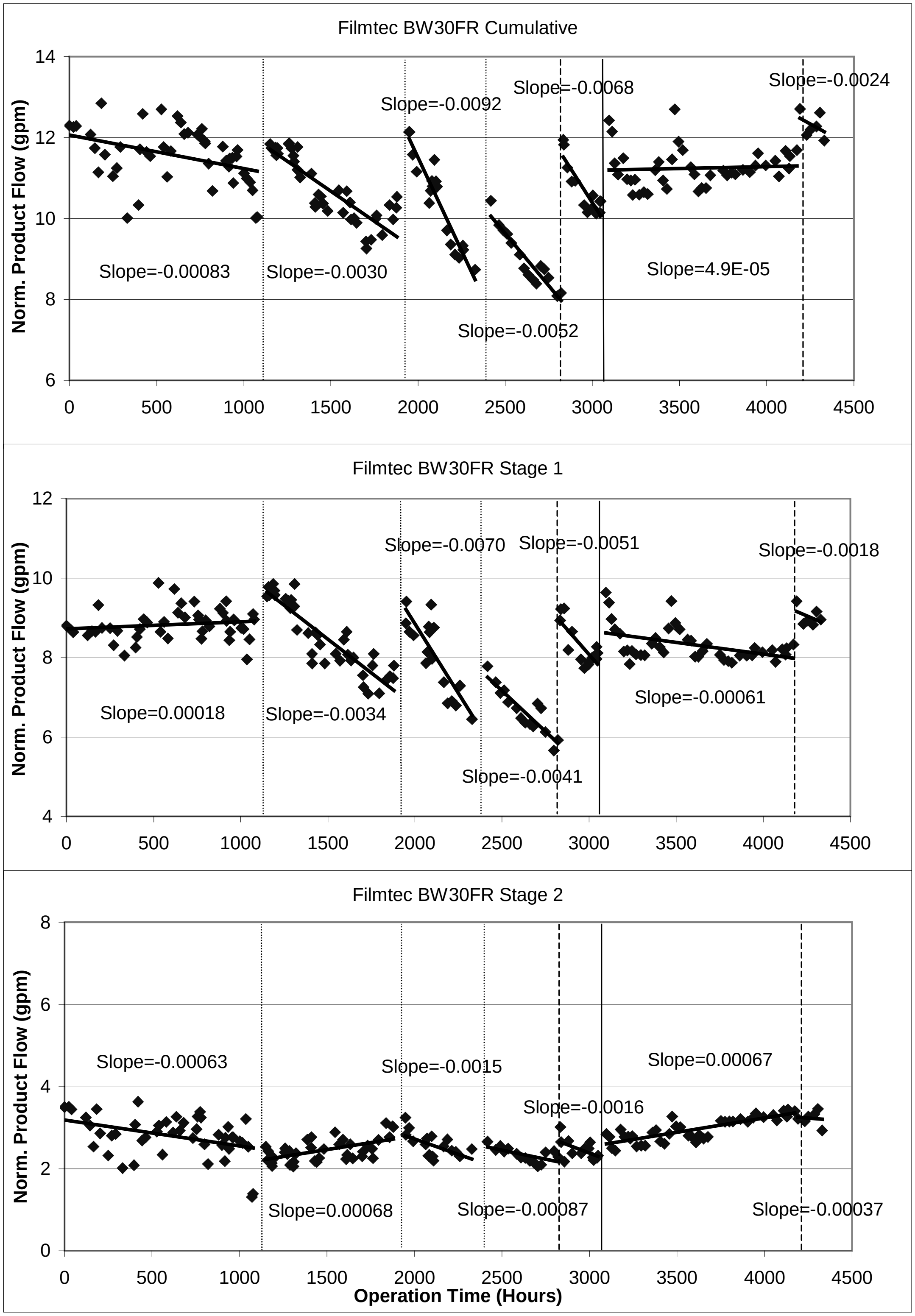


**Figure 112. Normalized Differential Pressure Coefficient Change; High Recovery System Interstage Comparison**

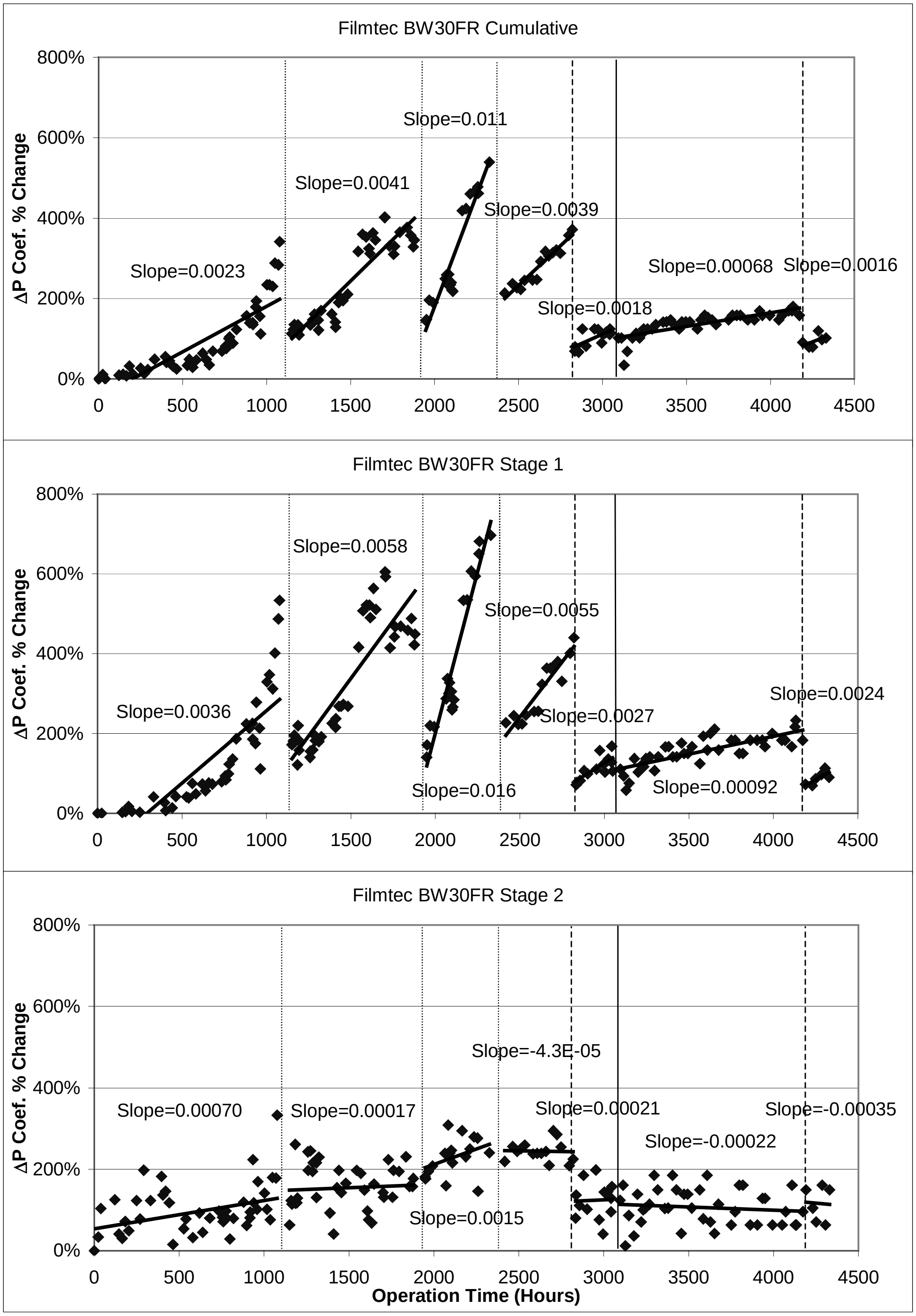
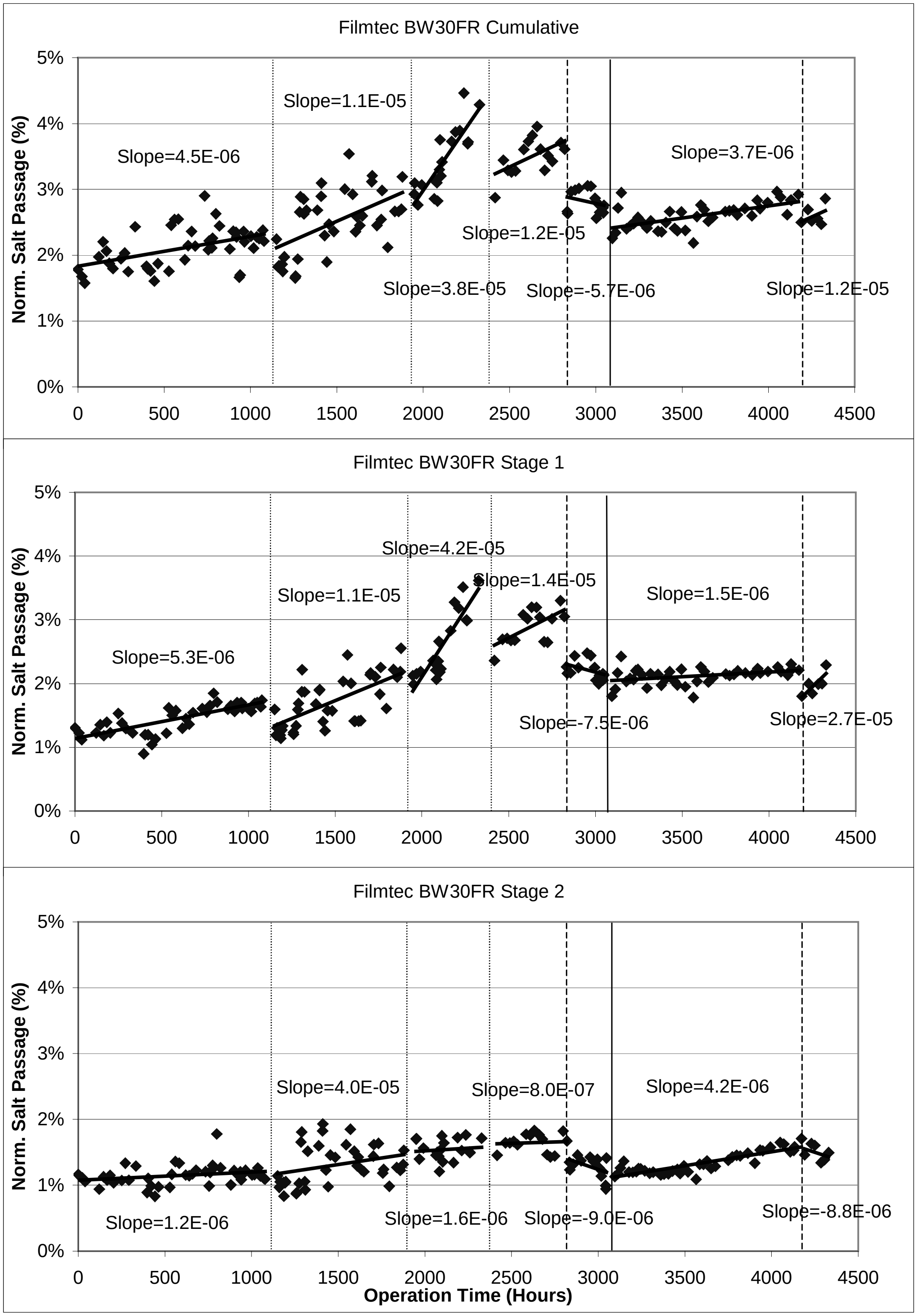


**Figure 113. Normalized Salt Passage; High Recovery System Interstage Comparison**



The overall system salt passage increase during chloramine testing was 2.4E-06 percent / hr (2.1 percent / year) from the period of 3,060 to 4,330 hours, after performance had been restored to the system by effective low pH / high pH cleans.

This represents operation at the optimized conditions conducted during this final testing period.

Using this rate of salt passage increase, suggests a total increase over a five year period of operation would be 12.8 percent, starting from the NSP at 3,060 hours (2.3 percent + 2.1 percent / yr * 5 yrs).

#### *Low Recovery Membrane Performance*

Low recovery testing was performed on three membrane types. The low recovery data allows for comparison of the BW30LE, X-20, and SG with the first vessel of the high recovery containing the BW30FR.

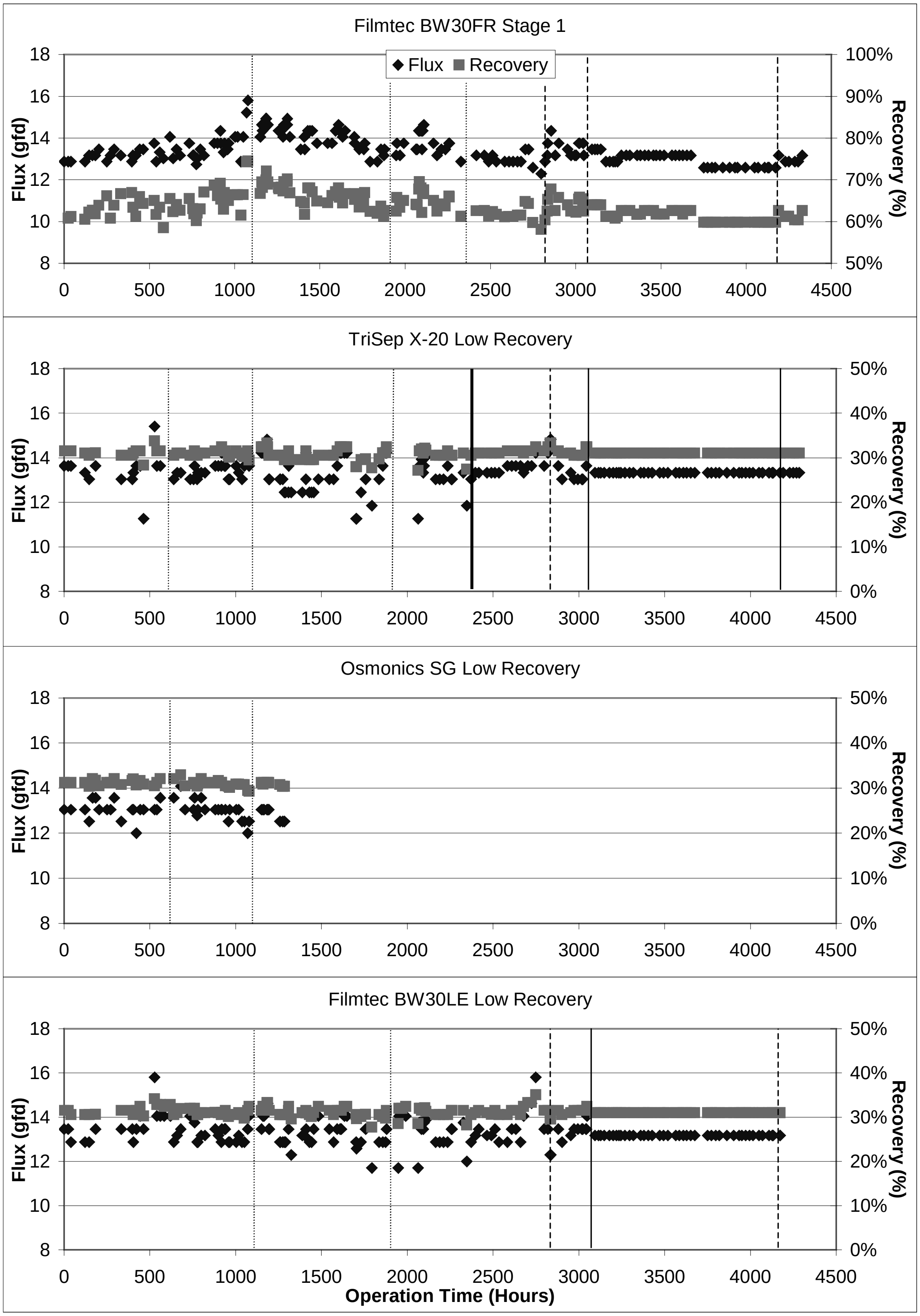
Table 85 summarizes the average flux and recovery of the membranes. As indicated in the table, the average flux during testing ranged from 13.0 gfd to 13.4 gfd. The average recovery for all systems was approximately 31 percent to 32 percent. The coefficient of variance suggests stable flux and recovery.

**Table 85. Flux and Recovery; Low Recovery and Stage 1 High Recovery Comparison**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance |
|---|---|---|---|---|---|---|
| **BW30FR Stage 1 Flux** | **(gfd)** | 13.4 | 15.8 | 12.3 | 0.6 | 0.05 |
| **BW30FR Recovery** | **(%)** | 32% | 37% | 29% | 2% | 0.05 |
| **LR 1 BW30LE Flux** | **(gfd)** | 13.3 | 15.8 | 11.7 | 0.6 | 0.04 |
| **LR 1 BW30LE Recovery** | **(%)** | 31% | 35% | 28% | 1% | 0.03 |
| **LR 2 X-20 Flux** | **(gfd)** | 13.4 | 15.4 | 11.3 | 0.6 | 0.04 |
| **LR 2 X-20 Recovery** | **(%)** | 31% | 34% | 27% | 1% | 0.03 |
| **LR 3 SG Flux** | **(gfd)** | 13.0 | 14.1 | 12.0 | 0.4 | 0.03 |
| **LR 3 SG Recovery** | **(%)** | 31% | 33% | 29% | 1% | 0.02 |

Figure 114 illustrates the flux and recovery of the first vessel of Stage 1 and the three low recovery vessels. As the figure illustrates, the BW30LE, SG, and X-20 were tested in parallel to the BW30FR.

**Figure 114. Flux and Recovery; Low Recovery and Stage 1 High Recovery Comparison**



Perforated lines on the figures represent high pH caustic cleans, dashed lines represent high pH / low pH cleans, and the solid line represents the shutdown of the system at 3,050 hours and the low pH / high pH / low pH clean following the system shutdown.

The X-20 was replaced at 2,370 hours, represented by a solid line on the X-20 section of the figure. The figure further illustrates the discontinuation of SG testing at approximately 1,285 hours.

Flux and recovery were held constant in the low recovery vessels; however, because it was not possible to balance flow between stages in the high recovery, the Stage 1 flux and recovery varied.

Figure 115 summarizes the feed pressure and temperature during testing. As the figure shows, the initial feed pressure for the BW30FR was approximately 110 psi. The initial pressure for the BW30LE was approximately 80 psi, 30 psi lower than the fouling resistant BW30FR.

The initial pressure for the SG was approximately 140 psi and the initial pressure for the X-20 was 120 psi.

Figure 116 illustrates the differential pressure for the low recovery membrane testing. Linear regressions were done for each set of data between membrane cleans to illustrate the change in differential pressure for each data set.

The figure illustrates that high pH / low pH cleans at operation times of 2,370, 2,820, and 3,080 hours were more effective at recovering differential pressure. Further, the rate of differential pressure loss was much lower following high pH / low pH cleans consistent with the impact of such cleans on the high recovery system.

The X-20 was replaced at 2,370 hours to show the effect of a new membrane without any fouling, for comparison to the elements that had been fouled during the first 2,370 hours of operation.

Figure 117 illustrates the NPF for the low recovery systems. The NPF accounts for changes in temperature and osmotic pressure.

As with the differential pressure, the NPF was progressively worse following every caustic clean. Once low pH cleans were combined with high pH cleans, the rate of loss in NPF became progressively better.

The lowest rate of NPF loss was observed during testing from 3,080 to 4,170. Further, the NPF increased in Stage 2 during this time.

## Figure 115. Feed Pressure and Temperature; Low Recovery and Stage 1 High Recovery Comparison

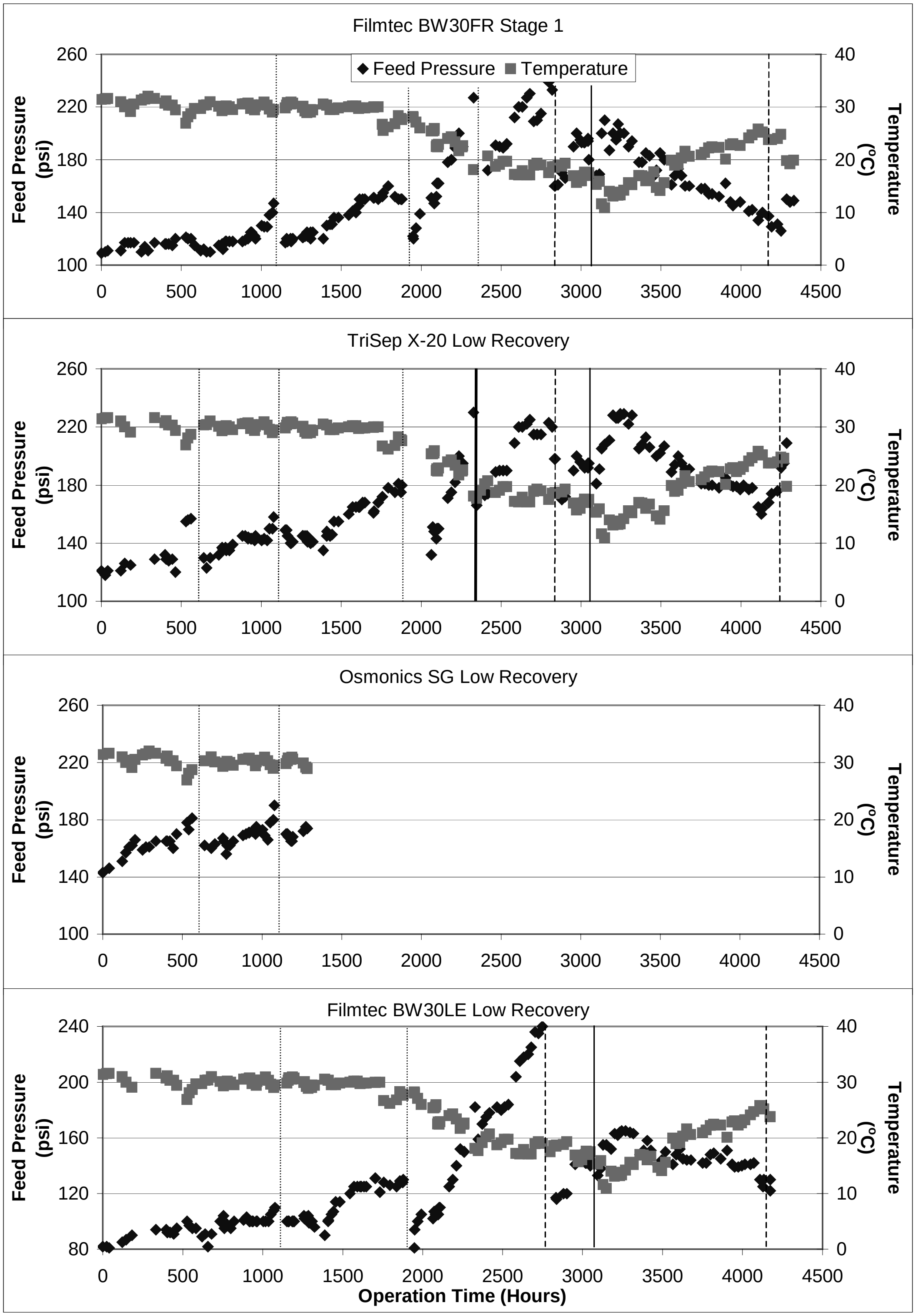


**Figure 116. Differential Pressure; Low Recovery and Stage 1 High Recovery Comparison**

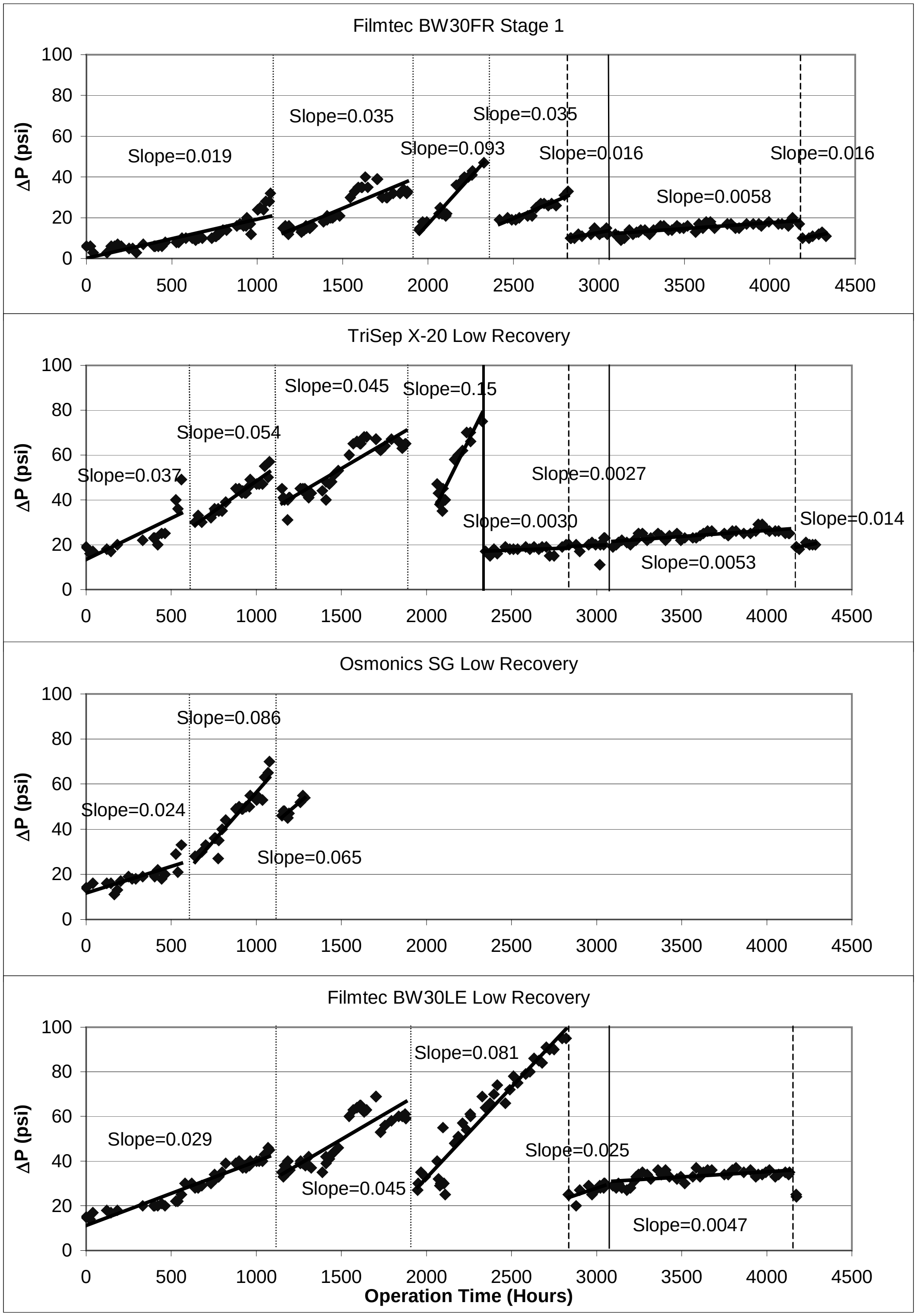
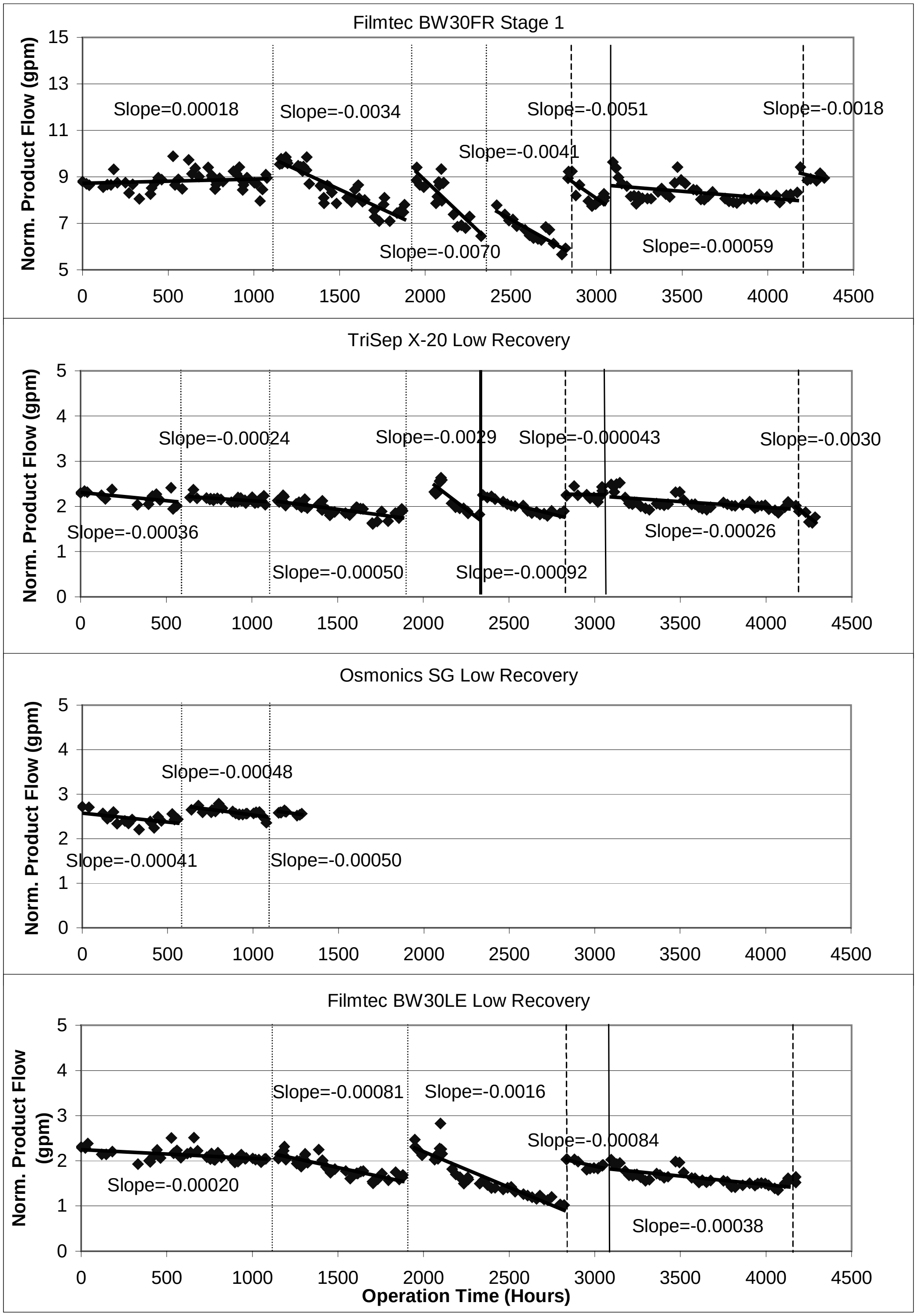


**Figure 117. Normalized Product Flow; Low Recovery and Stage 1 High Recovery Comparison**



Following replacement at 2,370 hours, the X-20 had the lowest rate of NPF loss when compared to the BW30FR and the BW30LE. This is to be expected because the membrane was replaced.

Figure 118 illustrates the DPC change, which accounts for changes in flow rate.

Again, DPC change was progressively worse following the high pH cleans. After the high pH cleans were coupled with the low pH cleans, the DPC change significantly decreased.

The lowest rate of increase for the systems occurred after the clean at 3,080 hours.

Following the replacement of the X-20 at 2,370 hours, the X-20 had the lowest rate of DPC increase.

Figure 119 illustrates the NSP for the low recovery systems. The NSP accounts for changes in pressure, temperature, and osmotic pressure.

As the figure illustrates, when using BioGuard, all systems showed an increase in salt passage. Following high pH clean at 620 hours, the SG had a higher rate of salt passage while the X-20 had a lower, but still unacceptable rate of salt passage.

Chloramines were started at 1,285 hours. After this change in operation, the increases in salt passage increased. Salt passage increases were reduced once the high pH / low pH cleans were started.

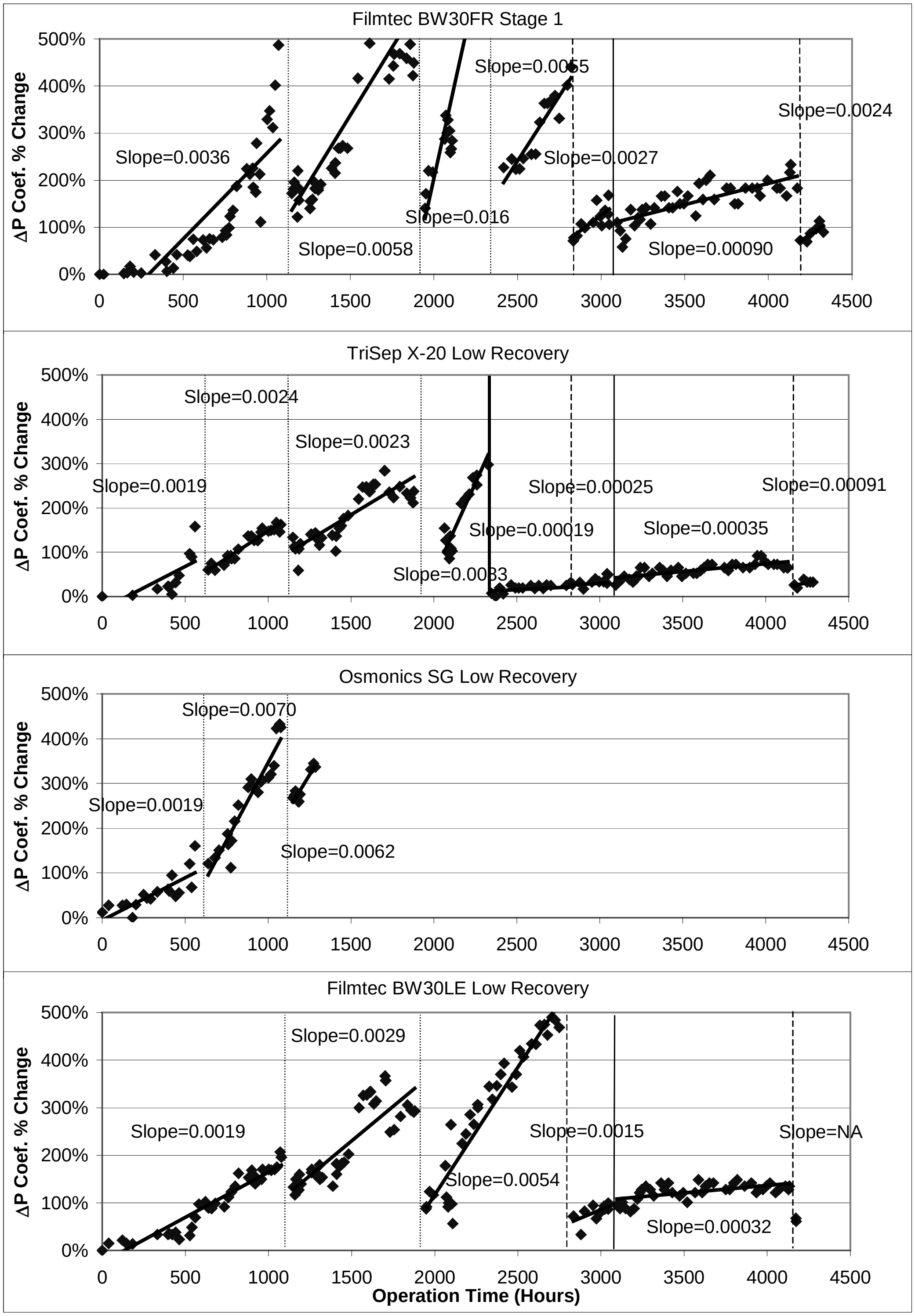
After the clean at 3,080 hours, there was a slight decline in salt passage for the X-20, while there was an increase in the BW30FR. The X-20 operated at low recovery actually had a decline in salt passage during testing. However, a salt passage increase is likely as evidenced by single element testing with the X-20.

The BW30LE had an unacceptable rate of salt passage increase regardless of membrane cleans, biological fouling control, and operation.

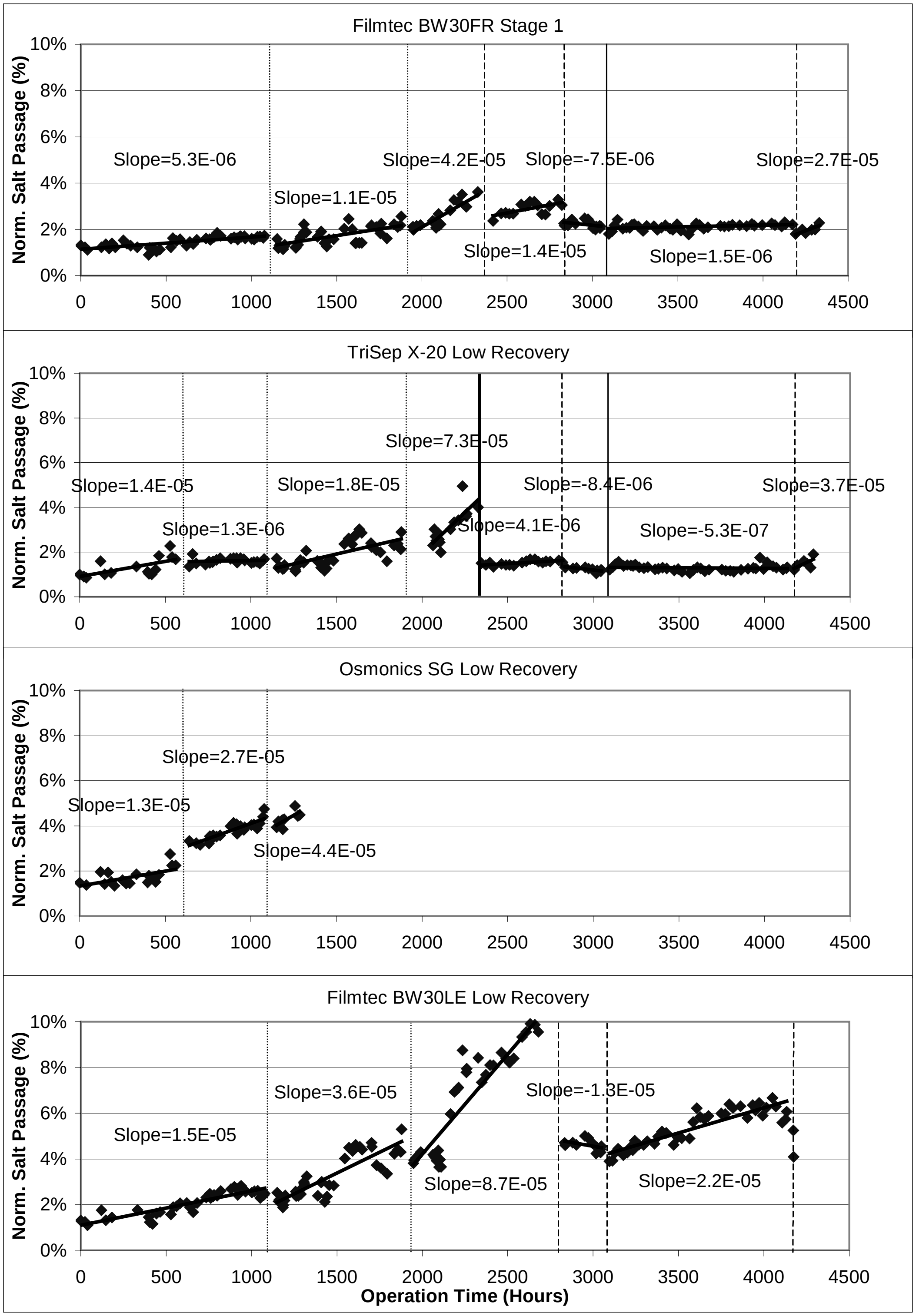
### Conclusions

The purpose of this testing was to obtain additional comparative performance data on the three membranes carried forward from the lead element selection phase (BW30FR, SG and X-20) and to evaluate the suitability of a non-fouling RO membrane (BW30LE) in side by side testing on a common feed water. Additionally, an alternative biofouling control method (BioGuard) was evaluated.

## Figure 118. Differential Pressure Coefficient Change; Low Recovery and Stage 1 High Recovery Comparison



## Figure 119. Normalized Salt Passage; Low Recovery and Stage 1 High Recovery Comparison



From the results of this testing, it can be concluded that the SG and BW30LE membranes are not acceptable for consideration at full-scale based on their poor performance relative to salt passage and differential pressure. Only the BW30FR and X-20 demonstrated acceptable performance stability with respect to salt passage and cleaning efficiency.

As importantly, the performance of the X-20 element installed at 2,370 hours and operated on chloramines was very stable with respect to all performance parameters. Fouling that reduced NPF and increased DPC could be effectively reduced using a chemical cleaning protocol of caustic followed by acid cleaning. Further, the rate of increase in NSP was very low and actually showed a decrease in NSP like due to buildup of foulants on the membrane surface.

Consistent with the results from single element testing, BioGuard is not an effective biofouling control agent for pretreated Lake Monroe water and will not be considered for full-scale use.

**AF/FTIR Analysis of Selected RO Elements**

To further investigate the cause of the unusual changes in membrane performance (increasing NPF and NSP) that were encountered during operation on chloraminated feed water, upon conclusion of the field testing, the following RO elements from both the single element and large RO unit were autopsied by the CH2M HILL Applied Sciences Laboratory and membrane sections removed for further analysis:

- New 15 gfd BW30FR from flux evaluation
- New 12 gfd BW30FR from flux evaluation
- Original BW30FR from pretreatment evaluation through the flux evaluation
- First BW30FR element in the first vessel of the high recovery system
- Last BW30FR element in the last vessel of the high recovery system
- First X-20 element in the low recovery vessel

The membrane sections, along with a section from a new BW30FR element (the FR control), were shipped to the Research and Development Group at the Orange County Water District, Fountain Valley, California. There small swatches were extracted from each membrane section. Swatches of the previously-operated elements were sonicated to remove any foulants. All swatches were then analyzed by attenuated total reflectance Fourier transform infrared (ATR/FTIR) spectroscopic analysis. The objective of the analysis was to determine if exposure of the membrane elements to combined chlorine through operation on chloraminated feeds caused changes to the polyamide thin film indicative of chlorine oxidative damage.

Two changes are commonly observed in the spectra of the polyamide layer when the membrane undergoes oxidation by chlorine. The peak exhibited by the amide II N-H bending band drops slightly and shifts significantly to a lower wave number and the peaks representing the C=C ring stretching vibrations drop in intensity. The change in amide II bending is caused by substitution of chlorine for hydrogen on the amide molecule and is reversible. The change in C=C ring stretching is caused by substitution of the chlorine for hydrogen on the benzene ring at multiple locations and is irreversible.

The results of the analysis, along with a description of the methods materials and data interpretation are presented in Appendix D.

The AFR/FTIR results suggest the following:

- No change was observed in the C=C ring vibrational peaks suggesting that no chlorine substitution had occurred on the benzene ring.
- The peak of the amide II bending band decreased in approximate proportion to the degree (loading) to which the membrane was exposed to chloramines. The greatest reduction in peak was observed for the membrane removed from the single element operated for nearly 6,000 hours on chloramines (SP/AF pretreatment), while the least reduction in amide II peak was measured for the elements operated in the large RO unit and at 15 gfd during the flux evaluation.

To illustrate, the difference in amide II peak, the AFR/FTIR results for the single element operated for over 6,000 hours is illustrated in Figure 120. The same results are shown for the single element operated for only 1,250 hours (at a flux of 15 gfd) during the flux evaluation and for the X-20 element operated for

1,960 hours in the low recovery system in Figure 121 and Figure 122. A line is shown from the amide I peak (not affected by chlorine oxidation) to the amide II peak to illustrate the reduction in amide II peak. For the new BW30FR membrane, the slope of the line is positive. For the BW30FR exposed to chloramines for >6,000 hours, the slope is clearly negative. Table 86 summarizes the results for the amide II peak impact based on change in slope for all elements analyzed using AFR/FTIR.

It cannot be firmly concluded that the reduction in amide II peak is clear evidence that chlorine substitution occurred nor that such substitution produced the observed performance changes seen with chloramination. However, if chlorine substitution did occur only on the amide II molecule, this substitution is reversible in the presence of a reducing agent. It is not without possibility that the changes in membrane performance might be reversed by exposure to bisulfite. This could be evaluated by UCF through carefully controlled bench tests to determine if a best management practice using periodic bisulfite dosing would control increased salt passage and extend membrane life.

Also illustrated at the bottom of Figure 120, Figure 121, and Figure 122 is the spectra for a Hydranautics ESPA1 membrane that encountered irreversible loss of salt rejection on the order of 20 percent (increased salt passage) from exposure to chloramines in the presence of iron.[15] The spectral changes are evident for shift in amide II peak and reduction in intensity for C=C vibrational bands at 1610 and 1440 $cm^{-1}$.

### Overall Conclusions

Based on all of the membrane field testing, the following conclusions can be drawn regarding the pretreatment (including biofouling control) and RO membrane evaluations.

All three pretreatment trains (UF, SuperP, and Actiflo high rate clarification followed by GMF) are acceptable for full-scale use in pretreating Lake Monroe water. Each will provide an RO feed water of appropriate turbidity and SDI; however, UF provides a lower and more consistent SDI feed. The differences observed in SDIs did not translate into distinct differences in the rate of fouling of the single elements.

[15] Spectra for this analysis was provided courtesy of the Metropolitan Water District of Southern California.

**Figure 120. AFR/FTIR Results for BW30FR after 6,000 hrs of Operation**

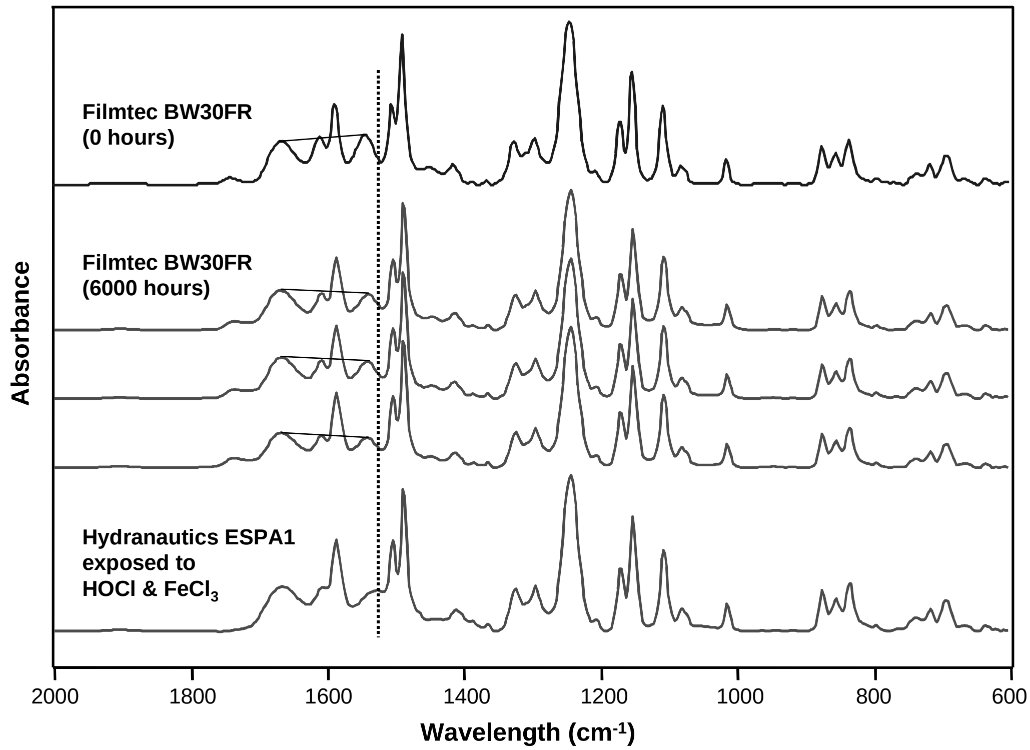



**Figure 121. AFR/FTIR Results for BW30FR after 1250 hrs of Operation**

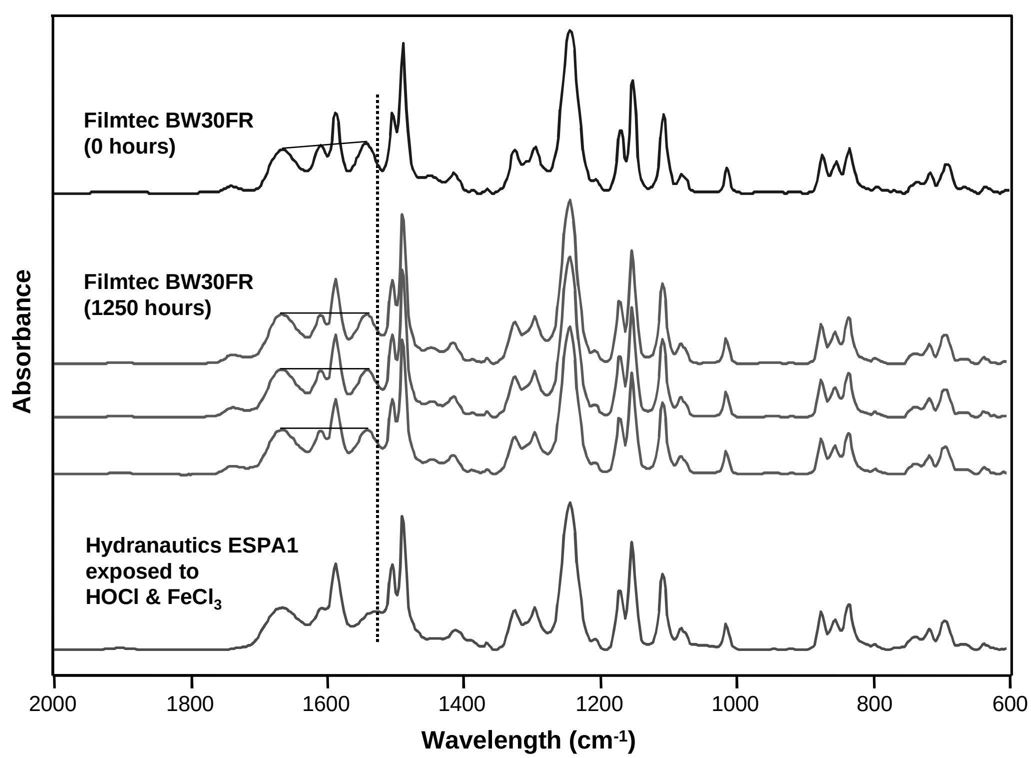


**Figure 122. AFR/FTIR Results for X-20 after 1960 hrs of Operation**

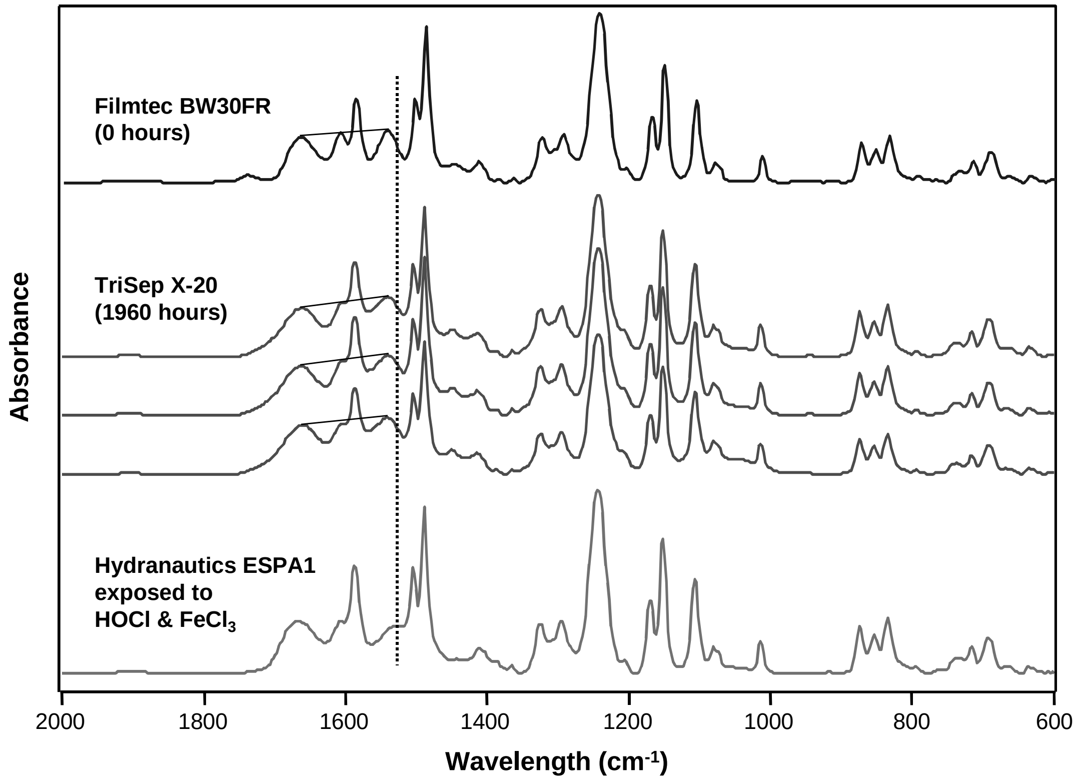



**Table 86. Amide I to Amide II Slope Between Peaks**

| Membrane | System | Hours of Operation (hours) | Chloramine Loading ($mg\text{-}Cl_2/L*hr$) | Amide I to II Slope |
|---|---|---|---|---|
| BW30FR | First element in the first vessel of high recovery system | 4330 | 5265 | + |
| BW30FR | Last element in the last vessel of the high recovery system | 4330 | 5265 | + |
| BW30FR | Original from pretreatment evaluation through flux evaluation | 6000 | 9097 | - |
| BW30FR | New element at 12 gfd from flux evaluation | 1250 | 2200 | No change |
| BW30FR | New element at 15 gfd from flux evaluation | 1250 | 2200 | No change |
| TriSep X-20 | First element in the low recovery vessel | 1960 | 3528 | + |

Using the single elements for flux evaluation, a flux of 15 gfd was achievable; however, at this time a flux of 12 gfd is recommended, since the majority of RO data was collected at a flux of 12 gfd. Although, no direct tests were conducted with polymer and flux rates, all of these flux data used for this recommendation were collected in the presence of polymer. The polymers required for treatment with Actiflo and SuperP were medium charge density cationic polymers. It was not observed that use of either of these polymers affected the membrane performance. However, in full scale implementation care must be exercised to prevent overdosing of polymer in these units that may cause unacceptable loss of membrane performance. The use of the polymer was carefully monitored during the use of this pilot study.

Chloramination of the pretreated Lake Monroe water is necessary to control biological (bacterial) fouling, both on the RO membranes and the cartridge pre-filters. Where high rate clarification is used, chloramines should be dosed to clarified water to optimize filtered water quality and filter run lengths and to reduce chloramine usage. If direct UF were to be used, chloramination would have to be applied to the UF filtrate. Raw water chloramination is undesirable because it correlated with higher rates of increase in RO membrane product flow and salt passage and is not recommended. The Filmtec BW30FR and TriSep X-20 performed consistently better than the other three elements and are considered appropriate for use at full scale. During single element testing on high rate clarified water, where chloramination was applied to both the raw and clarified waters, the BW30FR encountered more stable salt passage. However, when the X-20 was operated with chloraminated clarified water, the rate of increase in salt passage was very low.

Based on the large RO unit testing data and optimum operating configuration (chloramines and high pH / low pH cleaning regime) membrane fouling by both biofilms and iron oxides can be effectively controlled with respect to all three performance parameters (NPF, DTC and NSP). Based on the latter period of testing (+ 3,100 hours), RO cleaning frequency is estimated at 2,000 hours or greater.

Although chloramination caused an undesirable increase in salt passage during the single element tests, this increase was reversed when chloramination was stopped (Zenon testing). Further, significant increases in salt passage were observed during large RO unit operation without chloramines and element autopsies did not show the type of polyamide film changes previously correlated with irreversible loss of salt rejection due to chloramine addition.

Therefore, considering the single element data as well as the high recovery data, the cause of the increased salt passage is likely a combination of both fouling and chloramination.

To be conservative; the rate of salt passage increase for long term (design) operation was based on the results from both the single elements operated on SP/AF pretreatment using continuous chloramination as well as the high recovery system.

To determine membrane replacement based on salt passage, an analysis was performed to estimate the maximum allowable salt passage rate of increase that would allow a 5 year membrane life. To calculate this increase several assumptions were made:

- Maximum allowable TDS in the permeate is 200 mg/L.
- Maximum raw water TDS is 1,400 mg/L based on historical data collected by the USGS collected during the drought discussed in the Raw Water Characterization. Further, due chemical addition during pretreatment, the maximum feed water TDS is 1,500 mg/L.
- Minimum allowable membrane replacement of 5 years.
- An initial salt passage of 1.5 percent.

Based on the max allowable permeate TDS and max feed water TDS, the maximum allowable salt passage is 13.3 percent through the RO membranes. This translates to a maximum allowable annual rate of increase of 2.4 percent assuming 100 percent membrane treatment.

Based on single element testing of the SP/AF BW30FR, the rate of 0.75 percent increase per year is acceptable for a 5 year membrane life based on the above feed water and permeate water TDS levels. Further, the higher rate of salt passage increase of 2.1 percent per year for the high recovery system would also be acceptable under these conditions. The TriSep X-20 element operated at low recovery had a decrease in salt passage suggesting it would likely not increase to unacceptable levels within 5 years.

It should be noted that this analysis was conducted under very conservative conditions which included a feed water TDS of 1,500 mg/L which has only occurred during the 100-year drought event as well as a low permeate TDS level of 200 mg/L.

# CONCENTRATE MANAGEMENT—LITERATURE REVIEW

## Introduction

### Project Background

In April 2000, the St. Johns River Water Management District (SJRWMD) adopted the District Water Supply Plan (Vergara, 2000). The Plan is designed to address current and future water demands, traditional and alternative water sources, and water supply infrastructure improvements required to meet the water supply needs within the SJRWMD's jurisdiction through 2020. Development of alternative water sources such as surface water and brackish groundwater will be necessary to supply the increasing demands for water in east central Florida. The East Central Florida Water Supply Initiative St. Johns River Water Supply Project is part of that plan. It will focus on evaluating surface water withdrawn from the St. Johns River as an alternative or supplemental source of water supply for portions of Seminole and Volusia counties. In Phase I, three projects will identify plant locations, facilitate design through a Pilot Plant project and other assessments, and determine the costs of a surface water treatment facility (or facilities).

Because surface water is inherently variable in both quantity and quality, water quality monitoring and treatability studies are required before adequate surface water withdrawals, treatment, and storage systems can be designed. As part of the St. Johns River Water Supply Project, CH2M HILL was commissioned to conduct the Surface Water Treatability and Demineralization Concentrate Management Study. The purpose of the study is to determine how to treat the surface water to drinking quality standards and how to manage the waste products(Reverse Osmosis concentrate) of that treatment. The development of options and costs of for treatment to other standards, such as for reuse system augmentation and for recharge into the aquifer will be evaluated.

## Purpose of Task I

Task I of the Surface Water Treatability Project is a literature review summarizing recent technical information related to the impacts and management of low salinity waste concentrate and a synopsis of the hydrologic and biologic characteristics of the project reach of the St. Johns River.

A comprehensive review of management of salinity wastes and a literature search product were developed in Technical Memorandum C.2*, Demineralization Concentrate Management Plan,* (Reiss Environmental, Inc. 2002) submitted October 2002. Rules and regulations associated with concentrate management were detailed in Technical MemorandumB.5, *Applicable Rules and Regulations (Reiss Environmental, Inc. 2001)* submitted to the District in November 2001. The discussion of concentrate disposal presented here relies heavily on those two documents.

## Overview of Concentrate Disposal Options

Demineralization concentrate is the by-product produced when brackish water is treated with a pressure-driven membrane process such as reverse osmosis or nanofiltration. This process removes minerals from the water and concentrates them in a waste stream. The resulting concentrate must be managed in an environmentally safe manner (Mickley, 1996; 2001). Plant and process design may be important factors in the ability to create a safe disposal (e.g., Gluecksterna and Priela, 1997). Developing a plan to manage the concentrate involves careful analysis of many factors. Potential concentrate disposal methods include the following (Andrews and Witt, 1993; Reiss Environmental Inc., 2002):

- Placement in deep injection wells
- Discharge to surface waters
- Spreading over land surfaces
- Discharge to wastewater treatment facilities
- Reuse of the waste product

The full range of inland concentrate disposal options includes both technologically complex and relatively simple solutions (Andrews and Witt, 1993; Electric Power Research Institute, 1994; Squire et al., 1997). The SJRWMD has identified surface water discharge to the St. Johns River as the most favorable concentrate disposal option to consider based primarily on the river water quality and on the expected concentrate water quantity and quality. A withdrawal quantity of about 50 million gallons per day (mgd) is estimated from the St. Johns River within the next 10 years. A concentrate discharge volume of about 10-mgd is predicted for disposal. These are preliminary estimates and quantities could change, depending on further evaluations.

A Microsoft (MS) Access database (Membrane_Plants) was developed that provides a summary of all 57 facilities permitted to discharge demineralization concentrate in Florida (Reiss, October 2002). The database table *tblPlant* contains detailed information and requirements for existing permitted facilities that is useful for comparison of the proposed St. Johns River facility. The database includes a summary of information regarding source water quality, concentrate disposal, and permitting requirements. Currently, there are no facilities in Florida that are similar to the proposed facility with regard to facility size, source water quality, and proposed concentrate disposal type. Most facilities use groundwater as a source and injection wells or ocean discharge for concentrate disposal. There are 57 desalination water treatment plants (WTPs) in Florida with capacities greater than 0.1 mgd. None currently use brackish surface water (Reiss Environmental, 2002) or discharge to those waters or other Class III surface waters. Thus the envisioned application is without precedent in this state.

The regulatory approach to disposal of RO concentrate has been treated very differently through time and in different states (e.g., Andrews et al., 1991; Baker et al,. 1990; Conlon 1994) a proposed discharge to the Middle St. Johns River (including Lake Monroe) would likely require a National Pollutant Discharge Elimination System (NPDES) permit under the industrial wastewater facilities rules. This is because this reach is designated as a Freshwater Class III water body - chloride concentration is less than 1,500 milligrams per liter (mg/L) (F.A.C. 62-3.200), although the river downstream of Lake Monroe does have periods of reversed (upstream) flows. As noted in Reiss Environmental (2001), "…each situation is unique and the regulations are complex." That report reviews the subjects of the discharge compliance review, which include antidegradation, water quality-based effluent limits (WQBELs), surface water criteria, mixing zone criteria, toxicity, and issues of existing impairment in the receiving water body. There is potential for major ion toxicity in an RO concentrate (e.g., Mickley, 2001) which is a field of active investigation. The applicability of standard toxicity testing to brackish concentrate has been a long-standing subject of discussion, (e.g., Potts and Weingberg, 1993) but as yet no standard method or methods have been developed and accepted.

Different mixing zone standards probably would apply to the riverine sections of the study area and to Lake Monroe (62-4.244. *Florida Administrative Code* [F.A.C.]). Riverine mixing zones are defined as a specific distance downstream of the discharge source. A lake mixing zone is a defined as a specific area around the pipe end. The particular hydraulic conditions at potential discharge sites may have to be carefully compared to identify the alternative that minimizes environmental impacts.

The current regulation of concentrate disposal in Florida (summarized in Kimes, 1994; Thomas, 1995; and Mandrup-Poulsen, 1997)) were recently amended. Florida Senate Bill 536, signed in June 2001, amended the Florida statutes to allow the Florida Department of Environmental Protection (FDEP) to address demineralization rules in ways that would ease concentrate disposal concerns specifically related to “the presence of constituents identified … as naturally occurring in the source water” (Reiss Environmental, 2001). Applicable rule changes are still under consideration. The ultimate result should be regulation that provides a clearer (and perhaps less onerous) permitting process for demineralization concentrate management. These changes will include specific consideration of toxicity test failure due to naturally occurring constituents.

In summary, a potable water RO facility could be permitted in the middle St. Johns River, assuming it met the requirements in F.A.C. 62 for an NPDES permit. This may be an lengthy process, but there may be regulatory changes to the rules governing such a permit that will reduce the effort needed to achieve regulatory satisfaction.

## Literature Review

### Overview

A critical component involved in the implementation of this Surface Water Treatability Project involved conducting a comprehensive literature review. In addition to providing a synopsis of the hydrologic and biologic characteristics of the project reach in the St. Johns River, this literature review summarized technical information related to the impacts and management of low salinity waste concentrate. To effectively perform this review, the team conducted a series of tasks, including the following.

- Develop a bibliographic database.
- Identify current related projects and studies.
- Inventory of GIS coverage disaggregated by agency and type of map

These data sources provided the basis to describe the basin characteristics of the St. Johns River, to identify streamflow characteristics, and to describe river water quality and biological characteristics. A description of the database and the GIS information is provided below. Refer to Appendix E for the complete literature review.

**Bibliography Database**

A bibliographic database was developed using MS Access software that allows a search of the documents through various topic listings and tables. The bibliography includes a total of 200 entries, with 50 of these considered most relevant. Each entry contains the name of the author, the date of the publication, and the title of the document. References contained in the MS Access database can be queried to generate the following reports:

- Complete alphabetical listing of all 200 references
- A listing of references within the SJRWMD
- A listing of the 50 most pertinent references
- Topic category - concentrate disposal
- Topic category - water quality
- Topic category - hydrology
- Topic category - biological

Several sources were used to develop this database, including libraries of the Water Management Districts and the U.S. Geological Survey (USGS). Many of the concentrate disposal-related references were obtained from the existing bibliography database prepared by the SJRWMD district-wide concentrate management consultant (Reiss Environmental, Inc.).

Data and references also were obtained by searching the various agency web sites listed below.

- U.S. Environmental Protection Agency (EPA) (www.epa.gov)

- EPA – Surf Your Watershed (www.cfpub.epa.gov/surf/

- USGS (www.usgs.gov)
- U.S. Fish and Wildlife Service (www.fws.gov)
- U.S. Army Corps of Engineers (www.usace.army.mil)
- FDEP (www.dep.state.fl.us)
- Florida Fish and Wildlife Conservation Commission (FFWCC) (www.floridaconservation.org)
- SJRWMD (www.sjrwmd.com)
- Volusia County Environmental Mgmt. (www.volusia.org\environmental\)
- Brevard County (www.natres.countygovt.brevard.fl.us)
- Orange County (www.orangecountyfl.net/dept/CEsrvcs/epd/)
- Seminole County (www.co.seminole.fl.us/envsrvs/)
- Lake County (www.lakegovernment.com/water.htm)
- University of Florida Lake Watch (www.lakewatch.ifas.ufl.edu)

The database is an electronic ACCESS file provided as part of this report.

### Current Related Projects

The following ongoing SJRWMD projects are directly related to the Surface Water Treatability and Demineralization Concentrate Management Study. Project coordination and sharing of data between these projects will mutually benefit their development.

#### Investigation of Demineralization Concentrate Management

The SJRWMD is investigating the feasibility of alternative water supply strategies and has identified brackish groundwater, brackish surface water, and seawater as potential sources of supply to meet future demands (CH2M HILL, 1996a; CH2M HILL, 1996b). These alternative water sources will require treatment using demineralization technologies. These technologies are primarily pressure-driven membrane processes that include reverse osmosis or nanofiltration. During this process, minerals in the source water, including salts, are removed, producing potable water as well as a by-product known as demineralization concentrate.

Developing acceptable management strategies for demineralization concentrate is the goal of the Investigation of Demineralization Concentrate Management Project. In addition, the project will identify any required technical studies, data collection, or analysis needed to formulate, implement, and monitor the effectiveness of management strategies. A primary component of the Project will be the development of a Demineralization Concentrate Management Plan. The plan will outline environmentally acceptable options for concentrate management.

This project is being coordinated for the District by Reiss Environmental, Inc., of Winter Park and is scheduled for completion in early 2003. The management plan will consider technologies for demineralization, existing disposal projects, environmental and cultural impacts of disposal, current and future regulations, and disposal alternatives.

### Middle St. Johns River Basin SWIM Program

In year 2000, the District's Governing Board established a Surface Water Improvement and Management (SWIM) program encompassing the entire middle basin. Nineteen water segments in the basin are identified as impaired waters on the FDEP 2000 303(d) list (FDEP, 2000). The impairment of those segments reflects a combination of past unregulated land use and waste disposal practices and increased quantities and velocities of stormwater runoff resulting from urban development. There are a number of previous and existing projects in the Middle Basin including work in and around Lake Jesup and the Little Wekiva River as well as an active ecosystem management effort in Lake George. Efforts to improve water quality and to enhance natural systems in the basin will incorporate the Five-Year Lake Jesup Restoration Initiative and the Little Wekiva River Watershed Management Plan.

Two recent studies provide an inventory of existing conditions in the middle basin, which includes an important portion of the project reach of the St. Johns River. URS Inc. prepared an April 2001 report for the SJRWMD titled, *Middle St. Johns River Basin Final Reconnaissance Report (*URS, 2001). This report provides a summary of the issues and activities that exist within the basin and the strategies needed to address them. The elements addressed within this report are water quality, water quantity, ecosystems, and water supply. The report was used as a resource guide in the development of the January 2002 *Middle St. Johns River Basin Surface Water Improvement and Management (SWIM) Plan* (SJRWMD, 2002). The purpose of this plan is define a realistic course of action, identifying the projects and the effort needed to accomplish them, consistent with the levels and trends of SWIM funding. The plan focuses on four initiatives:

- Water quality enhancement, with emphasis on nutrient loading reduction and lake protection
- Watershed master planning, with emphasis on completing hydrologic models of sub-basins
- Stormwater retrofitting of areas built prior to 1983
- Compliance and rule enforcement of the existing permitted stormwater systems

### Minimum Flows and Levels Project

Florida law (Chapter 373, Florida Statutes) requires Florida's water management districts to establish minimum flows for water courses and minimum levels for ground and surface waters that represent the limit at which further withdrawals would cause significant harm to the water resources or ecology of an area. The goal of the minimum flows and levels program is "to establish ecologically based minimum flows and levels that will be implemented through the District's water supply planning, consumptive use permitting, and environmental resource permitting programs and to protect groundwater aquifers, wetlands, water bodies, and water courses from significant harm caused by water withdrawals or diversions." Minimum flows and levels (MFLs) are being developed by the District to ensure that water withdrawals from the St. Johns River will not harm the river, its tributaries, and associated wetlands. Establishing MFLs will help determine how much river water is available for other uses, while protecting the upstream and downstream river system.

The Middle St. Johns River streamflow characteristics currently are being assessed by the District and the USGS as part of a federal-state cooperative program. Minimum flows and levels for the St. Johns River at State Roads 44 and 50 and at Lake Monroe (Mace 2002) are targeted for adoption during early 2003.

### Surface Water Quality Monitoring Program

The SJRWMD's Surface Water Quality Monitoring Program (SWQMP) was established in 1983 and currently maintains a surface water quality monitoring network of 72 stations located throughout the SJRWMD that are sampled 6 times a year. The goal of the surface water monitoring program is "to monitor, assess, and report on the water, sediment, and biological quality of District surface waters." The SWQMP, through its own sampling network and with data acquired by other agencies, performs a District-wide assessment of water quality. This assessment is directed toward: 1) establishing background conditions; 2) determining temporal trends; and 3) identifying areas of poor or affected water quality.

SJRWMD makes a considerable effort to coordinate the District's monitoring activities with those of FDEP, other state agencies, and local governments. The program participates in FDEP's Integrated Water Resources Monitoring (IWRM) Tier 1 Network. Data generated under the program are sent to the EPA's National Water Quality DataBase (STORET) and used by FDEP for Florida's Biennial 305(b) Report. The program provides support for modeling efforts involving surface water quality and produces an annual district-wide assessment of surface water quality status and trends and other assessments.

### Surface Water Treatment Plant Siting Study

As part of the St. Johns River Water Supply Project SJRWMD commissioned HDR, Inc., to conduct a study to determine potential locations for a surface WTP. This work focuses on locating a site for the following WTP elements:

- Plant site
- River intake
- Raw water storage facility
- Demineralized concentrate disposal area
- Pipeline corridors

The study is being conducted using a multilevel screening process. The first two levels will include preliminary screening to determine a general site location and the third level will include a detailed analysis to select a specific site. The primary study area will be located approximately 5 miles either side of the St. Johns River between the outlet at Lake Monroe and the City of De Land.

Three to five candidate sites will be carried forward for a more detailed analysis. This analysis will include an evaluation of natural resource impacts, clarification of land use, and assessment of economic impacts. Cost estimates will be developed for each of the project components for each of the candidate sites. On the basis of this evaluation, the site will be ranked and one candidate site and pipeline corridor will be identified.

### Available GIS Coverages

During the literature review, many geographic information system (GIS) coverages were identified that are available from various government agencies. These coverages may be downloaded from their web sites or obtained through the agency GIS sections. The following GIS coverages may be useful for this project, primarily to evaluate potential environmental constraints.

#### St. Johns River Water Management District

- 2002 Acquisition Map
- Basin and Sub-Basin Boundaries
- Floodplains within SJRWMD
- Flow and Salinity (Hydrodynamics) Models
- Hydrologic Basins and Public Supply Withdrawals in the SJRWMD
- Lake Monroe Conservation Area
- Major Surface Water Programs
- Regionally Significant Habitat in the SJRWMD
- River Lakes Conservation Area
- Roads and SJRWMD
- SJRWMD Major Basins And Planning Units
- Seminole Ranch Conservation Area
- Upper St. Johns River Basin Project
- USJRB Restoration Projects
- Water Quality Status and Trends in Northeast Florida

#### Florida Department of Environmental Protection

- Bathymetry
- Drainage Basins
- Ecosystem management
- Future land use
- FFWCC management areas
- Hydrologic features
- Lakes
- Major rivers

- Manatee protection zones
- Marinas
- Outstanding Florida Waters aquatic preserves
- Parks and recreation areas
- SJRWMD land use
- Special Outstanding Florida Waters
- STORET 305b
- Surface water class boundaries
- USGS gauging stations
- Water quality 303d, 1998
- Water quality 305b, 2000

#### Florida Fish and Wildlife Conservation Commission

- Integrated wildlife habitat ranking system
- Strategic habitat conservation areas
- Biodiversity hot spots
- Priority wetlands for listed species
- Bald eagle nest sites
- Wildlife observation database
- Wading bird rookeries
- Critical wildlife areas

## CONCENTRATE MANAGEMENT—EVALUATION OF RISKS

### Key Issues of this Assessment

Task I of the Surface Water Treatability and Demineralization Study involved conducting a literature review summarizing recent technical information related to the impacts and management of low salinity waste concentrate and developing a synopsis of the hydrologic and biologic characteristics of the project reach of the St. Johns River. The discussion of concentrate disposal presented herein relies heavily on these documents.

### Prospective Analysis

This process of evaluating the potential environmental risks is based on likely characteristics for a discharge that has not yet occurred and is not yet sited. The best measurement endpoints of this potential exposure are standard test organism responses to the estimated water quality characteristics of an RO discharge. Given the need to rely on estimated water quality conditions and exposure to aquatic test organisms to evaluate the potential for toxicity, there is uncertainty in this assessment. This uncertainty can be described and, thus, managed. The discharge is primarily a concentration of the river water with similar ionic characteristics, and the river's water quality is relatively well understood. The three standard test organisms are reliable indicators for this type of impact. Further, toxicity through bioaccumulation is not assumed to be a pertinent issue relating to the chemicals in this discharge. Therefore, confidence can be placed in the results. The assessment endpoint, or the aquatic biological community of the river, is adapted to widely fluctuate TDS concentrations. The effects of a concentrate discharge in this fluctuating environment may be less than if it were in a less variable environment.

### Reverse Osmosis Concentrate

RO discharges present a somewhat different environmental issue than do more traditional single pollutant releases. Seawater RO concentrate is the most studied. Toxicity in seawater concentrate is often associated with different proportions of mineral ions than are present in the receiving marine water body. The effects of increased mineral concentrations on freshwater organisms are not as well documented. It is assumed for this report that: 1) the potential toxicity of potable water RO concentrate discharged to oligohaline (low salinity) waters is also associated with ion imbalance. In addition, 2) aquatic organisms may be directly affected by the TDS concentration (salinity) or by an excessive concentration of a particular ion. These assumptions form the basis for the evaluation of toxicity presented in this report.

## RO Pilot Plant

### RO Pilot Plant Operation

The general treatment process used at the pilot plant and to be used in a full-scale RO facility includes the following (in order of use):

Acid addition (sulfuric acid) to the raw water stream to reduce pH to levels best suited for organics removal by flocculation/sedimentation (about pH = 4).

Pretreatment technology designed to remove color, tastes, organic chemicals, and fine solids. Ferric sulfate was the flocculant used in the pilot plant. Two mechanical flocculation processes using ferric sulfate ("Actiflo" "and "Super P" ) were tested as part of pilot plant operation. Zenon Zeeweed 500, an immersed ultrafiltration membrane, was also tested. This report analyzes all of the available RO concentrate data from the various pretreatment chains to evaluate the potential for differences due to process mechanics.

Addition of a simple alkali (sodium hydroxide) to raise the pH above 6. For regulatory purposes and in the pilot plant, the pH increased to at a minimum of 6.5 during the phase. Anti-scaling compounds were also added in small doses to prevent the formation of mineral compounds on the membrane. There are a variety of these weak acid compounds available for use and, at this time, these are not used in doses sufficient to warrant further investigation with respect to environmental risk. All anti-scalant products are NSF/ANSI 60, NSF/ANSI 61 approved (NSF International 2001a, 2001b) for potable water production processes.

Following chemical pretreatment of the RO feedwater, 5-micron cartridge filters were used to protect the RO membranes from turbidity and/or suspended solids spikes resulting from upstream process upsets.

The water was then passed through an RO membrane system. Most of the water was recovered as it passed through the membrane and a small fraction was wasted along with the majority of the dissolved minerals present in the RO feedwater. The concentrate is the rejected water fraction containing the rejected minerals. The percent of the intake water recovered was a function of the plant operation.

The process added sulfate ions from the sulfuric acid and ferric sulfate. Sulfate was then replaced by other cations bonding to iron during the flocculation process, and it was highly rejected by the RO membrane given its characteristic as a multivalent ion. The concentrate water at times had a lower iron concentration due to the flocculation process, in which is was substituted for other cations. Increased sodium levels were also observed resulting from the addition of sodium hydroxide and the subsequent rejection of sodium during RO**.**

During the study the concentrate water and raw water samples were collected at the same time. Average values for these samples over the pilot plant operation period from April to June 2002 were used in the analysis.

### Pilot Plant Concentrate Characteristics

The pilot plant RO operation was projected to remove more than 90 percent of the mineral constituents and to recover about 85 percent of the water.

Actual operation resulted in a recovery of approximately 75 percent which increased mineral concentrations in the rejected water or concentrate (Table 87, Figure 123). Most of the ion concentrations increased between three and four times. The differences between individual ions resulted from specific interactions between each ion and membrane.

Due to chemical addition, sulfate concentrations increased in the concentrate relative to the raw water. Subtracting the amount of sulfate added in the process (about 300 milligrams per liter [mg/L]), the ratio falls within the expected concentration range.

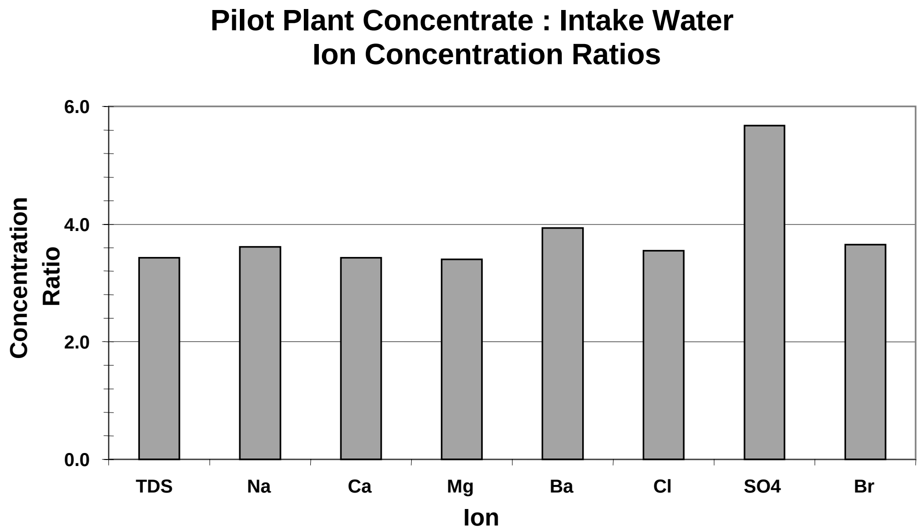
The chemical doses used in the pretreatment process were relatively uniform given the constant volume of intake water with relatively consistent characteristics. For this reason, the relative ionic effect of pretreatment chemical additions should be reduced as the TDS concentration in the intake water increases. This will become more important during higher river flows with lower levels of TDS. Initially low iron concentrations were almost always reported as undetectable in the concentrate. The levels were, therefore, not reported.

**Table 87. Average River Water Intake and Concentrate Water Quality Statistics**

| Parameter | River Water | Concentrate | Concentrate: Raw Water Ratio |
|---|---|---|---|
| TDS (mg/L) | 858.10 | 2942.63 | 3.43 |
| Ba (mg/L) | 0.08 | 0.32 | 3.94 |
| Ca (mg/L) | 49.96 | 171.39 | 3.43 |
| Mg (mg/L) | 23.96 | 81.57 | 3.40 |
| Na (mg/L) | 182.56 | 660.32 | 3.62 |
| Sr (mg/L) | 1.46 | 4.80 | 3.29 |
| Cl (mg/L) | 336.70 | 1194.93 | 3.55 |
| Br (mg/L) | 0.71 | 2.60 | 3.65 |
| $SO_4$ (mg/L) | 138.40 | 785.63 | 5.68 |
| Conductivity (µohms/cm) | 1450.90 | 5024.80 | 3.46 |

Notes:
Values are averages of pilot plant data from operations reported during 2002.

**Figure 123. Average Ratios of Concentrate Constituent Concentrations to the Average Intake Water Constituent Concentrations**




A comparison of the ratio of the ions to the TDS concentration in the raw intake water and concentrate from the RO units (Figure 124) indicated that sulfate presented the highest concentrate raw water ratio, followed by barium, sodium, and bromide. Sulfate and sodium ratios were expected to be high because those ions were added in the treatment process. Dr. Jim Taylor, UCF, whose laboratory analyzed the data, verified that the ion mass balances for the single element RO units (comparing input concentrations to permeate and concentrate values) were reasonable and confirmed the concentration data. Barium and bromide were highly rejected by the membranes tested. The high rejection rate for barium was partly due to anti-scaling additives that resulted in the rejection of dissolved barium that would otherwise have precipitated on the membrane and remained within the plant, on the membrane. Use of such anti-scaling agents is expected to be part of any full-scale plant operation.

Ionic ratios in the pilot plant intake water and the RO concentrate were compared by calculating the ratios for the ionic constituents from each source, and then dividing the average concentrate ion fraction by the raw water average fraction (Figure 125). For example, to compare chloride ion ratios in the intake and concentrate waters:

- *Chloride ion : TDS ratio = $Cl^-$ (mg/L) / TDS (mg/L)* *(1)*
- *Calculate the ratio for each intake water and concentrate sample.* *(2)*
- *Calculate the average intake water $Cl^-$ ratio* *(3)*

- *Calculate the average concentrate water $Cl^-$ ratio* *(4)*
- *Divide (4) by (3)* *(5)*

If the process were 100 percent effective on all ions and no ions were added or removed, the ratios should all be uniform (1:1). The two pretreatment processes (SuperP and Zenon) are shown separately to compare the resulting water quality differences. The values shown in the figures reflect the net performance of the system with different pretreatments and the addition of ions to the treatment stream.

The RO concentrates from the SuperP and Zenon pretreatment processes were slightly different. The two processes showed similar results for calcium, magnesium, and chloride ratios. The SuperP treatment was slightly less effective than Zenon at rejecting most of the ions except sulfate.

The degree to which the particular results are significant vis-à-vis environmental risk must be evaluated whenever a specific process is proposed. For the purposes of this study, the issue was resolved by testing toxicity on a dissolved solids solution concentrated five times in 20 percent of the original volume (plant operation of 80 percent intake water recovery with 100 percent rejection of dissolved solids). This scenario is a best-case plant operation and a worst-case discharge quality.

**Figure 124. Comparison of Lake Monroe Intake Water and Concentrate Ion Ratios**

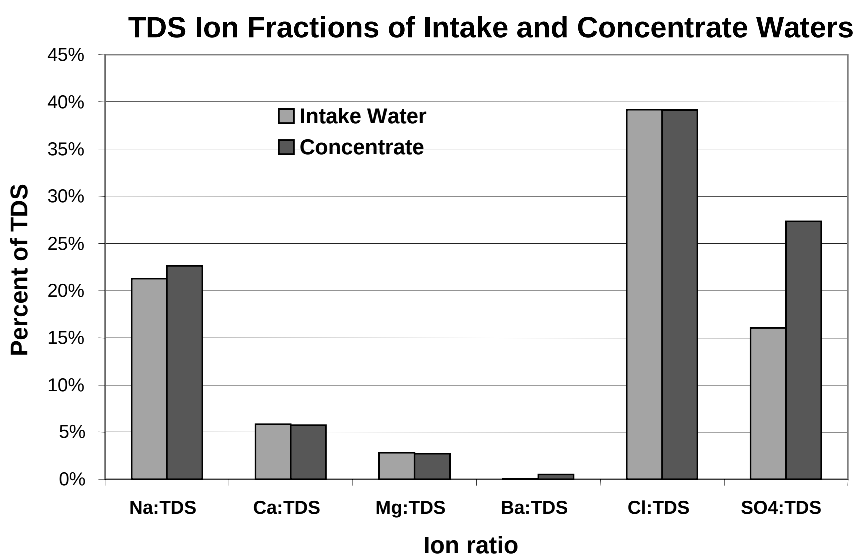
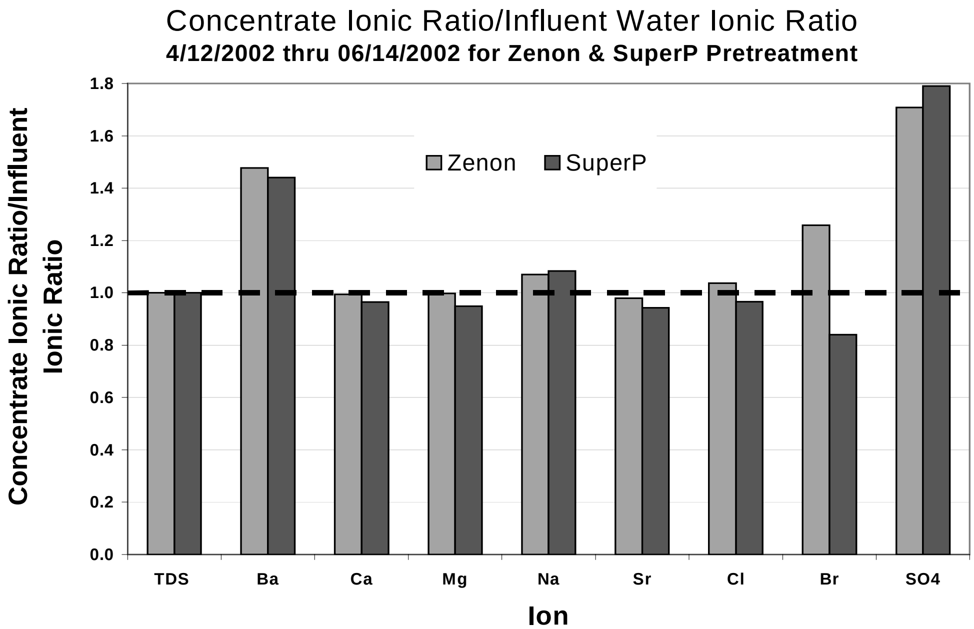


**Figure 125. Comparison of Ionic Ratios of Intake and Concentrate Waters**

***Note: Each paired bar represents the concentrates from two different membranes.***




## Site Background

The Middle St. Johns River (the middle basin) is the area in central Florida where the river widens, forming lakes Harney, Jesup, and Monroe. The specific study area for this project is the river downstream of Lake Harney to the confluence of the Wekiva River with the St. Johns River near DeLand. Ecosystem information about the river basin between the outlet of Lake Poinsett to the inlet of Lake George was collected to fully characterize the study area.

The total elevation drop of the river from its source in marshes south of Melbourne to its mouth in the Atlantic near Jacksonville is less than 30 feet, or about 1 inch per mile, resulting in a slow-flowing river. Sea water enters the river at its mouth in Jacksonville. In periods of low water, tides may cause a reverse flow as far south as Lake Monroe – 161 miles upstream from the river's mouth. Major tributaries or smaller streams and rivers that flow into the St. Johns River include the Wekiva River, the Econlockhatchee River, and the Ocklawaha River. The confluence of the Wekiva River and the St. Johns (a few miles downstream of Lake Monroe) is the formal downstream limit of this study.

Detailed descriptions of the river ecosystem and of field surveys of the area are provided in Technical Memorandum I1: *Literature Review: Concentrate Management and Hydrologic and Biologic Characteristics of the St. Johns River Between Lake Monroe and DeLand* (Barnes, Ferland & Associates and CH2M HILL, 2003). The descriptions below rely heavily on the information in that document.

The study area was divided into three areas for environmental evaluation (Figure 126):

- Government Cut area of the St. Johns River
- Lake Monroe
- The St. Johns River from Lake Monroe to the Wekiva River

### Government Cut Area of the St. Johns River

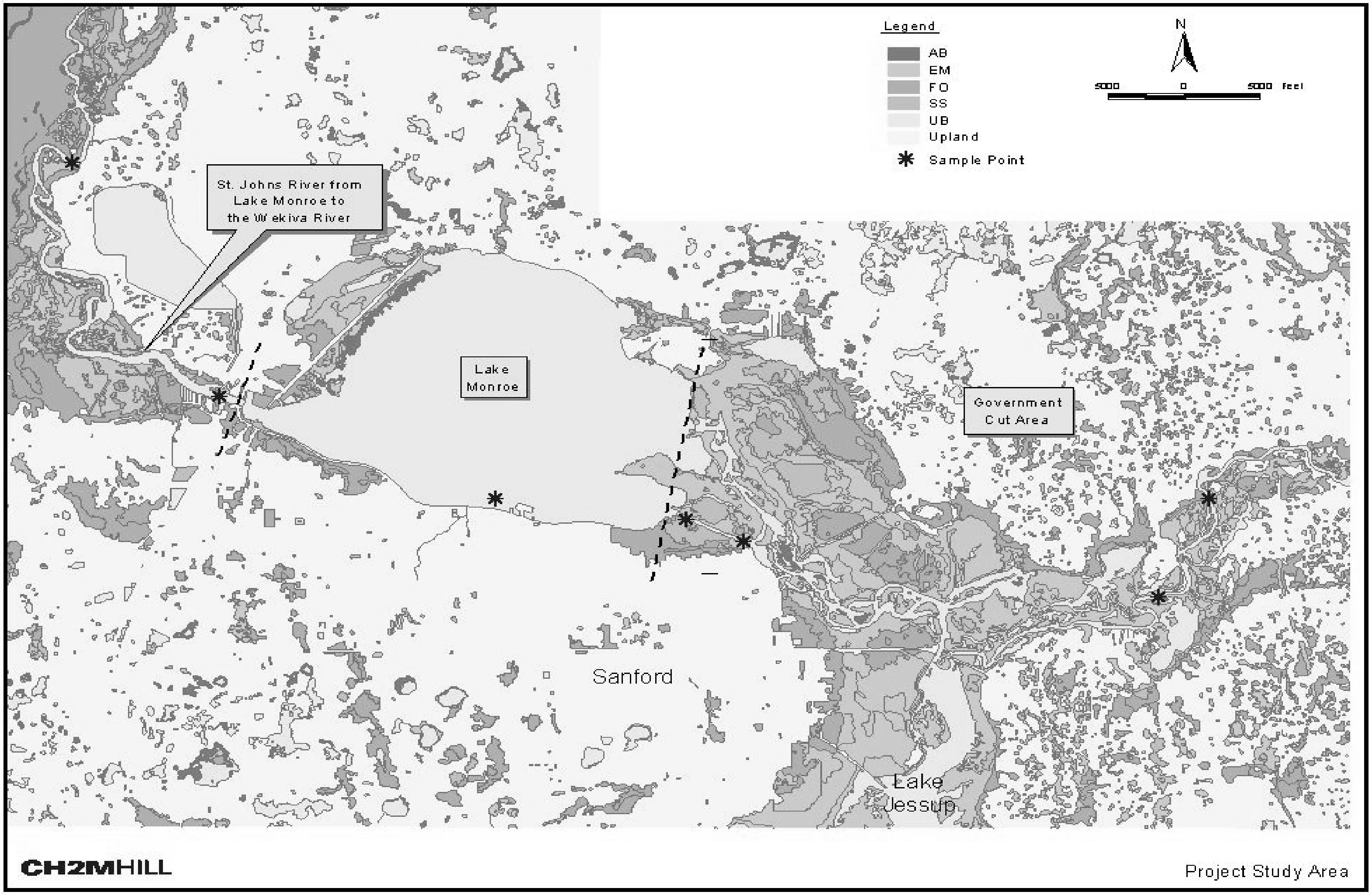
The river from the upstream end of Lake Monroe to the point where a single channel predominates (about ½ the distance to Lake Harney) was, for this report, designated as the Government Cut area. A channel created in the 1960s with that name is located in this reach near the confluence of Lake Jesup with the braided river channel in that area.

The river is characterized by multiple river channels passing through extensive emergent marshes that are affected by agriculture (primarily grazing), and the presence of some exotic and nuisance vegetation. There are several small communities on bluffs immediately adjacent to the river, and the area is a popular for recreational fishing and other activities.

### Lake Monroe

Lake Monroe is the focus for a potential surface water supply source because of strong local interest. It is a “river run” lake; that is, the lake is an enlargement of the river channel itself, and the river runs through the lake. The lake is 6 miles long, about 4 miles wide, and 7 feet deep on average, with a surface area of 9,406 acres. The southern (left side facing downstream) shore of Lake Monroe is occupied by the City of Sanford, and is at the headwaters of the commercially navigable portion of the St. Johns River. With the advent of commercial steamboat service in the mid-1800s, Lake Monroe became an important distribution point for goods essential for the growth of central Florida. The lake is used extensively for recreational purposes (fishing and boating).

**Figure 126. Location of Study Area and Reaches within the Study Area.** ***AB = aquatic Bed; EM = Emergent Marsh; FO = Forested; SS= Shrub Scrub; UB = Unconsolidated Bottom***



The Lake Monroe watershed is heavily developed, although wetlands exist on the eastern and western shores of the lake. It is within the highest growth potential area of Seminole County. A large amount of acreage in the I-4/SR 46 corridor is designated as higher intensity planned development that allows industrial, office, commercial, and multifamily developments. Mixed land uses in the Sanford area lie immediately south of Lake Monroe. Extensive residential areas exist in DeBary and Deltona, northwest and northeast of Lake Monroe, respectively.

Lake Monroe is identified as an impaired water body (303d), primarily because of low dissolved oxygen (DO), high nutrient, high lead and selenium levels, and levels of un-ionized ammonia. Lake Monroe is hydrologically distinct from the river upstream and downstream, and has a much more developed shoreline than the other two reaches within the study area.

**The St. Johns River from Lake Monroe to the Wekiva River**

The St. Johns River from Lake Monroe is generally characterized as a single channel river, with upland coming close to the river channel on the northern (right side facing downstream) and the floodplain of the Wekiva River on much of the southern (left downstream side) of the river. There is a large power generating plant just south of the lake on the eastern side. The immediate floodplain is the most natural and least apparently disturbed reach of the three reaches defined for this study.

**Statutory and Regulatory Background**

Regulatory issues have been thoroughly described in Reiss et al. (2001) and summarized in Barnes, Ferland & Associates and CH2M HILL (2003). The interested reader is encouraged to review those two documents. The following outlines the issues and identifies the focus of this report with respect to regulatory issues.

The basis of the regulations affecting demineralization concentrate management includes the Clean Water Act, the Safe Drinking Water Act, and the Resource Conservation and Recovery Act. Under federal regulations, demineralization concentrate is a category of industrial wastewater. Florida regulations have incorporated the federal requirements and, in some cases, developed more stringent requirements consistent with the unique characteristics of Florida’s natural environment. The State of Florida has enacted legislation and is developing regulations specific to demineralization concentrate. State law classifies concentrate as a drinking water treatment by-product, which is permitted as an industrial wastewater through the Industrial Wastewater Permitting Section of the FDEP.

There are a number of applicable state rules and regulations within Florida Administrative Code (F.A.C.) Chapter 62 that control waste discharges to waters of the state (Reiss Environmental, Inc., 2001). An industrial waste intended for discharge to surface water requires a NPDES permit. The permit process is complex and may be quite lengthy. Every new permit application is now reviewed for compliance with antidegradation policy and water quality-based effluent limits; compliance with surface water criteria and mixing zone; tidal influence (when applicable); toxicity; and contribution to existing impairments. The main focus of this evaluation with respect to the regulatory environment will be potential toxicity, and less directly, mixing zone requirements and potential contribution to existing impairments.

## Problem Formulation

### Management Goals

The primary management goals for the Middle St. Johns River with respect to this risk assessment include the following (SJRWMD, 2002):

- Maintain water quality that meets or exceeds Class III standards
- Assess the likelihood that RO discharges of the type and quantity proposed for the Middle St. Johns River can be managed within the required regulatory framework for maintaining Class III Waters found in F.A.C. Chapter 62

The management goals associated with the Ecological Risk Assessment are as follows:

- Quantify to the extent possible the potential ecological risks associated with exposure to the chemical constituents found in a concentrate created by RO treatment of water from the Middle St. Johns River between the Wekiva River and Lake Monroe
- Compare these potential ecological risks to those associated with the ambient (background) water quality environment in the Middle St. Johns River

### Stressors

The stressors considered in this risk assessment are the elevated ion and TDS concentrations in an RO discharge resulting from a potable water supply plant operation on the Middle St. Johns River. In particular, ion ratios (ion concentration: TDS concentration) that are different in the concentrate than in the receiving water body may have toxic effects.

The ecological components considered to be exposed to these stressors are the aquatic organisms inhabiting the Middle St. Johns River, the quality of the ecosystem, and the multi-use benefits that the ecosystem currently provides.

### Conceptual Site Model

The conceptual model is simple. Chemical components from the expected concentrate may have the potential to be acutely or chronically toxic because of the salinity of the discharge the differences in the ion ratios of the concentrate compared to the receiving water body, or the increased levels of a particular ion. Potential toxicity of this discharge is not associated with compounds that are alien to this ecosystem, and the chemicals in the discharge are not expected to bioaccumulate in a way that causes harm. No specific toxicity mechanism is considered in this assessment, and a finding of potential toxicity could be linked with a number of potential causes. Understanding the mechanisms of potential toxicity would, however, require an in-depth laboratory investigation, which is not part of this project.

The evaluation of toxicity will be based on an empirical toxicity database compiled into the model GRI-FW-STR (Mount et al., 1997). The model predicts acute toxicity of seven common ions to three standard freshwater test organisms, using stepwise probit regression to find a best fit for effects. The model results are reflective of what is likely to happen in a whole effluent toxicity (WET) test. The focus of this approach is the summed effect of all the materials in the effluent, and in typical application may be followed up with specific toxicity tests if the material fails the WET test.

The test organisms *Ceriodaphnia dubia*, *Daphnia magna*, and *Pimephales promelas* are standard toxicity test organisms used in USEPA and FDEP testing. Their behavior with respect to toxicity from a broad range of materials is well known. *Ceriodaphnia dubia* and *Daphnia magna* are broadly distributed in freshwater systems and are representative of aquatic invertebrates, primarily zooplankton, which are an important part of the aquatic food chain. They have a short lifecycle and are sensitive to a broad range of contaminants. *Pimephales promelas* (fathead minnow) is a native and common North American Cyprinid, part of the minnows and carp family. This species also has been used as a test organism for many years, and a large database regarding the toxicity effects is available.

The Middle St. Johns River water quality conditions analyzed are those for which data exist or which can be reasonably projected from that information. Although data are not available for all hydrologic conditions, we demonstrate that the available data provide a sufficient range of flows to account for the range of water quality conditions critical to this assessment.

**Assessment Endpoints**

Assessment endpoints serve to link the goals of the risk assessment regarding toxicity or stress to specific features that can be measured or estimated in some way as representations of risk. For this project, the assessment endpoint is the maintenance of viable aquatic fish and invertebrate communities and populations in the Middle St. Johns River aquatic habitat.

The ionic strength of the water in the Middle St. Johns River fluctuates widely on a seasonal basis. The discharge of brackish groundwater in to the river strongly influences the TDS concentration during low flows. Surface runoff creates higher flows with low TDS concentrations, which dilutes the saline groundwater entering the river.

The organisms in this reach of the river are adapted to these natural conditions either by seasonal migration as water quality conditions fluctuate, or by increased tolerance to these conditions. Typically, estuarine or marine organisms are commonly found in this reach (Draft Technical Memorandum I1: *Literature Review: Concentrate Management and Hydrologic and Biologic Characteristics of the St. Johns River Between Lake Monroe and DeLand* (Barnes, Ferland & Associates and CH2M HILL, 2003).

**Measurement Endpoints**

A measurement endpoint is a measurable ecological characteristic related to the valued characteristic selected as the assessment endpoint. The measurement endpoints for this study will be the comparison of predicted concentrations of chemical parameters in the concentrate to literature toxicity values associated with three laboratory test organisms, including *Ceriodaphnia dubia, Daphnia* *magna*, and *Pimephales promelas*. These test organisms are considered representative of freshwater fish and invertebrates that can occur in the Middle St. Johns River.

**Analysis**

The analysis of potential environmental risk is divided into three sections:

- An analysis of water quality dynamics of the Middle St. Johns River provides the basis for developing the expected range of concentrate characteristics and expected ion balance across the river discharge range
- A screening analysis that presents applicable statutory concentration limits and concentration guidelines for the chemical components of the concentrate
- An ecological characterization of risk based on the results of a statistical model of standard test organism survival exposed to a concentrate of various strengths

**Hydrologic Analysis**

A hydrologic analysis is necessary to characterize the flow and water quality conditions that are present in the Middle St. Johns River. This analysis focuses on the river just below Lake Monroe, where data for both discharge and water quality are available. However, the analysis can probably be extended, with some caveat, to the rest of the study reach. Specifically, TDS concentrations may be expected to increase above Lake Monroe in the Government Cut area, because of the smaller watershed and the increased influence of higher TDS water upstream of the study site. This assumption is taken into account in the interpretation of the results.

The location chosen for the hydrologic analysis was the St. Johns River near Sanford at a USGS monitoring station (Station 02234500). The data from this site were the most representative of the entire study section. Previous yield analysis work on the St. Johns River (CH2M HILL, 1996a) at the Sanford location used modified discharge data from a downstream gauge (DeLand, Station 02236000) because of the limited period of record available at the Sanford Gauge in 1996.

Approximately eight years of daily discharge (streamflow) data (May 1987 through September 1989 and March 1995 through September 2001) were available from the USGS for the Sanford Gauge (02234500) at the time of the analysis. However, the extreme drought the region has suffered during the last decade has resulted in a different range of discharges than found in the longer-term record. To evaluate whether the average streamflow was representative of historical conditions, numerous locations along the St. Johns River were examined that had significantly longer period of records. The stations used for the analysis along the St. Johns Rivers are listed in Table 88.

The mean annual flow for each gauge was plotted against the contributing drainage area for that particular gauge. The area was regressed against the mean annual flow (Figure 127, $R^2$ = 0.997). The predicted mean annual streamflow for Sanford was calculated using the developed regression equation. This methodology also was used in a previous yield analysis work for the Sanford site (CH2M HILL, 1996a).

**Table 88. Applicable USGS Station Names and Numbers**

| Location name | Station number |
|---|---|
| Cocoa | 02232400 |
| Titusville | 02232500 |
| DeLand | 02236000 |
| Switzerland | 02236500 |

As illustrated, the regression-predicted mean annual flow at Sanford was 2,319 cubic feet per second (cfs) (Figure 127). The sampled mean annual flow for the POR was 2,003 cfs. The sampled data were then adjusted by a factor of 1.16 (2,319 / 2,003 cfs) to account for the recent drought conditions. Figure 128 shows the discharge-duration exceedence curve for the St. Johns River near Sanford for the POR from 1987 through 2001 as sampled and with the adjustment factor of 1.16. (Note that negative flow values were adjusted by 0.84.) For the POR, for both cases, flow rates are positive 90.8 percent of the time.

Critical aspects of the river flow include the minimum and maximum discharge conditions under which the RO plant would operate and the associated water quality. A conservative approach similar to that used in CH2M HILL (1996a) was employed. As the river discharge decreases, the TDS concentration increases. This situation may dramatically increase RO costs, because the amount of water that can be recovered is reduced. In addition, there is a critical flow below which the ecosystem may be significantly harmed. This issue was discussed with other project staff and SJRWMD staff, and previous SJRWMD reports were studied (CH2M HILL, 1996a; CH2M HILL, 1996b; Mace, 2002).

**Figure 127. Regression of Long-term Average Discharge Values along the St. Johns River to Predict Long-term Average Flows at Sanford, Florida**

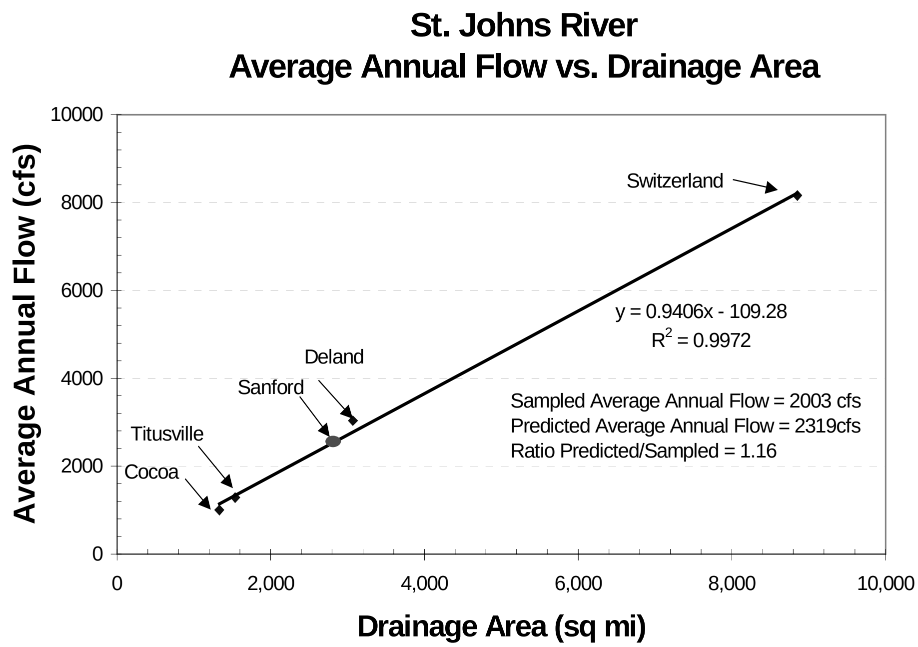
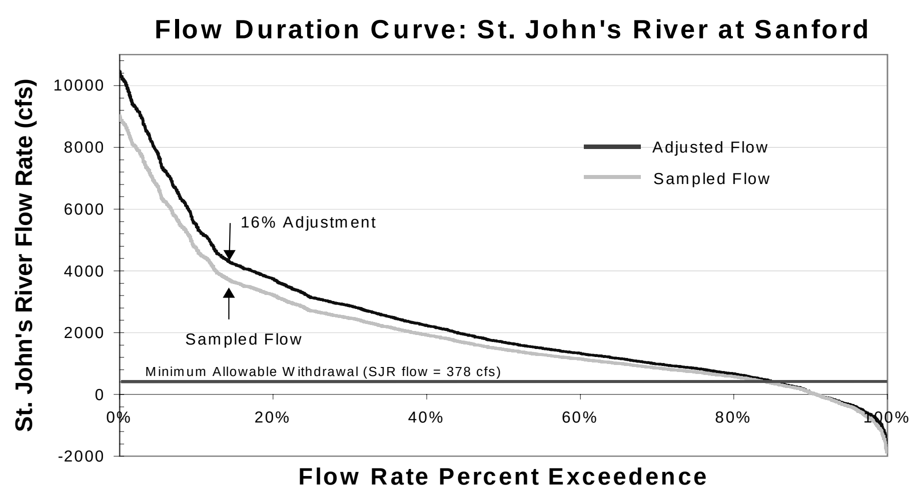



**Figure 128. Adjustment of Sanford, Florida, Flow Duration Curve to Account for Long-term Drought Effects**



For this assessment, the minimum discharge for withdrawal was the 95 percent discharge-duration exceedence point (i.e., that flow rate which is exceeded 95 percent of the time. This level is more conservative (higher) than the regulatory mixing zone flow criteria (7Q10 discharge) for industrial wastes. For toxicity evaluation purposes, the maximum design flow was set at the 10 percent discharge-duration exceedence point (i.e., that flow rate which is exceeded only 10 percent of the time).

At extreme low flow conditions, the river may reverse flow as far south as the southern end of Lake Monroe. Using only positive flows, the minimum (allowable) design flow frequency is 87 percent, or 95 percent of the positive streamflow rate. This is calculated as:

$$0.95*0.908 = 0.869$$

From the flow duration curve, this equates to a flow rate of 303 cfs in the St. John’s River at Sanford. However, this value also needs to account for the required withdrawal amount of 75 cfs, because 303 cfs is the minimum required flow level in the St. Johns River. Thus, the minimum St. Johns River flow during which withdrawals can take place is 378 cfs (378 cfs = 303 cfs + 75 cfs).

The maximum diversion frequency would be 10 percent of the positive streamflow values or 9.1 percent, calculated as:

$$0.10*0.908 = 0.908$$

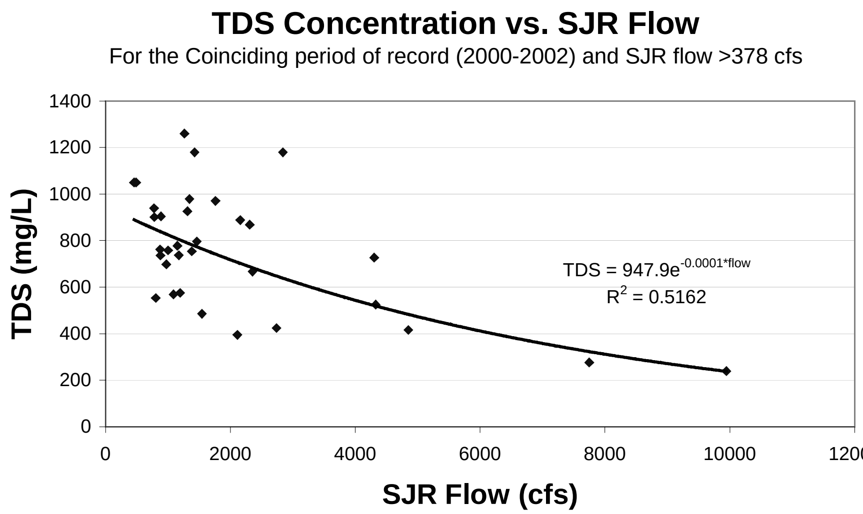
From the adjusted flow duration curve, this amount equates to a flow rate of 5,951 cfs in the St. John’s River at Sanford. Although this value has been established for the purposes of this assessment, RO may not be necessary for high flow conditions because of better water quality (i.e., TDS concentrations acceptable for potable water).

### Water Quality Analysis

Once the critical flow levels were established, relationships between water quality and St. Johns River flow were established for TDS and chloride. Chloride was selected because it is a biologically conservative (not biologically reactive) element and major constituent of the TDS in the river. After analysis of these two parameters, the other parameters were examined graphically to verify that the other constituents were consistent with the behavior of chloride. The water quality POR was limited (June 2000 to May 2002 for TDS and January 2000 to May 2002 for chloride), and flow data were not available for every day that water quality was sampled.

The correlation between St. Johns River flow and TDS is weak, but represents the best available data (Figure 129). The most significant aspect of the relationship is the large range of TDS concentrations within a relatively narrow portion of the discharge range. Better correlation was found in the data available for sites upstream of Sanford.

**Figure 129. TDS Concentration vs. SJR Flow, Sanford, Florida**




A quick assessment of data for sites upstream of the Sanford point suggests that the relationship between flow and TDS becomes weaker downstream. However, the relationship between chloride and TDS is extremely robust (Figure 130 R2 = 0.98). An evaluation of other parameters indicated similarly strong relationships with TDS.

Once the relationship between TDS and St. Johns River flow was established it was possible to predict the TDS concentration in the St. Johns River post-RO process discharge. The post-RO process discharge concentration is a function of the ratio of the St. Johns River flow and St. Johns River flow after post-RO process discharge and TDS concentration:

TDS concentration post RO = SJR Flow / (SJR Flow - 60 cfs) *TDS Concentration

Figure 131 compares the TDS concentration for pre- and post-RO process discharge as a function of St. Johns River flow. The most significant aspect of this comparison is the fact that the TDS concentrations diverge significantly at mean TDS values above about 800 mg/L. However, Figure 131 also suggests that the TDS value selected may apply to a range of discharge values.

**Figure 130. Chloride Concentration vs. TDS Concentration, Sanford, Florida**

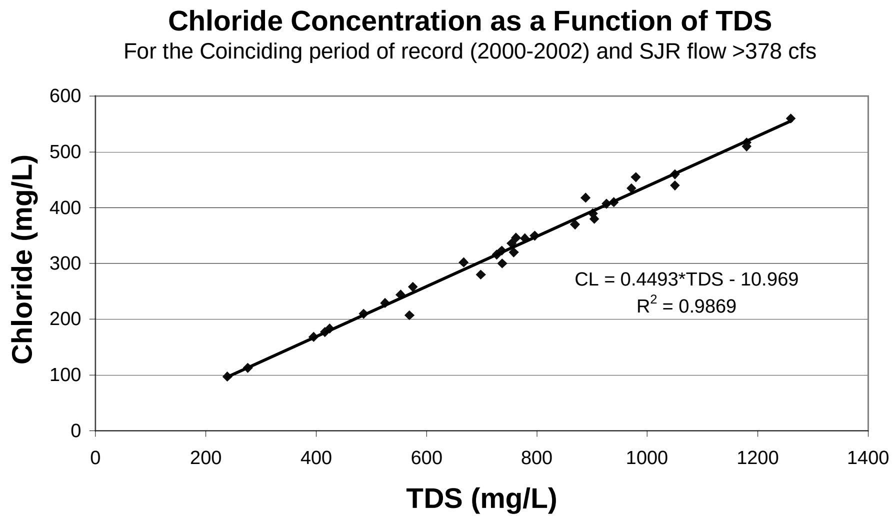
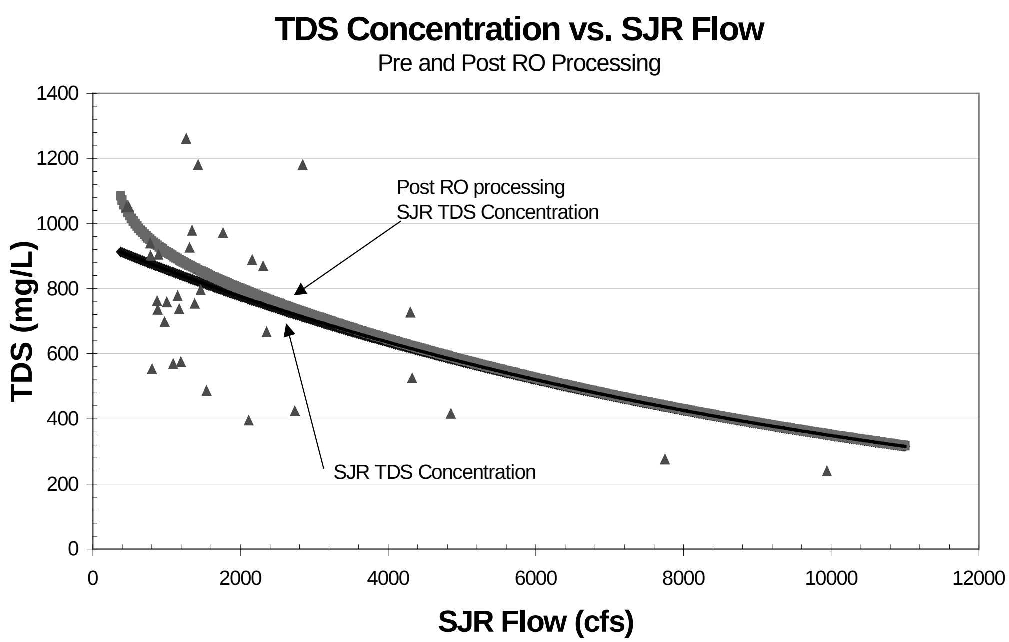



**Figure 131. TDS Concentration Pre- and Post-RO Process Discharge, Sanford, Florida. Individual points are sampled data. Lines are average expected results predicted from the data.**



### Comparison of Dissolved Solid Ratios in River Water and Concentrate

An evaluation of ion: TDS ratios was developed using water quality data from the same 2-year intensive USGS study of the Middle St. Johns River used to assess the hydrologic characteristics. This information was compared to concentrate from the RO pilot plant operation conducted April through June 2002.

The evaluation focused on the following questions:

- What are the characteristics of dissolved solids in the river? Is the ratio of each ion concentration to TDS consistent, or do the ratios change with changing TDS concentration? Changing ratios in the raw water may affect the toxicity of the concentrate.
- How does the pilot plant concentrate dissolved solids composition compare to the raw intake water? What concentrate values should be used for risk characterization?

### River Water Quality

Water quality statistics for the Sanford USGS station suggest that the constituents of the TDS vary consistently with TDS and the ion concentration ratios (the ratio of each ion to the TDS concentration in a sample) remain fairly constant (Figures 132 and 133).

TDS concentration varied seasonally (generally with flow), and the concentration of major ions varied similarly (Figure 132). When the ion concentrations were converted to a fraction of the TDS, the ratios changed little over the POR (Figure 133). This concentration consistency also can be seen in the size of the standard deviations of the concentration fractions (Table 89). The concentrate should therefore also reflect relatively constant ionic ratios, with the exception of ions added to or ions removed from the water during the process. Changes such as these may influence toxicity.

In summary, the data from the river and the pilot plant were consistent in demonstrating that the ion ratios are sufficiently stable to use as a base for this risk assessment. Although TDS concentrations varied considerably over a wide range of discharges, the river ion ratios were relatively constant over that range. The pilot plant intake water was similar to the available river data (Table 90). Pilot plant concentrate ion ratios were similar to the pilot plant intake water ion ratios, with the exception of sulfate (which was expected).

**Figure 132. Concentrations of Middle St. Johns River TDS Constituents (Major Ions) 2000 – 2002**

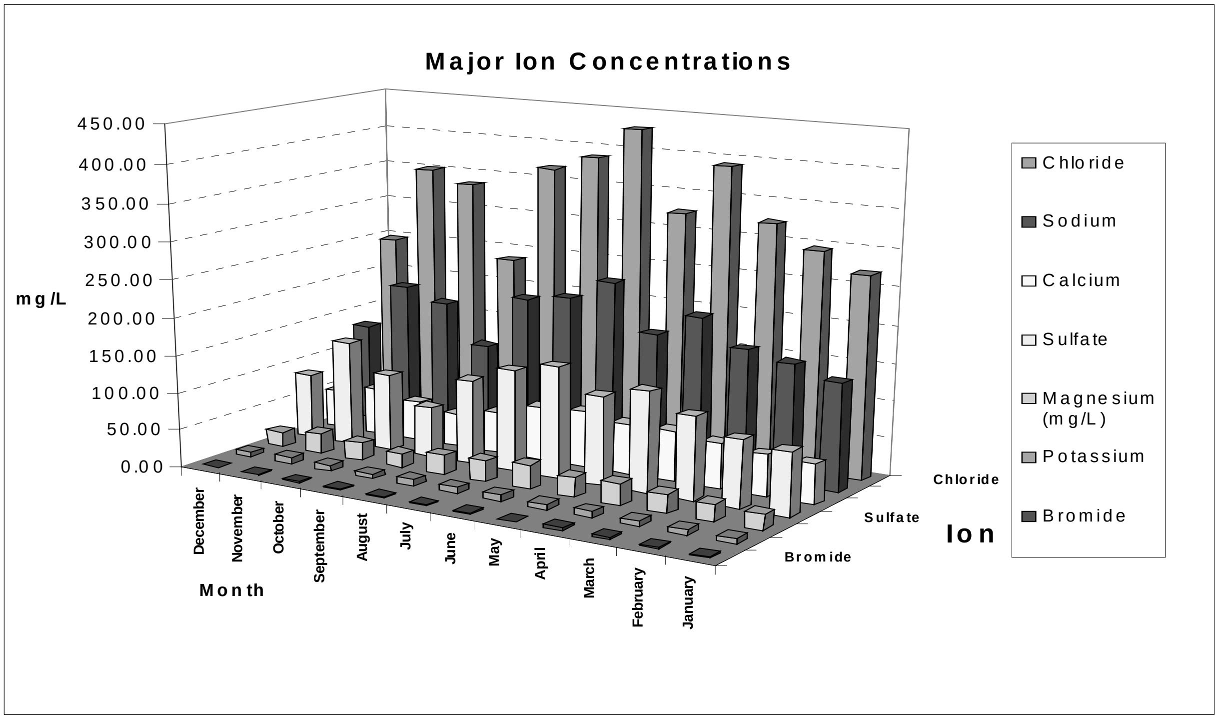
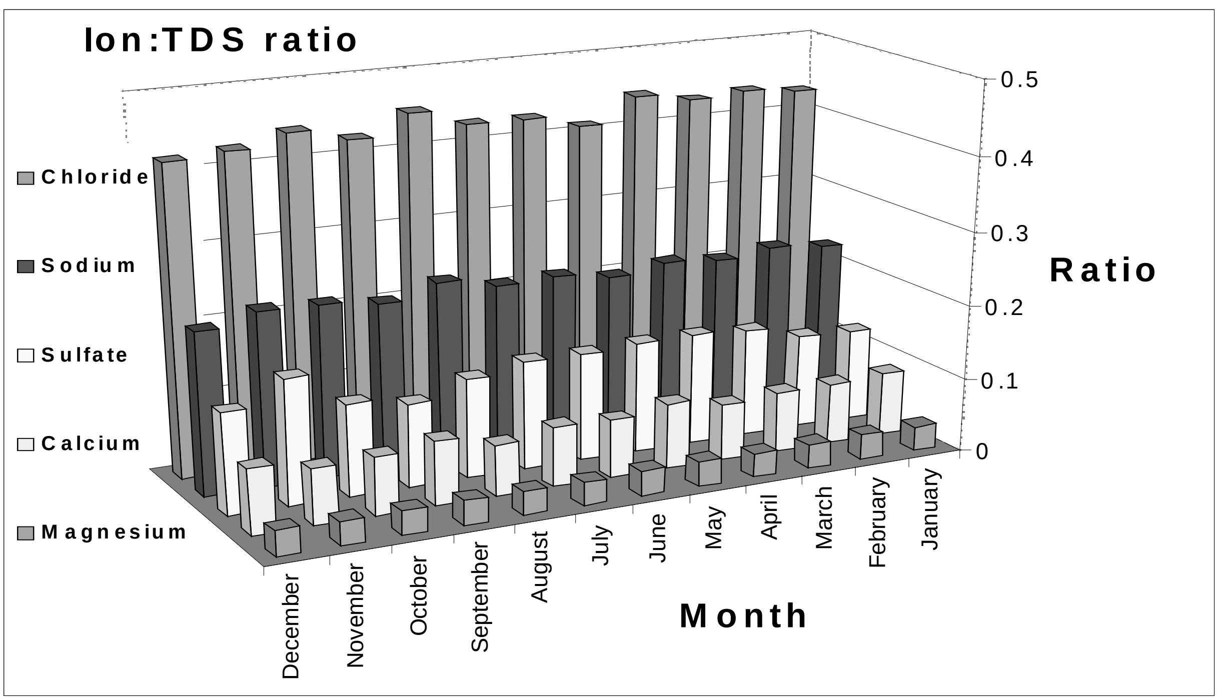



**Figure 133. Ion Concentration Ratios of Middle St. Johns River 2000 – 2002**



## Table 89. Water Quality Statistics, Middle St. Johns River near Sanford Florida, 2000 – 2002

| Parameter | Average | Maximum | Minimum | Std dev. |
|---|---|---|---|---|
| Flow (cfs) | 1,232 | 8,570 | -1,440 | 1,796 |
| Spec Cond (µS/cm) | 1,434 | 2,380 | 462 | 441 |
| Total Dissolved Solids | 756 | 1,260 | 239 | 241 |
| Calcium | 59 | 89 | 24 | 15 |
| Magnesium | 24.8 | 40 | 7.9 | 7.5 |
| Sodium | 177.4 | 300 | 50 | 62.6 |
| Bromide | 1.6 | 8.3 | 0.5 | 1.6 |
| Chloride | 329.2 | 560 | 97 | 111.1 |
| Sulfate | 109.4 | 200 | 19 | 46. |
| Barium (µg/L) | 31.2 | 45 | 16 | 7.9 |
| Strontium (µg/L) | 1,481.1 | 2,400 | 600 | 447.2 |
| Potassium | 7.6 | 12 | 3.8 | 2.1 |

Notes:
Values in mg/L unless noted otherwise
Data from USGS.

## Table 90. Average Pilot Plant Intake and River Water Ion Ratios. USGS and Pilot Plant Intake Water Samples

| | Pilot Plant Intake 2002 | Middle St. Johns River USGS Data 2000 - 2002 | | | |
|---|---|---|---|---|---|
| Parameter | Mean | Mean | Max | Min | Std dev |
| Calcium:TDS | 5.83% | 8.11% | 10.72% | 5.97% | 1.21% |
| Magnesium:TDS | 2.81% | 3.29% | 3.69% | 3.05% | 0.15% |
| Sodium:TDS | 21.28% | 23.06% | 25.90% | 19.33% | 1.53% |
| Bromide:TDS | 0.08% | 0.21% | 0.89% | 0.12% | 0.19% |
| Chloride:TDS | 39.16% | 43.15% | 47.36% | 36.38% | 2.40% |
| Sulfate:TDS | 16.03% | 13.82% | 18.10% | 7.61% | 2.90% |
| Barium:TDS | 0.01% | 0.00% | 0.01% | 0.00% | 0.00% |
| Strontium:TDS | 0.17% | 0.20% | 0.25% | 0.16% | 0.02% |
| Potassium:TDS | NA | 1.30% | 2.04% | 0.65% | 0.38% |
| Total % $\sum$ ions: TDS | 85.38% | 93.03% | 97.13% | 83.27% | 3.98% |
| CFS | NA | 1,232 | 8,570 | -1,440 | 171% |

For the purposes of this study, a 50 million-gallon-per-day (mgd) withdrawal is assumed. This withdrawal would result in an estimated 10-mgd concentrate discharge. The concentrate is assumed to be composed of 100 percent of the intake water TDS in 20 percent of the intake volume.

## Characterization of Ecological Effects

### Screening Analysis – Regulatory Standards and Guidelines

A screening analysis of regulatory water quality numeric criteria and guidelines for the primary chemical constituents was conducted to make a first assessment of the potential of the individual ions to create environmental risk. The review relied heavily on two documents that provided a relatively comprehensive and up-to-date international database of standards, criteria, and guidelines (MacDonald et al., 1999; EPA, 1999). F.A.C. 62.302 was reviewed for Florida standards. Values in addition to those provided in Florida statutes have been considered because several of the ions have no definite standard in Florida, and standards are liable to change as the potential impacts of concentrate is better understood. As part of the evaluation, a range of values has been used to characterize hazard presented by the individual ions. The values include the Florida numeric criteria value if that value was the most stringent, or second most stringent values for a particular ion.

The treatment process envisioned for this project includes a chemical pretreatment process followed by RO membrane treatment. The pretreatment may include acidification and flocculation to remove color, taste, fine solids, etc. This process also significantly reduces carbonate alkalinity and iron concentration. The resultant stream is then neutralized (brought up to pH of 6.5 or greater) prior to membrane treatment. During the pretreatment process, about 300 mg/L of sulfate ion was added as sulfuric acid and as ferric sulfate, and small amounts of sodium were added as sodium hydroxide.

The membrane wastes a small fraction of the water (20 to 30 percent), along with more than 90 percent of the remaining minerals. The process does not increase the temperature of the concentrate significantly (a maximum of less than 2 degrees) (Robert Bergman, CH2M HILL, personal communication, 2002). The concentrate is fairly clear (depending on the effectiveness of the pretreatment to remove color) and relatively odorless.

Therefore, the constituents of interest in the concentrate include the following:

- TDS concentration and salinity
- Major cations sodium, calcium, magnesium
- Minor cations barium and strontium (less than 5 percent of the TDS combined)
- Major anions chloride and sulfate
- Minor ion bromide (less than 0.1 percent of TDS)

There are few numeric water quality criteria associated with these materials (Table 91). Of those constituents represented in Table 91 (barium, bromide, chloride, pH, sodium, and TDS), bromine, chloride, pH, and total suspended solids may exceed guidelines or standards.

The concentrate chemical data used for comparison with regulatory standards and guidelines were based on conservative assumptions:

- The concentrate water was assumed to be a five-fold increase in TDS concentration in 20 percent of the intake volume. Although this is a greater concentration than the pilot plant operation, it is a possible operational condition for a full-scale RO plant (Robert Bergman, CH2M HILL, personal communication, 2002), and thus was used to assess likely toxicity. To account for the expected addition of sulfate, 300 mg/L sulfate was added to the five-fold increase in ambient water sulfate concentration.

TDS concentrations for specific discharge values were predicted from the cfs – TDS relationship. The expected ion concentrations for these values were generated from average ion ratios of river water (Table 90). The data from the USGS sample with the highest TDS value and the sample from the highest flow also were used.

The concentrate presumed to result from the following TDS concentrations (in order of decreasing TDS concentration) were evaluated:

- The maximum TDS value (TDS = 1,260 mg/L) recorded in the 2-year USGS water quality database. This value occurred at a discharge of 1,090 cfs.
- The estimated average TDS concentration (TDS = 913 mg/L) at the lowest discharge (378 cfs) at which withdrawal for treatment was recommended (see above).

**Table 91. Water Quality Criteria and Guidelines Pertinent to the Potential Toxicity of an RO Concentrate from Middle St. Johns River Water**

| Chemical Name | Water Type | Guideline | Units | Application | Jurisdiction | Reference |
|---|---|---|---|---|---|---|
| Alkalinity | FW | 2000 | mg/L | Recommended maximum | United States | USEPA 1999 |
| Alkalinity | FW | Shall not be depressed below 20 | mg/L | Statutory minimum | Florida | FAC 62-302.530 |
| Specific Conductance | FW | Shall not be increased more than 50% above background or to 1,275, whichever is greater | | Statutory maximum | Florida | FAC 62-302.530 |
| Ammonia (un-ionized) | FW | 0.02 | mg/L | Statutory maximum | Florida | FAC 62-302.530 |
| Barium | FW | 4 | µg/L | Secondary Chronic Toxicity Tier II | United States | Sutter and Sao 1996 |
| Barium | FW | 110 | µg/L | Secondary Acute Toxicity Tier II | United States | Sutter and Sao 1996 |
| Bromine | FW | 0.17 | µg/L | Criterion; Chronic | Quebec | MDEQ 1996 |
| Calcium | | 116000 | µg/L | FW Lowest Chronic value | United States | Sutter and Sao 1996 |
| Chloride | FW | 230 | mg/L | Criterion; Continuous | United States | USEPA 1998 |
| Chloride | FW | 860 | mg/L | Criterion; Maximum | United States | USEPA 1998 |
| Color | FW | Narrative | | Standard; May not interfere with or make the water unfit or unsafe for the use; Secondary recreation | Alaska | ADEC 1998a |
| Color | SW | Narrative | | Standard; Surface waters must be free of substances that produce objectionable color; For secondary recreation | Alaska | ADEC 1998a |
| Color (change) | FW | 30 | color units | Interim Guideline; Maximum change above natural value | Alberta | AEP 1997 |
| Color (change) | SW | Narrative | | No abnormal change in color; Mandatory for bathing waters | Europe | CEC 1988 |
| Iron | FW | 0.3 | mg/L | | Florida | FAC 62.302 |
| Iron | FW | 1000 | µg/L | Criterion; Chronic | United States | USEPA 1993 |
| Iron | FW | 1000 | µg/L | Criterion; Continuous | United States | USEPA 1998 |

**Table 91. Water Quality Criteria and Guidelines Pertinent to the Potential Toxicity of an RO Concentrate from Middle St. Johns River Water**

| Chemical Name | Water Type | Guideline | Units | Application | Jurisdiction | Reference |
|---|---|---|---|---|---|---|
| Lead | FW | 1.0 | µg/L | Statutory maximum | Florida | FAC 62-302.530 |
| pH | FW | 5.0-9.0 | Standard Units | Guideline; Aesthetic Objective; In low buffering capacity | British Colombia | BCMOELP 1998 |
| pH | FW | 5-9 | Standard Units | Guideline for body contact recreation, for waters with very low buffering capacity | Canada | H&WC 1983 |
| pH | FW/SW | 8.5 | Standard Units | Standard; Upper value; Primary and secondary contact and water of exception recreation or ecological significance | Delaware | USEPA 1988 |
| pH | FW-Lakes | Narrative | Standard Units | Standard; No measurable change from natural conditions; Lake Class; Primary contact | Washington | Washington State 1997 |
| pH | FW | Narrative: Shall not vary more than one unit above or below natural background in predominantly fresh waters and coastal waters … | Standard Units | | Florida | FAC 62-302.530 |
| Selenium | FW | 5.0 | µg/L | Statutory maximum | Florida | FAC 62-302.530 |
| Sodium | FW | 30-75 | % | Interim Guideline; Maximum | Alberta | AEP 1997 |
| Total Dissolved Solids | FW | 1000 | mg/L | Standard; Proposed Maximum; Including natural conditions; There shall be no concentrations of TDS in water that cause an adverse effect to aquatic life; Includes aquaculture | Alaska | ADEC 1998b |

Notes:
FW = Freshwater
SW = Salt Water
EST = Estimated

- The average ambient TDS concentration of the 2-year database (TDS = 758 mg/L).
- TDS = 500 mg/L. This is the potable water legal limit for TDS in the State of Florida and occurs (on average) at a discharge of 3,110 cfs.
- The minimum TDS value (TDS = 239 mg/L) recorded in the 2-year database.

For comparison to regulatory values, the maximum and minimum TDS concentrate and associated ion concentrations were used.

The screening analysis compared estimated maximum and minimum ion concentrations to primary and secondary values identified from Table 91. For each ion concentration and each screening value, hazard quotients were calculated. A hazard quotient is the ratio of the concentration of interest to the regulatory value or values. The higher the hazard quotient, the greater the potential risk. Although this method is purely relative, it provides a way to put the entire set of potential issues in perspective.

Of the chemical parameters reported in the data, barium, bromide, and chloride provide hazard quotients of concern (Table 92). The primary maximum quotient for barium is almost an order of magnitude below the average river concentration. Thus, the value of this standard in this situation may not be great. The hazard quotients (2.0 and 0.7) for the secondary barium standard were considered to represent a minimal potential for risk. The primary hazard quotient for bromide was the highest reported in Table 92. No secondary screening value was identified. However, the primary screening value was an order of magnitude below the river average. That and the relatively low reliability of the sample data for this parameter strongly suggest that there may be less hazard than identified here. The chloride quotient of 12 is not surprising, because salinity itself may be a toxicity factor, and chloride is a primary constituent of the river TDS.

TDS and calcium are the second set of ions that may cause toxicity. TDS is likely to be an important factor. Mickley and Associates (2001) have identified calcium as a likely source of toxicity in groundwater RO concentrates, but did not identify a mechanism of toxicity. The level of hazard for calcium (Table 92) is associated with the mean ambient value. Individual values

**Table 92. Concentrate Ranges, Regulatory Screening Values, and Hazard Quotients**

| Ion | Average River | Concentrate Values* | | Screening Values** | | Hazard Quotient Range | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Maximum (mg/L) | Minimum (mg/L) | Primary mg/L | Secondary (mg/L) | Primary Maximum HQ | Primary Minimum HQ | Secondary Maximum HQ | Secondary Minimum HQ |
| TDS | 758 | 6320 | 1683 | 1000 | NA | 6.3 | 1.7 | NA | NA |
| Alkalinity (mg/L) | 79 | 62.2* | 13.4* | 20[1] | 2000 | 0.3 | 1.5 | 0.0 | 0.0 |
| Conductivity | 1316 | NA | NA | NA | NA | NA | NA | NA | NA |
| Barium (µg/L) | 29.6 | 225 | 80 | 4.00 µg/L | 110 µg/L | 56.3 | 20.0 | 2.0 | 0.7 |
| Calcium (mg/L) | 54.7 | 445 | 120 | 116 | NA | 3.8 | 1.0 | NA | NA |
| Magnesium (mg/L) | 23.96 | 200 | 39.5 | NA | NA | NA | NA | NA | NA |
| Potassium (mg/L) | 7.7 | 60 | 21 | NA | NA | NA | NA | NA | NA |
| Sodium (mg/L) | 182.56 | 1500 | 385 | 30% | 75% | 0.8 | 0.8 | 0.3 | 0.3 |
| Strontium (mg/L) | 1.46 | 12 | 3 | NA | NA | NA | NA | NA | NA |
| Bromide (mg/L) | 1.7 | 41.5 | 2.5 | 0.17 | NA | 244.1 | 14.7 | NA | NA |
| Chloride (mg/L) | 336.7 | 2800 | 485 | 230 | 860 | 12.2 | 3.3 | 3.3 | 0.6 |
| Sulfate (mg/L) | 138.4 | 1300 | 619 | NA | NA | NA | NA | NA | NA |

* Alkalinity values were the maximum and minimum values reported during the test period. Alkalinity is controlled during the treatment process, and so is relatively stable in the discharge.

** All screening values and references can be found in Table 5.

1 This criterion is “not less than 20 mg/L.” Therefore, the primary screening value was divided by the maximum and minimum values to calculate a hazard quotient.

vary by an order of magnitude (e.g., Table 92: maximum calcium – 445 mg/L) suggesting that the hazard value should be viewed with a great concern. Furthermore “This toxicity [calcium-related toxicity] most frequently occurs in situations where waters are less sodium chloride dominated and more calcium carbonate or calcium sulfate dominated (or dominated by some other species).” (Mickley 2003) The study reach is more sodium chloride dominated (see Table 90).

Although these ions are the primary constituents of the concentrate, other ions and chemical factors should be considered. The nutrients are associated with narrative standards. There is no reason to think phosphorus or nitrogen would be a factor if dilution is sufficient for the maximum projected concentrate flows. The water quality maximum standard for specific conductance (conductivity) in Florida (Table 91) is a correlate of TDS. TDS is a primary potential toxicant, is the major factor in conductivity values and was used here rather than conductivity.

Adjusting the concentrate pH results in the control of that factor and removes it from the potential risk category. Typical standards and guidelines are provided in Table 91 as an indicator of the wide range of acceptable levels for this characteristic.

Temperature will be raised minimally, if at all, as a result of the treatment process. It was therefore not considered to present a potential risk in this system.

The screening evaluation primarily illustrates that the minerals that make up TDS are not generally considered toxic, and when they are, the toxic concentrations are not much lower than are likely to be found in the proposed RO concentrate. Therefore, the chemicals are in general not expected to be an issue due to the rapid dilution that is expected to occur when the concentrate is discharged. The potential exception is chloride. These results suggest that toxicity may be more likely associated with ion imbalance or the salinity of the waste stream than with the concentration of any particular constituent.

### Potential Concentrate Toxicity

#### Methods

The potential for ion imbalance to cause harm also must be considered. In marine systems, the potential of concentrates to cause harm may result from different ratios of TDS constituents, as well as from the total concentration of dissolved solids. The use of whole effluent in toxicity testing is gaining prominence as an additional way to test the toxicity of discharges, and this type of testing is now required for all new NPDES permits (EPA, 1999). Both acute and chronic toxicity tests are required. Florida has a procedure for testing major seawater ion toxicity in membrane-technology water treatment concentrate (FDEP, 1995), but a corollary procedure for freshwater has not yet been developed. We have analyzed TDS and ion imbalance toxicity as the primary potential toxicants in a desktop analysis.

Characterization of potential ecological effects was performed using the model GRI-FW-STR for toxicity of the standard test species *Ceriodaphnia, Daphnia,* and *Pimephales promelas* (fathead minnow) to multiple ion solutions. A full description of the model and a summary of the model development process are provided in Teitge et al. (1994), provided with the software. More detailed information about the model is available in Mount et al. (1997) and references therein. The model input data were based on the assumptions and developed from the calculations described at the beginning of this section. Input data sets were developed for the following:

- The maximum TDS value (TDS = 1,260 mg/L) recorded in the 2-year USGS water quality database. This value occurred at a discharge of 1,090 cfs.
- The estimated average TDS concentration (TDS = 913 mg/L) at the lowest discharge (378 cfs) at which withdrawal for treatment was recommended (see above).
- The average ambient TDS concentration of the 2-year database (TDS = 758 mg/L).
- TDS = 500 mg/L. This is the potable water legal limit for TDS in the State of Florida and this level occurs (on average) at a discharge of 3,110 cfs.
- The minimum TDS value (TDS = 239 mg/L) recorded in the 2-year database.

The minimum TDS value occurred at a discharge of 8,750 cfs. This value was used because the available data suggest that TDS concentration changes little at high discharges. Thus, the use of actual data was preferable to an estimate based on a few data points. This discharge is approximately the 1 percent discharge exceedence level. It is used here as a surrogate of a TDS concentration that might be found at 10 percent of the cfs exceedence curve for positive flows (5,280 cfs) at this point in the river (Figure 129). While the TDS value used here may be slightly lower than a predicted value the analysis taken as a whole accounts for the range of TDS values that may be represented at this discharge.

Acute toxicity tests on whole effluent (in this case, concentrate) normally include 24- to 96-hour exposure tests of test organisms in 100 percent concentrate and serial dilutions of that material (e.g., 80 percent, 60 percent). The concentration at which less than 50 percent survival occurs establishes the 50 percent lethal concentration (LC50). These WET tests are required as part of the NPDES permit approval for new discharges (EPA, 2002). If failure occurs, a further set of more detailed toxicity identification evaluation (TIE) tests is conducted.

The model requires, as input, concentrations of sodium, calcium, magnesium, potassium, chloride, bicarbonate alkalinity, and sulfate. The program reports the millequivalents for each ion, the charge balance for the solution, and the predicted survival for three standard toxicity test organisms. It reports the estimated TDS concentration, the LC50 concentration, the percent of the estimated full strength solution, and the predicted survival rate for each of the species. All parameters were clearly defined as multiples of ambient concentrations, except alkalinity. Therefore, after testing both concentrations, the lowest alkalinity value (13 mg/L) was selected for reporting, because the model results were slightly poorer (lower survival) using that value. The lower alkalinity level did not change any test result significantly.

### Results

The concentrations used in the model were, with one exception, within the limits of the software program for the resulting charge balance. The program warns the user when the error in the charge balance exceeds 15 percent. Most of the test solutions contained no more than a 5 percent charge balance error.

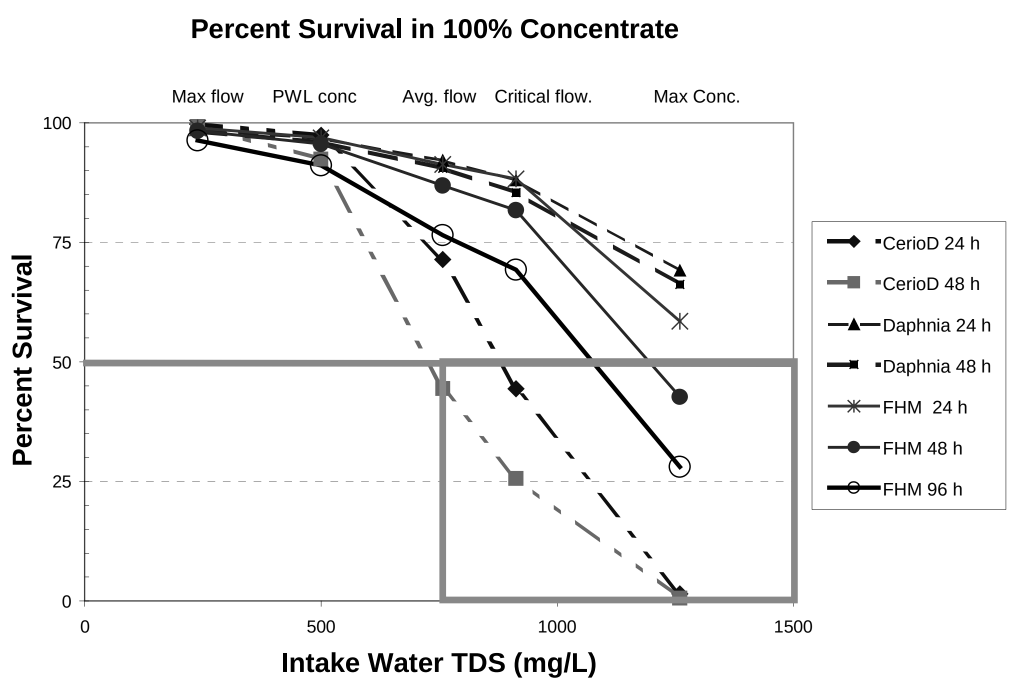
The model predicted significant (>50 percent) acute toxicity for the 100 percent concentrate for a number of conditions (Table 93). The model results suggested that acute toxicity to *Ceriodaphnia dubia* begins at a TDS concentration between 3,000 and 4,000 mg/L and that *C. Dubia* was the most sensitive organism. Most of the failures were predicted to occur at critical flow and maximum concentration values. Test failure (greater than 50 percent mortality in the concentrate) occurred first with the 48-hour test with *Ceriodaphnia* at the average ambient condition, at a 98 percent solution (TDS = 3,876 mg/L) which is essentially a no dilution condition.

**Table 93. LC50 Test Failure Results**

| Test Conditions | Intake TDS mg/L | Concentrate LC 50 TDS mg/L | LC 50 TDS Percent Solution | Potential Survival (Percent) |
|---|---|---|---|---|
| Avg. Ambient WQ, *Ceriodaphnia* 48 h | 758 | 3,876 | 98% | 44.4 |
| Critical low flow TDS *Ceriodaphnia* 48 h | 913 | 3,029 | 88 | 25.6 |
| Maximum sampled concentration, *Ceriodaphnia* 24 h | 1,260 | 4,364 | 69 | 1.6 |
| Max sampled concentration, *Ceriodaphnia* 48 h | 1,260 | 3,793 | 60 | 0.5 |
| Max sampled concentration Fat-head Minnow 48 h | 1,260 | 6,005 | 95 | 42.1 |
| Max sampled concentration Fat head minnow 96 h | 1,260 | 5,310 | 84 | 27.8 |

Note:
The program does not estimate intake TDS. All other values are predictions for GRI-FW STR.

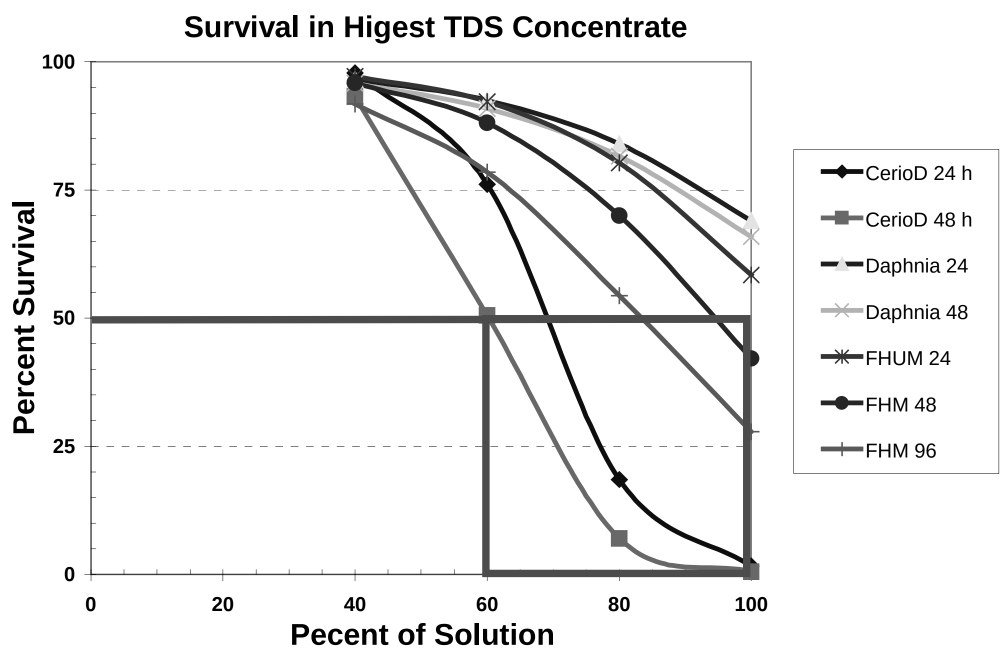
**Figure 134. Percent Survival of Test Organisms *Ceriodaphnia* (CerioD), *Daphnia Magna* (Daphnia), and *Pimephales Promelas* (FHM – fathead minnow) in Concentrate Discharge Water Quality using GRI-FW-STR**



The worst-case failure occurred in a 48-hour test with *Ceriodaphnia* using a 69 percent solution (TDS equal to 4,364 mg/L) of the maximum concentration tested. *Daphnia* was not found to be significantly affected. Fathead minnow (Figure 134) was significantly affected in the 48- and 96-hour tests, but at a much higher concentration (5,000 to 6,000 mg/L).

To further explore the worst-case situation, 80 percent, 60 percent, and 40 percent percent solutions of the maximum TDS concentration (equal to 6,320 mg/L) was input to the model. Only *Ceriodaphnia* showed less than 50 percent survival in the 80 percent solution. All test organisms were predicted to meet the minimum 50 percent survival criteria in a 60 percent solution. A 40 percent solution resulted in a prediction of greater than 90 percent survival of all test organisms for all tests (Figure 135).

**Figure 135. Survival Predictions from GRI-FW-STR for Test Organisms in the Highest TDS Concentrate and 80 Percent, 60 Percent, and 40 Percent Dilutions of that Concentrate**




The combined results suggest that TDS toxicity potential may significantly increase above about 3,800 mg/L, or when the intake water TDS concentrations exceed 750 mg/L. Because the ecosystem under evaluation commonly experiences TDS concentrations of more than 1,000 mg/L and marine organisms are common in this area, 750 mg/L represents a very conservative value. With more intensive evaluation, a higher no lethal effects limit may be identified.

In most cases, a 1:1 dilution of the concentrate was protective of the aquatic test organisms. In the worst case, if the receiving water contains 20 percent of the concentration present in the RO discharge, a protective dilution in river water would be about 60 percent (1.66 L river water: 1.0 L concentrate).

**Risk Characterization**

This investigation is the first phase of a more detailed effort to be undertaken if and when an RO facility is designed for this part of the St. Johns River. The model test results herein, however, can be interpreted and used as a first indication of the issues that will need to be fully explored later. This analysis also might be considered a hazard evaluation, as it is a prospective, desktop analysis that identifies potential, rather than realized risk.

> "Hazard is defined as a source of potential danger to the environment. Hazard assessment refers to an evaluation of inherent properties of, for example, contaminants to cause harm. Risk is defined as the probability that a hazard will be realized. In this regard, WET serves to identify hazard, and thus fits the first stage of an ecological risk assessment… Risk characterization builds on the results of the analysis phase to develop an estimate of risk, in particular to the assessment endpoints…In this regard, WET test measurement endpoints (e.g., survival, growth, reproduction) are appropriate for quantitative risk assessment. However, this alone does not provide a linkage to the possibility of real world (i.e., outside the laboratory) effects…" (Chapman, 2000).

The statutory limits and guidelines give relatively little direction in the matter of mineral ions typically found in freshwater. Chloride was the only major ion with a high hazard quotient. Barium and bromide also stood out as potentially hazardous, but in both cases, the average concentration in the river is an order of magnitude higher than the primary screening value (and concentrate is less than 10 times the river value). Therefore, the secondary screening value may be a more useful indicator of hazard. The secondary hazard quotients for barium were not greatly elevated and no secondary screening value was identified for bromide.

The numeric TDS concentration limit for Florida freshwater may be exceeded during the seasonal cycle of the river. The biological community in this river is adapted to large changes in salinity, and the available records suggest that such changes can occur rapidly. Thus, the organisms are pre-selected for reduced sensitivity to relatively high TDS concentrations and relatively rapid fluctuations of salinity. However, the TDS solution fractions remain relatively constant over the range of TDS changes.

Test organisms also vary in their sensitivity to TDS. Goodfellow et al. (2000) analyzed data suggesting that if the LC50 for the fathead minnow is lower than that of *C. dubia*, it is probably safe to rule out TDS as a dominant toxicant. If the situation is reversed, it indicates that TDS may be a major factor. The fathead minnow had a higher LC50 than *C. dubia* in the model results testing the pilot plant concentrate (Table 93).

The American Petroleum Institute (1998) considered conductivity of greater than 2,000 microsiemen per centimeter (µS/cm) to indicate that the TDS concentration has the potential to affect freshwater test species. This opinion is supported at least narrowly by the analysis presented here. Comprehensive WET test results for concentrate of this type in freshwater are not generally available, and the model used is the most comprehensive attempt to estimate the overall effects.

The ions in the concentrate that were most out of balance with the receiving water are the least toxic of the dominant constituents of the concentrate. Relative ion toxicity in the studies on which the model is based was on the order of $K^+ > HCO3^- \approx Mg^+ > Cl^- > SO4^{2-}$ (Mount et al., 1997). Another study of the toxic effects of common ions on the three test species used in the model (API, 1998) showed that “$Cl^-$ is more toxic that $Na^+$ and $SO4^{2-}$ is less toxic than $Cl^-$.“

WET acute toxicity tests typically are developed for 24 to 96 hours on a range of concentrate dilutions as part of the basis for toxicity evaluation of whole effluents (EPA, 2002). Sufficient data for 96-hour tests were only available for the fathead minnow (Tietge, Mount and Gully, 1994; Mount et al., 1997). The model results for *Ceriodaphnia dubia* and *Daphnia* are based on data from 24- to 48-hour acute toxicity tests only.

Diamond and Daley (2000) presented evidence from the analysis of a database of 250 point discharge tests that may help interpret the results provided here. They found that the relationship between whole effluent tests and stream biota "will be strongest for acute test endpoints and weakest for chronic test endpoints, particularly sublethal endpoints." Fathead minnow test endpoints were better related to in-stream biological conditions than were *Ceriodaphnia*. Moreover, "effluents that comprised less than 20 percent of the stream had a low probability of exhibiting impairment, even if several WET failures were observed over a one year period…". These findings suggest that the model results above can be interpreted as evidence (albeit indirect) that the risks to the environment from a discharge of this type may be relatively low at any concentration. The effluent concentrations causing the significant minnow mortality resulted from the maximum TDS concentration tested and passed the acute toxicity test when only slightly diluted (Table 7). The necessary dilution level should be easy to achieve even under low flow conditions.

It appears from this first evaluation that TDS may be a primary toxicity factor relative to any particular ion. Because the lowest river discharge at which water will be withdrawn is 378 cfs, the projected 10-mgd (15.5-cfs) concentrate discharge will always be less than 5.1 percent of the river discharge (15.5 cfs / 303 cfs). A relatively small dilution of the concentrate likely would eliminate TDS toxicity to the test organisms (Table 93), even at the highest concentrate values. This suggests that potential risks are greatest at the end of the pipe and will rapidly fall as the concentrate is mixed with the river water. Thus a mixing zone is a key feature to the permitting strategy for a surface water treatment facility in the Middle St. Johns River.

Bromide and chloride should continue to be considered as potential ion toxicants because of the screening analysis results. Specific tests to separate TDS effects from single ion effects would have to be considered. In any case mixing would ameliorate effects.

Mickley and Associates (2001) evaluated a large number of membrane concentrates, primarily from groundwater sources, and found that ion toxicity was the primary and probably the only cause of toxicity. Treatment processes were not involved. Calcium and fluorides were implicated as primary toxicants. In this case, there is no *a priori* reason to believe that calcium is a likely cause, and fluoride is not a major constituent of this concentrate.

### Uncertainties

This assessment contains some large uncertainties, resulting from the following:

- The absence of toxicity tests on a concentrate to accurately establish sensitivities.
- The lack of comparative information on which to base an opinion. Application of a concentrate to a major freshwater river is a novel application for Florida.
- The current level of understanding about TDS effects on the structure and function of the freshwater ecosystem present in the Middle St. Johns River.

The effect of these uncertainties can be reduced and managed using results of a more intensive evaluation of the concentrate and of the river, which will have to be done if and when a full-scale plant is proposed. The analysis here bracketed the uncertainty contained in this first-level analysis in several ways:

- The minimum river discharge for withdrawal was chosen conservatively, and a maximum discharge was also considered in spite of the high likelihood that the water was already of sufficiently high quality to manage without risk.
- A range of numeric water quality criteria or guideline values were identified for the constituents of the TDS, and the hazard associated with the constituents was developed on that basis.
- A range of concentrates was estimated that bracketed the likely conditions under which water would be withdrawn from the river. These estimates were used to model potential toxicity.

Currently, the future location of RO plants in this reach of the river has not been determined. However, the results of this analysis indicate that a discharge of this type in the Middle St. Johns River may be accomplished in ways that are protective of the environment and meet current regulatory criteria and statutes while understanding that other issues in addition to toxicity must be considered.

## Risk Management

Risk management considers the actions that can be taken to avoid and reduce environmental risks that may result from a discharge.

Risk management has already been considered in this analysis in selecting a conservative minimum river discharge for withdrawal. This was done so that dilution volumes would be relatively high, and to avoid taking water in conditions near to minimum flow criteria. Reverse flow occurs during otherwise low-flow conditions and probably should be avoided as part of the minimum flows avoidance strategy.

Other actions that should be considered as part of risk management for this type of discharge include the following:

- Use of maximum TDS withdrawal limit as well as river discharge withdrawal criteria
- Use of appropriate chemicals in the RO treatment chain
- Use of a single channel area of the river as a discharge point
- Use of rapid diffusion discharge heads to ensure the maximum mixing in the minimal mixing area to minimize the area and temporal extent of acute toxicity effects.
- Use of ecosystem monitoring

The use of TDS maximum withdrawal limits will provide an additional tool to maintain plant discharges within permit limits, regardless of the discharge conditions. The use of a TDS standard for withdrawal in addition to a flow is suggested because RO plant operation and permitting are based on expected water quality. As TDS increases, toxicity increases. Withdrawal control based on discharge alone may result in water quality exceedences because of the variability of TDS concentrations within a narrow flow range. It also may help maintain the most efficient plant operation.

Many chemicals can be used in the pretreatment chain for an RO plant. The use of chemicals that increase the levels of ions the least, and provide the least toxic ions, should be made a part of the plant design. The chemical selection process for the RO pilot plant did not include consideration of potential toxicity, but the chemicals selected were those with low toxicity potential. However, a specific effort to evaluate and identify the best chemicals will provide increased public and regulatory confidence in safe plant operation.

Flow concentrated in single channel river sections provides greater dilution and potentially more mixing than multi-channel conditions. In the evaluation presented in Barnes, Ferland &Associates and CH2M HILL (2003), the river in single-channel areas was deeper than in areas where the channel is braided. The river cross section in single channel areas also has more volume per unit area of river bottom/edge, where much of the biological activity (e.g., attached benthic invertebrates, aquatic plants) is located. This is where the river ecosystem may be the most sensitive. Therefore a large, single-channel system would provide less potential exposure to benthic organisms.

A larger, deeper river channel will provide more opportunity for the construction of structures that provide immediate adequate mixing. Because the concentrate will be denser than the river water, it will tend to fall. Therefore, ensuring good initial mixing is critical to reducing any potential area of impact. A design for the discharge pipe that most rapidly mixes the concentrate, such as multiple diffuser heads, will further the goal of minimizing the area within the receiving water body where the environment may be adversely affected.

The results of this analysis suggest that relatively little mixing of the concentrate and river water is required to reduce potential toxicity to safe levels. A 1.7:1 mix of river water with the highest strength concentrate defined herein (a 60 percent dilution) was found to be sufficient to eliminate the projected toxicity. Therefore, it should be relatively easy to design a discharge system for the type of concentrate described here that protects the ecosystem.

Lake Monroe currently does not meet designated Class III water quality standards for un-ionized ammonia, lead, and selenium, among others (see Table 6 for numeric criteria). Data on these constituents were not available in the datasets used in this analysis, but a concentrate created from the lake water and discharged there could be considered to contribute to impairment of the water body. Therefore, placement of a discharge into the lake will have to be carefully evaluated in this respect.

Careful ecosystem pre-operational and post-operational monitoring is recommended because large, brackish to freshwater rivers not in tidal areas are poorly understood, and relatively rare. An adaptive management monitoring effort that provides increased understanding of the river while monitoring for potential effects would provide the best long-term protection for the environment and the maintenance of Class III conditions.

# T&O REMOVAL EVALUATION DISINFECTION TESTING

Dozens of chemicals may cause taste and odor (T&O) problems in surface waters. However, the most prevalent T&O compounds are 2-methylisoborneol (MIB) and geosmin. Geosmin and MIB, two earthy-musty odor compounds, regularly cause problems with taste and odor in drinking water.

To evaluate T&O removal, PAC isotherm testing was performed at the CH2MHILL Applied Sciences Lab in Corvallis, Oregon. Further, flat sheet testing was conducted to evaluate T&O compound removal using RO membranes. Testing was performed using granular media filtered water pretreated by Actiflo clarification (clarified/filtered). Geosmin and MIB were not detected in the clarified/filtered water sample. The clarified/filtered sample was therefore spiked with geosmin and MIB in order to effectively evaluate removal of these compounds. The testing conditions were as follows:

- Temperature = 25°C
- Target MIB and Geosmin Concentration = 100 ng/L each
- PAC dosages = 0 mg/L, 5 mg/L, 20 mg/L, 40 mg/L and 80 mg/L
- Sampling Times = 0 min, 15 min, 30 min, and 5 days

The MIB and geosmin concentrations spiked to the water were significantly higher than those expected in the river. However, the approach taken in this exercise was to estimate "worst-case" T&O conditions and to provide significant resolution of the analyte removal.

Figure 136 illustrates the removal of geosmin, MIB and DOC at varying PAC dosages as a function of contact time. As the figure suggests, geosmin was more readily removed from the samples compared to MIB at the 15 minute and 30 minute contact times. Further, the data suggests geosmin and particularly MIB decreased significantly after 5 days of contact time. However, the control sample (0 mg/L PAC dose) suggests that decay of the analytes was occurring without the use of PAC. This may indicate that the decreases in concentration after 30 minutes of contact time may not be due to PAC adsorption, but rather, natural decay.

Figure 137 suggests the 40 mg/L PAC dosage achieved approximately the same level of removal at both the 15 and 30 minute contact time for all three analytes. In fact, the 40 mg/L PAC dosage achieved more than 40 percent removal of MIB and nearly 70 percent removal of geosmin. Further, this dosage achieved an additional 35 percent DOC removal.

**Figure 136. Removal of Geosmin, MIB, and DOC Based on PAC Dosage**

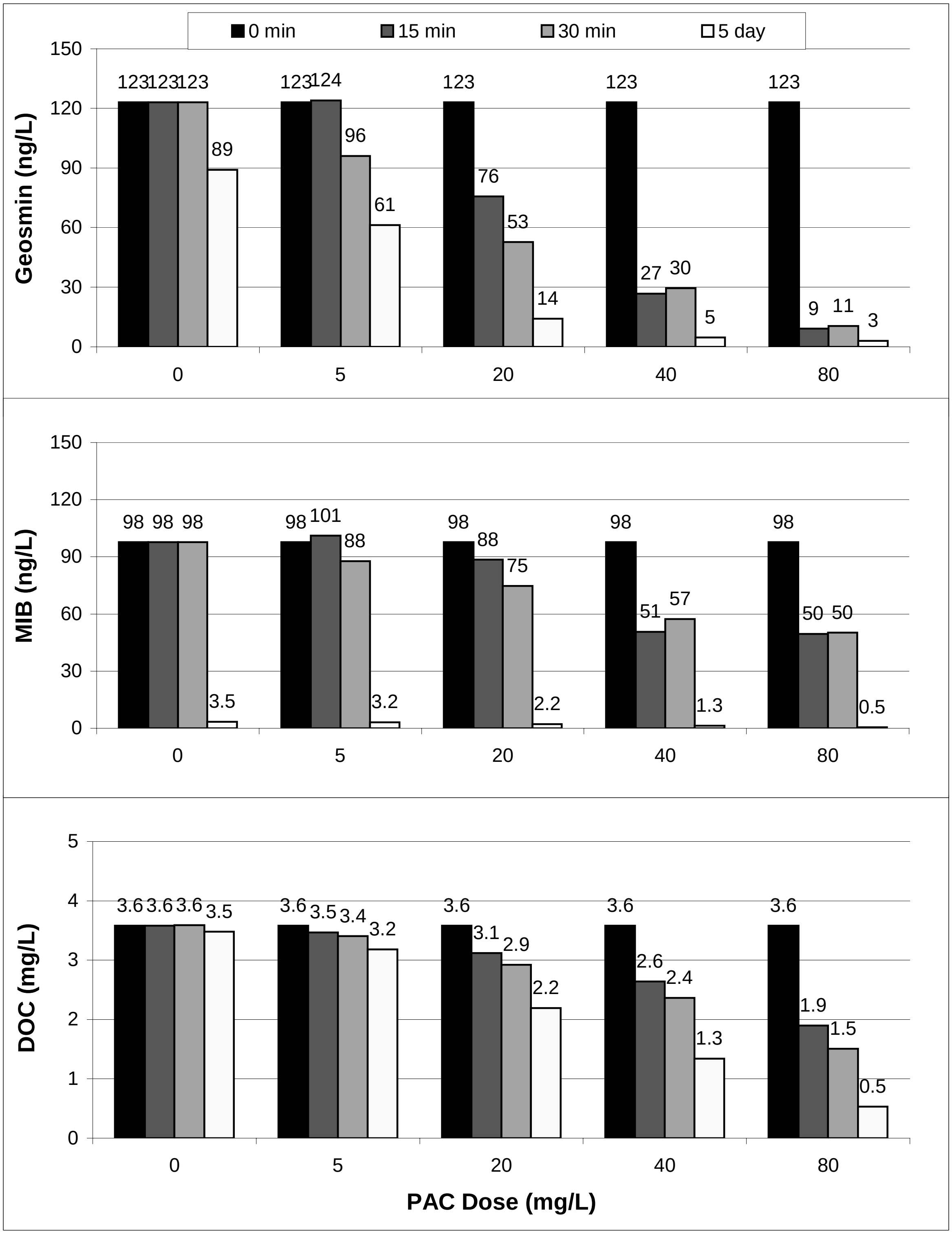
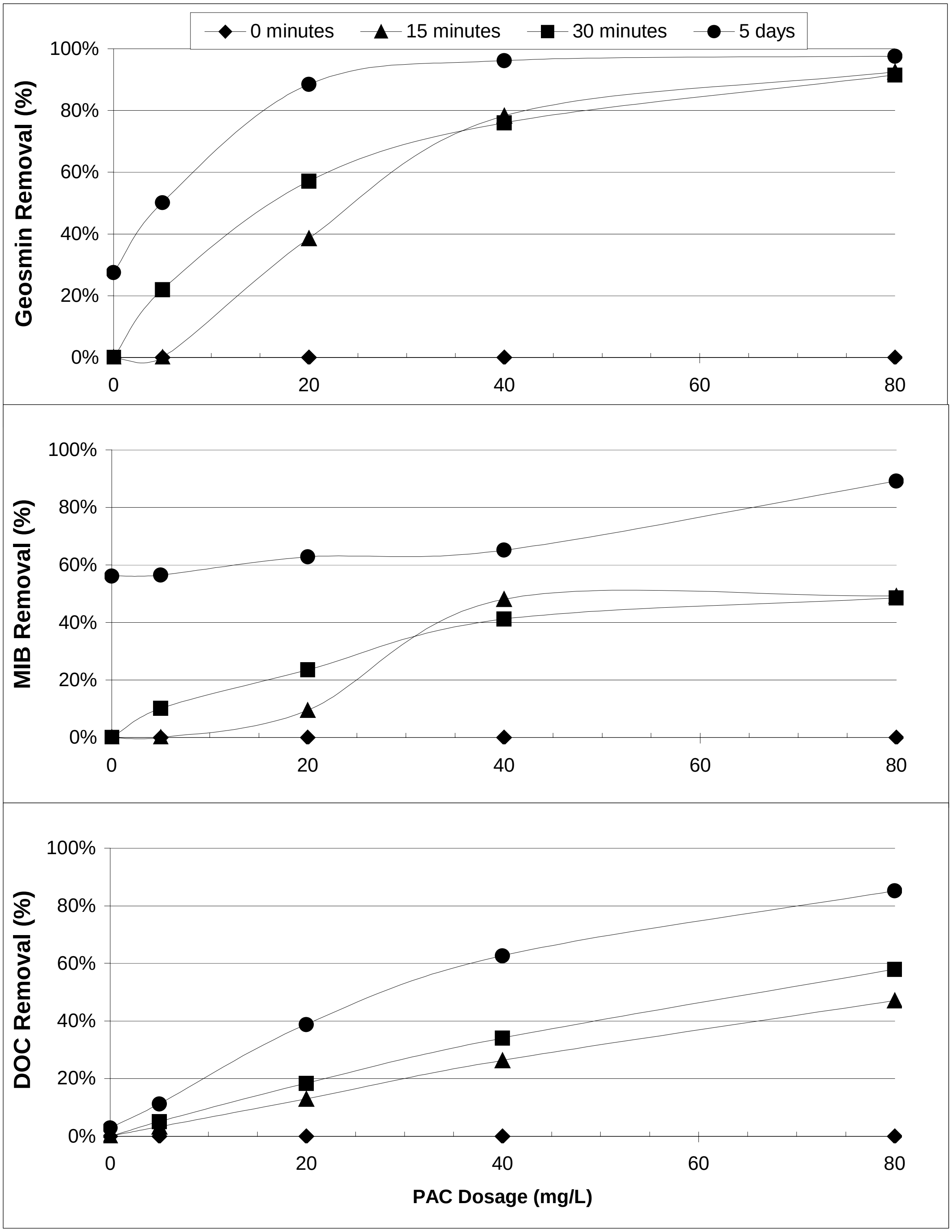


**Figure 137. Percent Removal of Geosmin, MIB, and DOC Based on PAC Dosage**



As the figure suggests, at the 80 mg/L PAC dosage, nearly 20 percent more geosmin was removed from the system, while little to no additional MIB was removed. This further illustrates the point that geosmin is more readily removed from solution when compared to MIB.

Figure 138 illustrates the ineffective removals of the three parameters by the 5 mg/L dosage, while the 80 mg/L dosage was the most effective at removal of the parameters within the first 15 to 30 minutes. Again, the additional removal observed at 5 days is likely due to natural degradation of the parameters which suggests the initial 15 to 30 minutes of contact time would be sufficient to remove the T&O parameters.

Flat sheet tests were conducted using a Filmtec BW30FR RO membrane flat sheet to evaluate the additional removal of T&O by the membranes. The tests were conducted on the 15 gfd RO element used for membrane testing at the pilot site. The element was used during the flux evaluation and had 1250 hours of operation. The flat sheet test was operated at a flux of 12 gfd and a recovery of 75 percent.

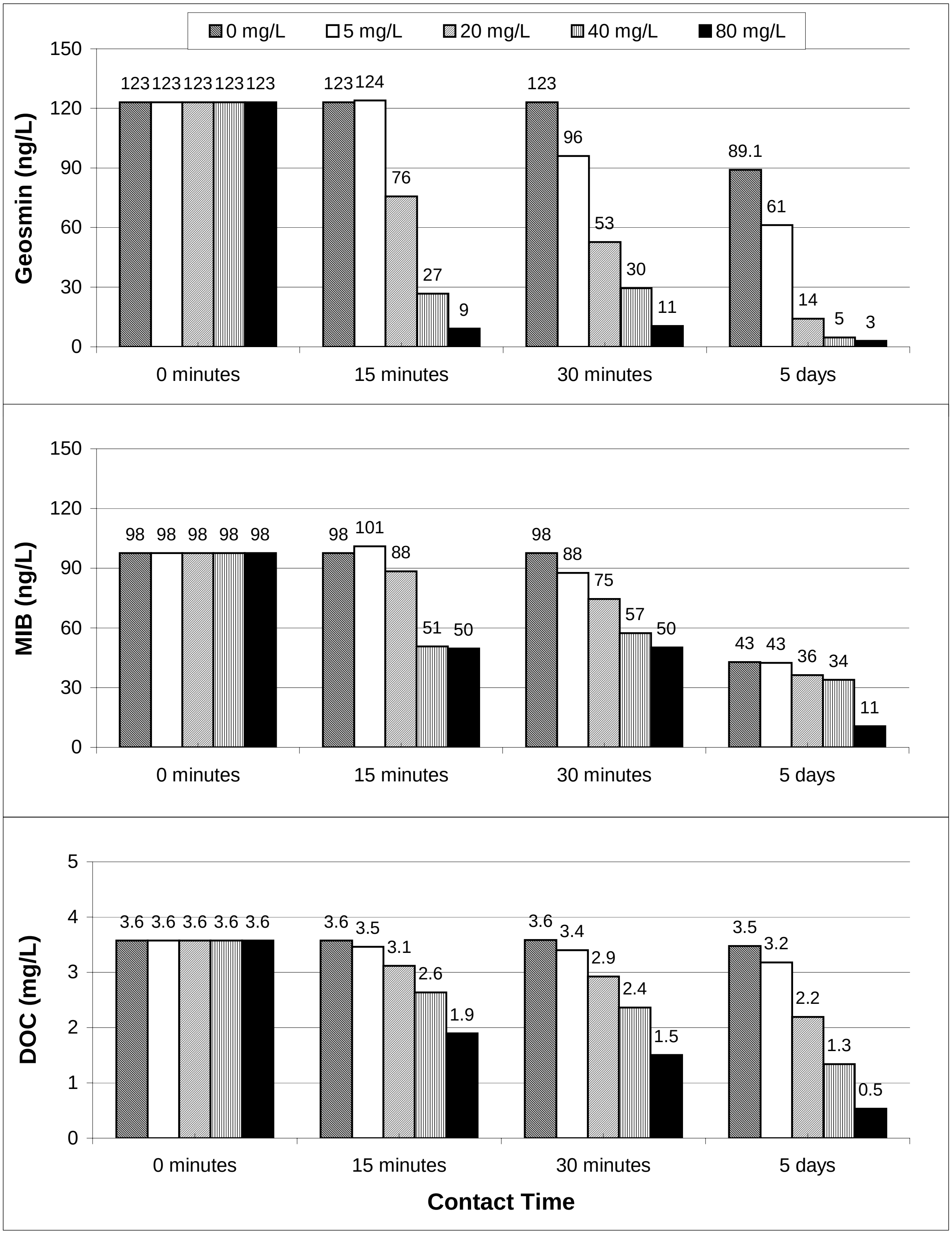
As Table 94 indicates, geosmin and MIB were removed to below detectable limits for both trials. Both parameters were removed more than 93 percent in all cases. The testing also indicated that membrane degradation due to chloramines and fouling may result in more passage of these taste and odor compounds over time. However, any decrease in rejection of these compounds by the membranes, as they approach replacement, can be mitigated with higher PAC dosages during pretreatment. Therefore, the use of PAC in conjunction with the RO membranes is an effective approach for taste and odor control for this source water.

In addition, some preliminary testing indicated that the BW30FR, even with only 82 percent salt rejection was able to achieve over 90 percent removal of Geosmin and MIB. This would suggest that the decrease in Geosmin and MIB rejection, as the salt passage increased due to fouling and chloramine addition, may be minimal.

**Table 94. Flat Sheet Test Results**

| Trial | Geosmin | | | MIB | | |
|---|---|---|---|---|---|---|
| | Feed Water (ng/L) | RO Permeate (ng/L) | Removal (%) | Feed Water (ng/L) | RO Permeate (ng/L) | Removal (%) |
| Trial 1 | 86.6 | < 4.0 | > 95.0 | 59.6 | < 4.0 | > 93.0 |
| Trial 2 | 129 | < 4.0 | > 96.0 | 119 | < 4.0 | > 96.0 |

**Figure 138. Removal of Geosmin, MIB, and DOC Based on Time**



## Disinection Testing

Primary disinfection using chlorine or ultraviolet irradiation will be required for water treatment. The use of ozone was eliminated from consideration due to high levels of bromide ($Br^{-}$>0.5 ppm for 80 percent of the year) in the raw water which would result in high levels of bromate formation.

Bench scale disinfection studies were conducted at the applied sciences lab of CH2M HILL in Corvallis, Oregon. Chlorine experiments consisted of demand/decay and DPB formation testing. Ultraviolet (UV) testing consisted of UV light scans (190 nm to 350 nm) of various filtered waters from both Actiflo and SuperP during two seasons. Further, UV scans were performed on the RO permeate from the water for comparison and selection of the best point of UV disinfection.

With respect to oxidants and disinfectants, non-chemical processes such as UV disinfection will not generate any Disinfection By-Products (DPBs). However, chemical oxidation/disinfection processes such as free chlorine will result in the formation of DBPs. Chloramination, as an alternative to free chlorine, is a weak oxidant and disinfectant but will result in much lower DBP levels than free chlorine. However, chloramines would not be feasible as a primary disinfectant due to it's comparatively weak oxidation potential when compared to free chlorine. For disinfection, the pathogens of primary concern include:

- Coliforms
- Giardia
- Cryptosporidium
- Viruses

Challenge studies with coliforms, *Giardia* and *Cryptosporidium* removal, were performed during field testing and are described previously.

### Chlorine Disinfection and Disinfection By-Product Formation

When using chlorine for disinfection, DBPs are of great concern. DBPs result when free chlorine reacts with natural organic matter (NOM) in the source water. Several DBPs have been identified as health concerns; therefore, the EPA regulates maximum levels of these DBPs in treated water.

The DBPs of primary concern when chlorinating include:

- Total trihalomethanes (TTHMs)
- The sum of five haloacetic acids (HAA5s)

Currently, the Stage 1 Disinfection By-Product Rule (Stage 1 DBPR) requires the annual average of TTHM and HAA5 concentrations to be below 80 µg/L and 60 µg/L, respectively. These requirements are based on a system wide running annual average in which quarterly samples are averaged for the previous year of data. Future regulation, under the Stage 2 Disinfection By-Product Rule (Stage 2 DBPR) will require compliance with these levels at each point in the distribution system, known as a location running annual average.

To ensure compliance with these regulations, chlorine demand/decay testing was performed at the CH2M HILL Applied Sciences Lab in Corvallis, Oregon. Further, the formation of TTHMs and HAA5s was evaluated based on contact time.

Testing was performed on two finished waters, the RO permeate and on filtered water which had been pretreated by Actiflo clarification (clarified/filtered). The basis of the testing was to evaluate the use of free chlorine as a primary disinfectant for viruses and *Giardia* for both desalting and non-desalting alternatives. The use of free chlorine was evaluated to also comply with Stage 2 D/DBP regulations. As mentioned earlier, ozone is not being evaluated due to the very elevated levels of bromide in this source water and the potential for bromate formation posed by ozone.

These two waters were tested to illustrate the recommended disinfection strategy for a number of reasons. First, a number of different end uses are possible for this treated water. The final blend characteristics of this water with other utilities will not be determined at this time. The intent of this testing is to evaluate the two extreme conditions, the highest organic levels with no desalting (clarified/filtered water) and then the lowest organic levels (RO permeate). The premise is to identify the available contact time for each alternative as well as if chlorine or chloramines can be used as the residual disinfectant.

The results of the clarified/filtered water (no desalting) testing indicate that up to 15 minutes of contact time is available with free chlorine for *Giardia* and virus inactivation while maintaining TTHM an HAA5 levels below 60 ppb and 40 ppb levels, respectively. This suggests that any alternative from no RO to any percentage of RO treatment (other than 100 percent RO treatment) can use free chlorine as the primary disinfectant for *Giardia* and viruses and comply with Stage 2 D/DBP regulations. Under this scenario, due to the long-term formation potential of this water and the length of travel to blend with other systems, chloramines are recommended as the residual disinfectant to maintain compliance with Stage 2 D/DBP Rule. Under this scenario, inactivation for *Cryptosporidum* is recommended with UV. Therefore, the recommended disinfection strategy for any alternative, from no desalting to less than 100 percent RO capacity, is primary disinfection for *Giardia* and viruses with free chlorine, inactivation of *Cryptosporidium* with UV and chloramines as the residual disinfectant. Optimization of this strategy can be conducted to see if, for example, 85 percent to 95 percent RO treatment will remove enough organics to maintain free chlorine as the residual disinfectant. However, since this optimization is totally dependent on the amount of time the water is in the transmission/distribution system as well as blended water characteristics, this testing would need to be site specific and those details are not available at this time.

For the 100 percent RO alternative, as expected, there was practically no formation of either THMs or HAAs with free chlorine. This is due to over 98 percent removal of organics with 100 percent membrane capacity. Under the 100 percent RO scenario, free chlorine can be used as both the primary and residual disinfectant while maintaining compliance with Stage 2 D/DBP regulations. Under this scenario, UV disinfection can be used if, for any time, the membranes need to be bypassed for maintenance and cleaning events so that plant production could continue.

The testing conditions were as follows:

- Temperature = 25 °C
- Target residual at 3 days = 1.5 mg/L as $Cl_2$
- Total and free chlorine sampling = 5 min, 15 min, 30 min, 60 min, and 3 days
- TTHM sampling times = 5 min, 15 min, 30 min, 60 min, and 3 days
- HAA5 sampling times = 5 min, 30 min, and 3 days
- Target pH = 8.0

The DOC level for the RO permeate was 0.4 mg/L compared to 4.0 mg/L for the clarified/filtered water. This would suggest that TTHM and HAA5 formation potential as well as chlorine demand would be higher for the clarified/filtered water when compared to the RO permeate. Figure 139 serves to illustrate these points. Figure 139 illustrates the TTHM, HAA5, and total chlorine concentrations at the five contact times for both the RO permeate and the clarified/filtered water.

As the figure suggests, the chlorine demand of the RO permeate was significantly less than the clarified/filtered water. The initial RO permeate chlorine dosage was 1.5 mg/L as $Cl_2$, while the final chlorine concentration after 3 days of reaction time was 1.31 mg/L as $Cl_2$. The initial clarified/filtered chlorine dosage was 7.0 mg/L as $Cl_2$ with a final chlorine concentration of 2.38 mg/L as $Cl_2$ after 3 days. For comparison, the chlorine demand for the clarified/filtered water was 4.6 mg/L while the demand for the RO permeate was 0.19 mg/L.

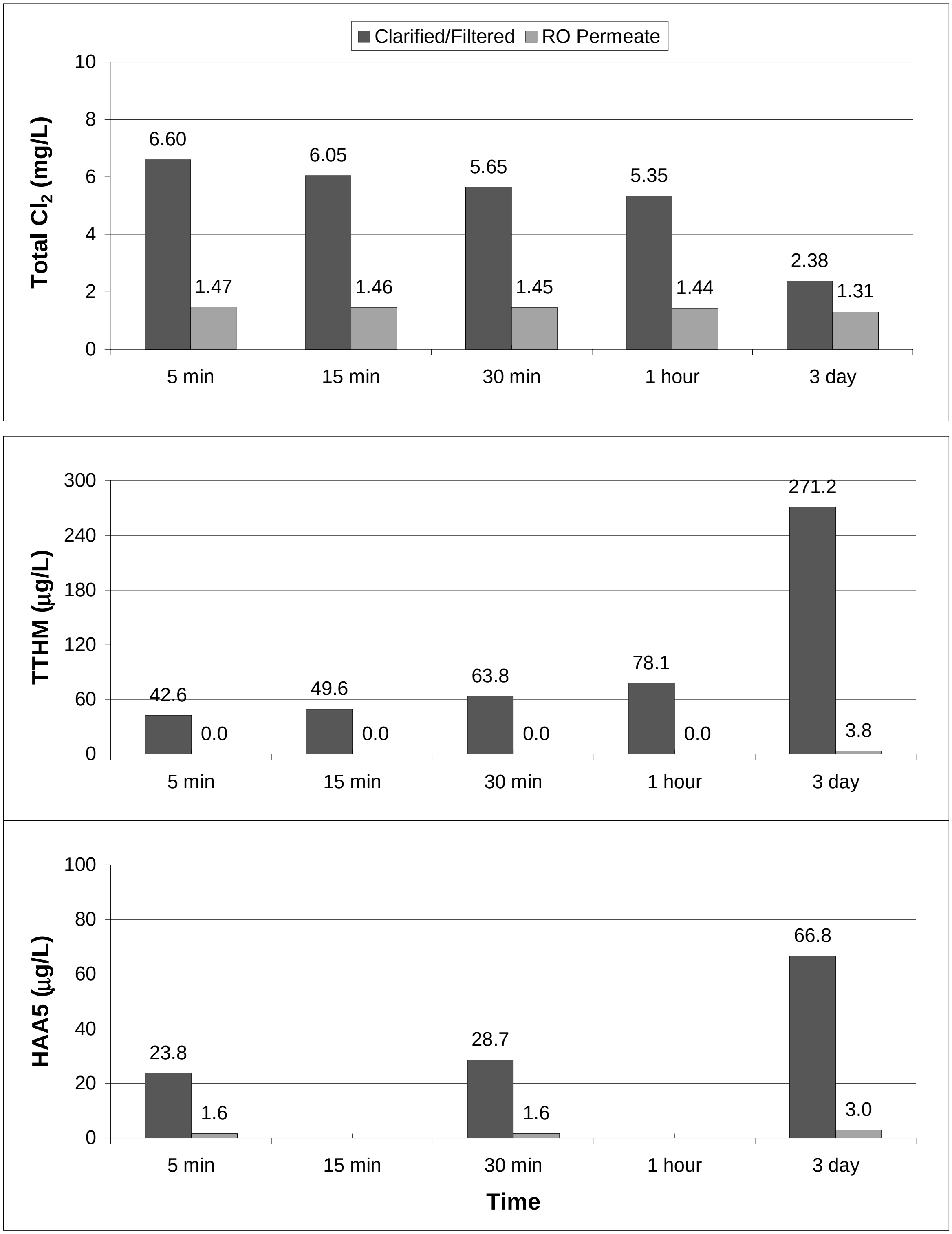
TTHM and HAA5 formation was significantly higher for the clarified/filtered water compared to the RO permeate. After 3 days of contact time, the RO permeate had only formed 3.8 µg/L and 3.0 µg/L of TTHMs and HAA5s, respectively. The clarified/filtered had formed 271.2 µg/L and 66.8 µg/L of TTHMs and HAA5s, respectively.

The figure suggests that a contact time with the clarified/filtered water of up to 1 hour could be possible without violation of the regulatory limit for TTHMs and HAA5s. However, TTHM levels at the 1 hour contact time were very close to the 80 µg/L limit, while TTHM formation at the 15 min and 30 min times was only 49.6 µg/L and 63.8 µg/L, respectively. This suggests that free chlorine contact time should be limited to between 15 and 30 minutes at the applied dosage of 7 mg/L as $Cl_2$.

These data suggest that using free chlorine as a disinfectant on the clarified/filtered water could be possible. However, the free chlorine demand and the disinfection byproduct formation potential of the clarified/filtered water suggest that chloramines would be needed for residual disinfection to allow compliance with the Stage 1 and Stage 2 DBPRs.

Alternatively, these data suggest that both primary and residual disinfection of the RO permeate would be possible. The DBP formation potential of the RO permeate was low enough to easily allow compliance with the Stage 1 and Stage 2 DBPRs.

**Figure 139. TTHM and HAA5 Formation and Chlorine Demand Decay**



## UV Disinfection

UV disinfection for primary disinfection in municipal water treatment is gaining popularity throughout the United States. One of the factors driving the need for UV disinfection is the upcoming the Stage 1 and Stage 2 DBPRs. Advances in UV technology have resulted in more efficient lamps and more reliable equipment, and therefore, the use of UV technology has increased dramatically. Further, UV light does not provide enough energy to form DBPs such as aldehydes or ketones. Non-ozone generating lamps can be specified to prevent any aldehyde formation. Because the UV does not react with halogens, there is no direct formation of THMs, HAAs, or haloacetic nitriles (HANs), and no bromate is formed.

UV has long been recognized as a cost-effective disinfectant for inactivation of bacteria and viruses, as evidenced by the many commercial applications in the pharmaceutical, food, and electronic industries as well as applications for municipal wastewater disinfection. Unlike oxidant-based disinfectants, UV systems use electromagnetic energy to inactivate microorganisms. UV disinfection is a physical process that uses photochemical energy to prevent cellular proteins and nucleic acids (i.e., DNA and RNA) from further replication. The germicidal effect of UV light is accomplished through the dimerization of pyrimidine nucleobases (e.g., thymine) on the DNA molecules to distort the normal helical structure and prevent cell replication. A cell that cannot replicate also cannot infect.

UV electromagnetic energy is typically generated by the flow of electrons from an electrical source through ionized mercury vapor in a lamp. Several manufacturers have developed systems to align UV lamps in vessels or channels to provide UV light in the germicidal range for inactivation of bacteria, viruses, and other microorganisms. The UV lamps are similar to household fluorescent lamps, except that fluorescent lamps are coated with phosphorous, which converts the UV light to visible light. Ballasts (i.e., transformers) that control the power to the UV lamps are either electronic or electromagnetic. Electronic ballasts offer several potential advantages, including lower lamp operating temperatures, higher efficiencies, and longer ballast life.

The UV electromagnetic waves range from 40 to 400 nanometers (nm) long (between the X-ray and visible light spectrums). The germicidal UV light wavelengths range from 200 to 300 nm, with the optimum germicidal effect occurring at 253.7 nm.

The inactivation of microorganisms by UV is directly related to UV dose; this is similar to CT used for other common disinfectants such as chlorine and ozone. The average UV dose is calculated as follows:

$$D = I \bullet t$$

where:

$D$ = UV Dose, $mW\text{-}s/cm^2$ ($mJ/cm^2$)
$I$ = *average* intensity, $mW/cm^2$
$t$ = *average* exposure time, s

The survival fraction is calculated as follows:

$$Survival\ Fraction = Log\ N/N_o$$

where:

$N$ = Organism concentration after inactivation
$N_o$ = Organism concentration before inactivation

This equation for UV dose indicates that dose is directly proportional to exposure time and inversely proportional to system flow rate. UV intensity (I) is a function of water UV transmittance and UV reactor geometry as well as lamp age and fouling. UV intensity can be estimated by mathematical modeling and confirmed by bioassay. Exposure time is estimated from the UV reactor-specific hydraulic characteristics and flow patterns. Mathematical models based on computational fluid dynamics are good tools to define the residence time distribution for various flow elements.

The major factor affecting the performance of UV disinfection systems is influent water quality. Particles, turbidity, and suspended solids can shield pathogens from UV light or scatter UV light–preventing it from reaching the target microorganism and thus reducing its effectiveness as a disinfectant. Some organic compounds (such as humic acids and fulvic acids) as well as inorganic compounds (such as iron and permanganate) can reduce UV transmittance by absorbing UV energy, requiring higher levels of UV to achieve the same dose.

Water turbidity and UV transmittance are commonly used as process controls at UV facilities. The UV percent transmittance of a water sample is measured by a UV-range spectrophotometer set at a wavelength of 253.7 nm using a layer of water 1 centimeter (cm) thick. The water UV transmittance is related to UV absorbance (A) at the same wavelength by the equation:

$$\text{Percent Transmittance} = 100 \times 10^{-A}$$

This indicates that UV absorbance (UVA) has an inverse relationship to UV transmittance (UVT) in the range of wavelengths measured for this study (190 nm to 360 nm). Therefore, lower levels of UVA result in higher levels of UVT.

To develop criteria for UV reactor design using UVT, UVA was evaluated in the CH2M HILL Applied Sciences Lab on Actiflo filtered, SuperP filtered, and RO permeate. UVT was compared between the different processes, Further, UVT during the fall (wet weather) and spring (dry weather) was compared.

As Figure 140 illustrates, UVT was highest for the RO permeate when compared to the SP/GF and the AF/GF. This was expected because higher levels of DOC generally result in high absorbencies at 254 nm. The DOC concentrations for the RO permeate, SP/GF, and AF/GF were approximately 0.4 mg/L, 2.6 mg/L, and 4.2 mg/L, respectively, providing correlation with the trend in UVT. As the figure suggests, at 253.7 nm, the UVT was greater than 99 percent for the RO permeate, while the UVT for the SP/GF and AF/GF was approximately 89 percent and 83 percent, respectively. The SP/GF achieved a 6 percent higher UVT likely due to the added removal of DOC using PAC during treatment.

Figure 141 suggests the UVT during the spring (dry season) was higher than during the fall (wet season). The UVT during the spring season was approximately 86 percent, 3 percent higher than the UVT from the same treatment process during the wet season. The DOC levels form the AF/GM were 4.2 during the fall season and 3.8 during the spring season, again correlating to the differences in UVT between the two samples.

The footprint size and the associated cost of a UV disinfection system depend on the selected UV design dose. Because UV transmittance is a direct measure of the capacity of the water to transmit UV light, the required size and cost of a UV system also depend directly on the design value of UV transmittance. UV reactor requirements could be minimized by disinfecting the RO permeate rather than the AF/GM or SP/GM due to the significantly lower UVT of the RO permeate. Further, because the RO system rejects approximately 15 percent of the water as a concentrated brine, the hydraulic requirements of the UV system could be reduced by as much.

For treatment of the RO permeate, a UVT of 98 percent could be used for design compared to a design UVT of 80 percent for the AF/GF or the SP/GF. While the SP/GF did achieve a significantly higher UVT, this was likely as a result of the use of PAC for treatment. Because PAC would only be employed during taste and odor events, the UVT of the AF/GF should be used as the "worst-case" for design.

**Figure 140. UV Transmittance for Comparison of RO Permeate, SP/GF, and AF/GF**

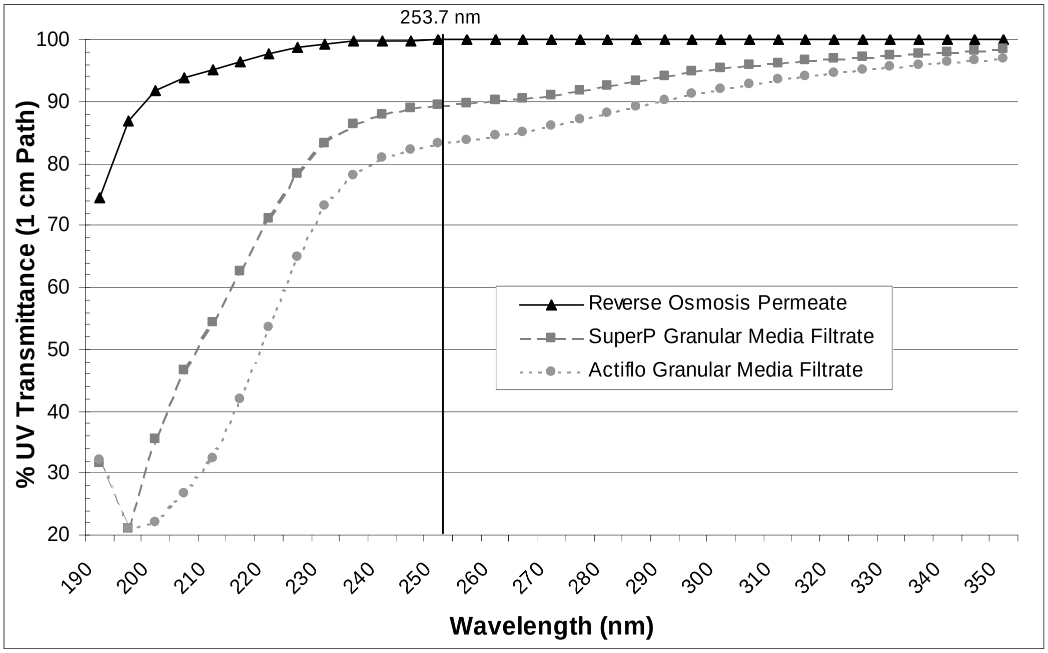
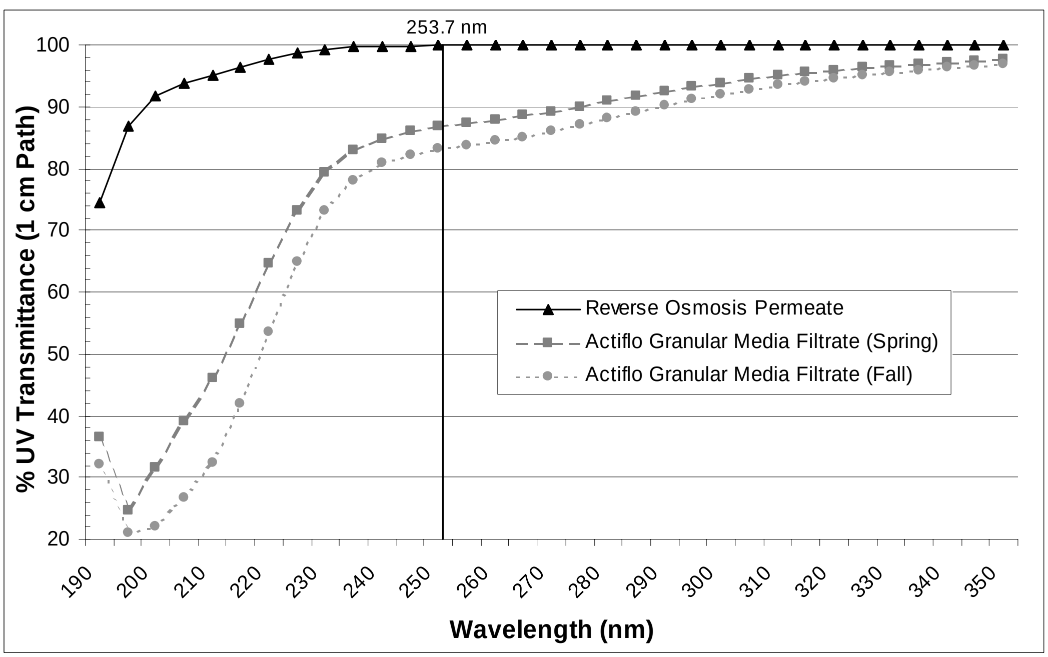



**Figure 141. UV Transmittance for Comparison of RO Permeate with Seasonal Variation in AF/GF**



# MICROBIAL CHARACTERIZATION AND CHALLENGE TESTING

Microbial testing was conducted to examine the water quality of Lake Monroe for natural microbial contaminants that are of concern in drinking water. This study was done to provide data to assess the microbial characteristics of the St. Johns River both above and below Lake Monroe to evaluate the potential areas at which a surface water plant may be sited. Specifically, levels of *Cryptosporidium, Giardia,* enteric viruses, several indicator organisms, and algal toxins were sampled.

An evaluation of treatment processes for reducing the levels of these contaminants during water treatment was also conducted. Microbial challenge studies were conducted during Phase 2A, 2B and 3 with the three pretreatment systems. The pilot feed streams to the treatment units were challenged with polystyrene micro-beads as a surrogate to *Cryptosporidium* oocysts. The challenge was conducted to evaluate the pathogen removal efficacy of the pretreatments.

## RAW WATER MICROBIAL CHARACTERIZATION

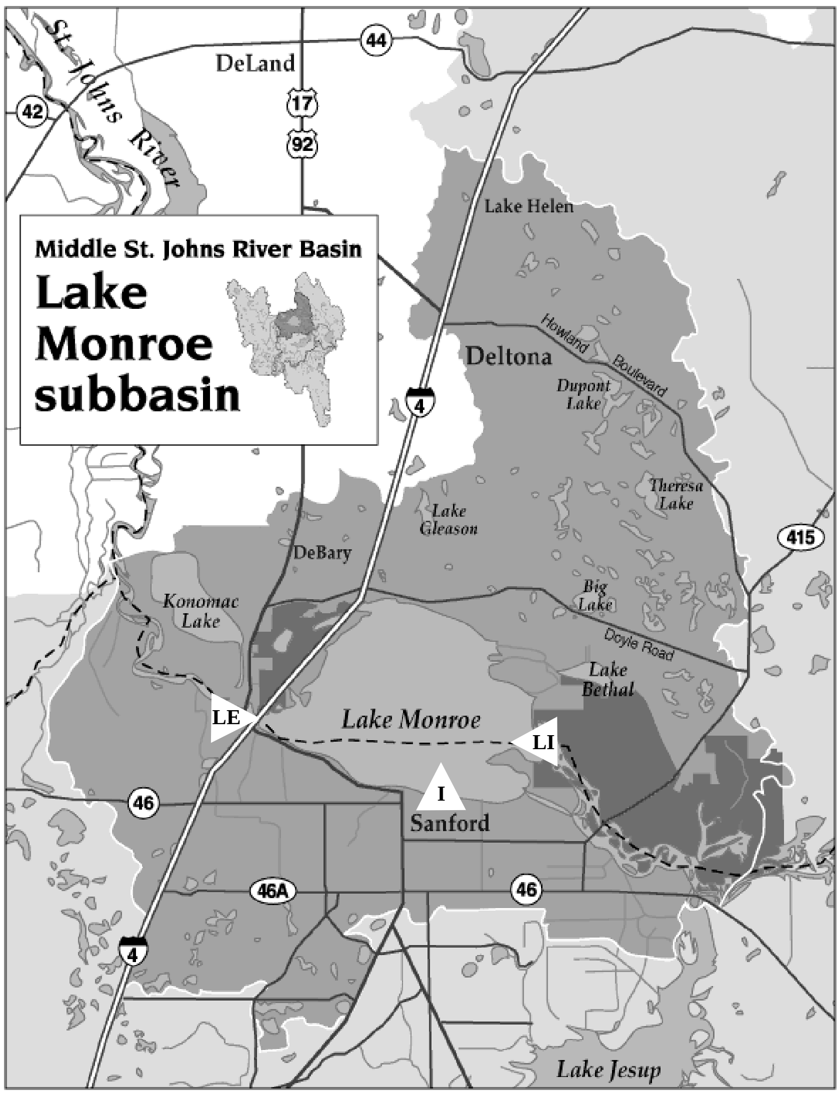
Raw water microbial testing examined the water quality of Lake Monroe for natural microbial contaminants of concern in drinking water. Three sites were monitored at Lake Monroe to develop a comprehensive characterization of the natural microbial water quality in Lake Monroe. The sites were monitored monthly for 12 months to assess the influent raw water to the Lake Monroe watershed, the raw water at the pilot plant intake, and the effluent raw water of the Lake Monroe watershed.

The characterization included the pathogens *Cryptosporidium* and *Giardia*, human enteric viruses, and *Clostridium* spp., in addition to indicator organisms: total coliforms, fecal coliforms, *Escherichia coli* (*E. coli*), *Enterococci* spp., and coliphages. Cyanobacteria, algal toxins and several physical parameters were also analyzed.

Figure 142 illustrates the three selected sampling sites on Lake Monroe. The lake influent site is represented by LI, the pilot plant intake is represented by I, and the lake effluent is represented by LE. While both the LI and LE sites were located on the Seminole/Volusia County Line, site I was located in the Seminole side of Lake Monroe. The sites were sampled by boat every 30 days for one year starting July 2002 until June 2003.

Two different surface discharging wastewater treatment plants are located adjacent to Lake Monroe. One plant is located in Volusia County slightly downstream of sample collection site LE and the other is located in Seminole County in Sanford, in close proximity to sample collection site I.

**Figure 142. Microbial Characterization Sample Collection Sites on the Middle St. John's River Basin**



## Testing Summary

Sampled organisms included the protozoan parasites *Cryptosporidium, Giardia,* enteric viruses, several indicator organisms, and algal toxins. Organisms, methods for assessment, and the laboratories for analysis are listed in Table 95. Samples were collected according to the standard methods described in Table 95 and preserved by storage in a cooler containing blue ice. Samples were shipped by overnight delivery to their respective locations (Michigan State University, East Lansing, Michigan; University of Florida, Gainesville, Florida) or returned directly to the laboratory at Orange County Utilities (Orlando, Florida). While shipping bacteria samples in this way is considered an acceptable practice, there is a risk that the bacterial growth could continue, despite the cold temperature. Therefore, as a control Orange County Utilities simultaneously analyzed for fecal coliforms and E. coli.

Several physical parameters were also assessed in the field during each microbial sampling event including pH, turbidity, temperature, chlorine residual, salinity, dissolved oxygen, and conductivity. Flow rates were determined using USGS station 02234500 located adjacent to the LE sampling site. Daily rainfall data were obtained from the National Oceanographic and Atmospheric Administration web site using the Climvis (Version 6) database for the Sanford International Airport located in close proximity to Lake Monroe.

**Table 95. Selected Parameters and Methods for Assessment of Microbial Water Quality**

| Organism/Analyte | Analysis Method | Analysis Laboratory |
|---|---|---|
| Cryptosporidium | USEPA Method 1623 | Orange County Utilities Laboratory |
| Giardia | USEPA Method 1623 | Orange County Utilities Laboratory |
| Total Coliforms | SM 9222B | Michigan State University |
| Fecal Coliforms | SM 9222D | Michigan State University;<br>Orange County Utilities Laboratory |
| E. coli | SM 9222D confirmation | Michigan State University;<br>Orange County Utilities Laboratory |
| Enterococci spp. | USEPA Method 1600 | Michigan State University |
| Clostridium perfringens | Bisson and Cabelli 1979; Sartory et al. 1998 | Michigan State University |
| Coliphage | USEPA Method 1602 (modified) | Michigan State University |
| Enteric viruses | EPA 600-4-84-013 | University of Florida |
| Microcystin | ELISA | Michigan State University |

ELISA = Enzyme Linked Immuno-Sorbent Assay

*Cryptosporidium* and *Giardia* were simultaneously analyzed by USEPA Method 1623 at the Orange County Utilities Laboratory (Orlando, FL). Total coliforms, fecal coliforms, *E. coli*, *Enterococci*, and *Clostridium* were analyzed at MSU. Samples were analyzed using membrane filtration methods along with the coliphage analysis by double agar overlay methods. Orange County Utilities Laboratory also analyzed the samples for fecal coliforms and *E. coli*. Microcystin algal toxins were analyzed in duplicate using the Microcystin Kit (EnviroLogix, Portland, Maine) by Enzyme Linked Immunosorbent Assay (ELISA) at MSU. The detection limit of the kit was 50 ng/L. Enteric Viruses were analyzed at the University of Florida using a most probable number procedure.

## Sampling Results

Chemical and physical parameters are summarized in Table 96 and Figure 143 for the three sampling sites. Average, max, min, standard deviation, and coefficient of variance are summarized for each parameter. Further, lake wide values are summarized and were determined by combining the three data sets.

Stream flow data was acquired from USGS station 02234500 near Sanford, Florida. Stream flow ranged from –653 Ft3/s in May 2003 to 10,000 Ft3/s in September 2002 and was highest between July and September 2002 suggesting rainy season conditions. Another lesser peak was observed from December 2003 through January 2003.

Rainfall was measured at the Sanford International Airport. Heavy rains occurred on the day of the September 2002 sampling event and at least 3 days prior to the February, March, May, and June 2003 sampling events. Further, light rain occurred prior to sampling in October, November, and December 2002, and April 2003.

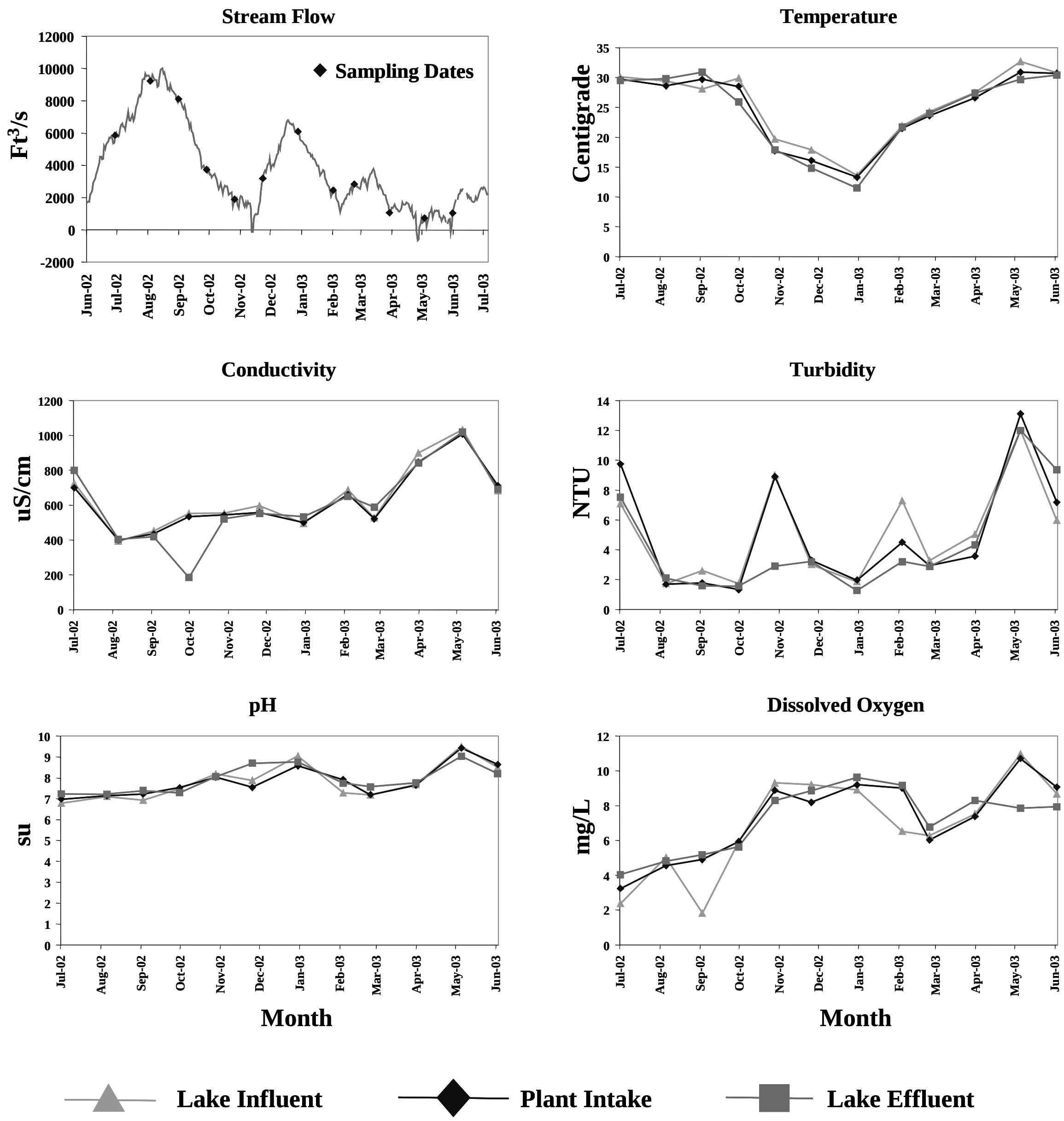
Water temperature was consistent from site to site and declined from a high of 32.7 °C in July 2002 to 11.5 °C in January 2003 and gradually increased again to 30 °C by June 2003. Both DO and pH generally increased from the start of the study. Lake wide DO ranged from 1.83 mg/L to 10.98 mg/L while pH ranged from 6.8 to 9.5.

Conductivity was relatively consistent between sites, with peaks in July 2002 and from April to May 2003 during low stream flows. Values ranged from 18.4 to 103.2 S/m with an average of 61.7 S/m. As Figure 143 suggests, conductivity was similar from site to site throughout sampling. However, the October 2002 conductivity sample at the LE site was likely an anomaly since the measurement was significantly different from the LI and I values for that date.

**Table 96. Lake Monroe Chemical and Physical Parameters Summary; Microbial Characterization**

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance | Number |
|---|---|---|---|---|---|---|---|
| **Lake Influent** | | | | | | | |
| Temperature | $^oC$ | 25.5 | 32.7 | 13.6 | 6.0 | 0.24 | 12 |
| pH | | 7.8 | 9.5 | 6.8 | 0.9 | 0.12 | 12 |
| Dissolved Oxygen | (mg/L) | 6.9 | 11.0 | 1.8 | 2.8 | 0.41 | 12 |
| Conductivity | (S/m) | 63.2 | 103.2 | 39.2 | 18.6 | 0.29 | 12 |
| Turbidity | (NTU) | 5.0 | 12.0 | 1.7 | 3.3 | 0.66 | 12 |
| **Plant Intake** | | | | | | | |
| Temperature | $^oC$ | 24.7 | 30.9 | 13.3 | 6.2 | 0.25 | 12 |
| pH | | 7.8 | 9.4 | 7.0 | 0.7 | 0.09 | 12 |
| Dissolved Oxygen | (mg/L) | 7.3 | 10.7 | 3.2 | 2.3 | 0.32 | 12 |
| Conductivity | (S/m) | 61.8 | 100.7 | 39.9 | 17.6 | 0.29 | 12 |
| Turbidity | (NTU) | 5.0 | 13.1 | 1.3 | 3.8 | 0.76 | 12 |
| **Lake Effluent** | | | | | | | |
| Temperature | $^oC$ | 24.5 | 30.9 | 11.5 | 6.6 | 0.27 | 12 |
| pH | | 7.9 | 9.0 | 7.2 | 0.6 | 0.08 | 12 |
| Dissolved Oxygen | (mg/L) | 7.2 | 9.6 | 4.0 | 1.9 | 0.26 | 12 |
| Conductivity | (S/m) | 60.0 | 101.9 | 18.4 | 22.2 | 0.37 | 12 |
| Turbidity | (NTU) | 4.3 | 12.0 | 1.3 | 3.4 | 0.79 | 12 |
| **Lakewide** | | | | | | | |
| Temperature | $^oC$ | 24.9 | 32.7 | 11.5 | 6.1 | 0.24 | 36 |
| pH | | 7.8 | 9.5 | 6.8 | 0.7 | 0.09 | 36 |
| Dissolved Oxygen | (mg/L) | 7.1 | 11.0 | 1.8 | 2.3 | 0.32 | 36 |
| Conductivity | (S/m) | 61.7 | 103.2 | 18.4 | 19.1 | 0.31 | 36 |
| Turbidity | (NTU) | 4.8 | 13.1 | 1.3 | 3.4 | 0.71 | 36 |
| Stream Flow | ($ft^3/s$) | 3827 | 10000 | -653 | 2605 | 0.68 | 12 |

**Figure 143. Lake Monroe Chemical and Physical Parameters Temporal Trends; Microbial Characterization**

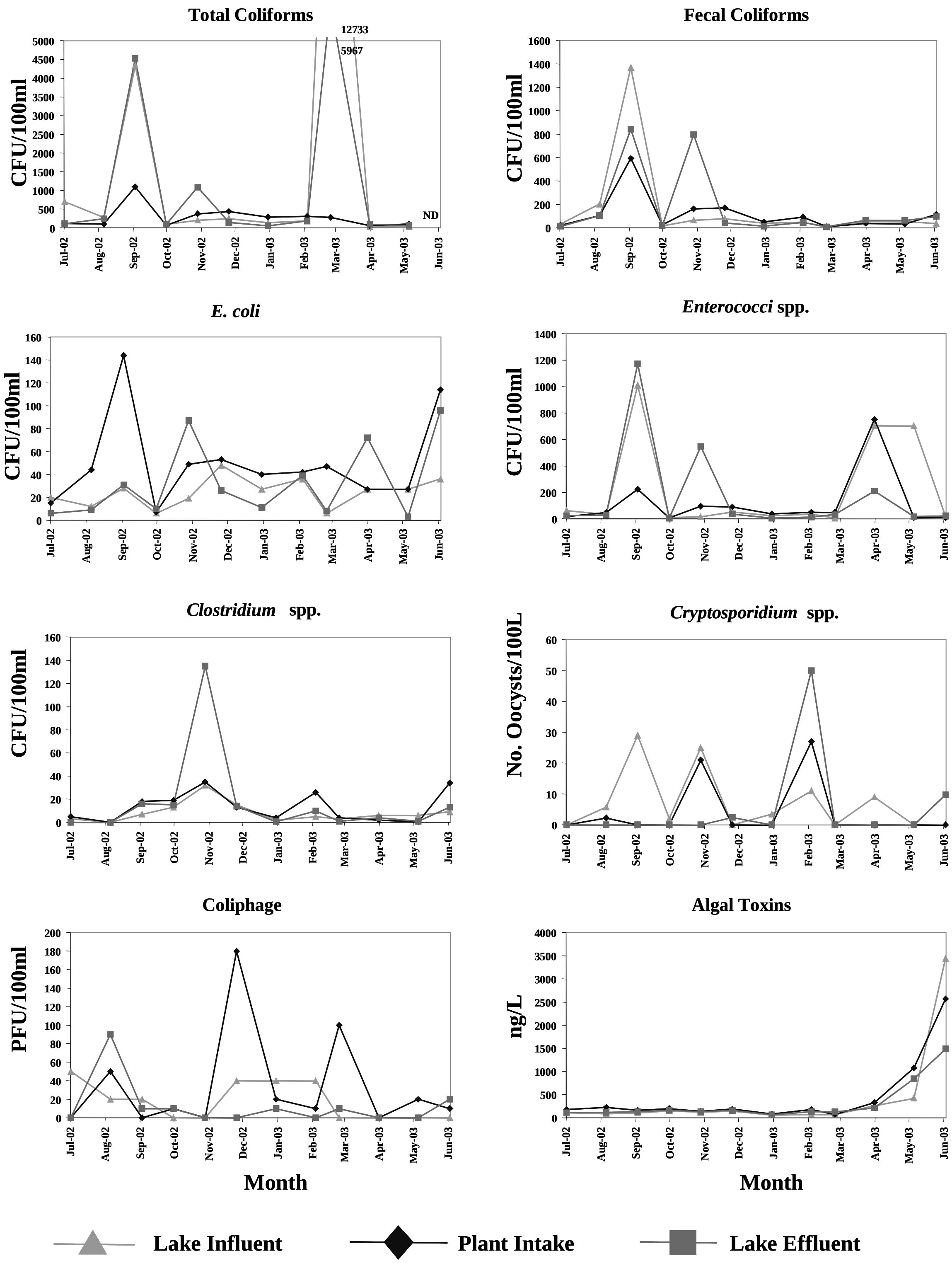



Microbial parameters are summarized in Table 97 and Figure 144 for the three sampling sites. The table summarizes average, maximum, minimum, standard deviation, and CV for the parameters. Further, the table summarizes lake wide values, determined by combining the three data sets.

## Table 97. Lake Monroe Microbial Parameters Summary; Microbial Characterization

| Parameter | Units | Average | Max | Min | Standard Deviation | Coefficient of Variance | Number |
|---|---|---|---|---|---|---|---|
| **Lake Influent** | | | | | | | |
| Total Coliforms | (CFU/100ml) | 1724 | 12733 | 30 | 3860 | 2.24 | 11 |
| Fecal Coliforms | (CFU/100ml) | 166 | 1370 | 6 | 382 | 2.30 | 12 |
| E. coli | (CFU/100ml) | 24 | 48 | 6 | 13 | 0.52 | 12 |
| Enterococci | (CFU/100ml) | 223 | 1010 | 6 | 360 | 1.61 | 12 |
| Clostridium perfringens | (CFU/100ml) | 8 | 32 | <0.2 | 9 | 1.02 | 12 |
| Coliphage | (PFU/100ml) | 18 | 50 | <10.0 | 20 | 1.15 | 12 |
| Cryptosporidium | (Oocysts/100L) | 8 | 29 | <2.0 | 10 | 1.24 | 12 |
| Giardia | (Cysts/100L) | 0.1 | 1.7 | <2.0 | 0.5 | 5.00 | 12 |
| Enteric virus | (MPN/100L) | <0.2 | <0.2 | <0.2 | NA | NA | 12 |
| Microcystin | (ng/L) | 419.4 | 3441.0 | 60.0 | 957.1 | 2.28 | 12 |
| **Plant Intake** | | | | | | | |
| Total Coliforms | (CFU/100ml) | 293 | 1094 | 61 | 296 | 1.01 | 11 |
| Fecal Coliforms | (CFU/100ml) | 117 | 593 | 10 | 160 | 1.36 | 12 |
| E. coli | (CFU/100ml) | 51 | 144 | 7 | 40 | 0.78 | 12 |
| Enterococci | (CFU/100ml) | 117 | 753 | 9 | 209 | 1.79 | 12 |
| Clostridium perfringens | (CFU/100ml) | 13 | 35 | <0.2 | 13 | 0.96 | 12 |
| Coliphage | (PFU/100ml) | 33 | 180 | <10.0 | 55 | 1.64 | 12 |
| Cryptosporidium | (Oocysts/100L) | 4 | 27 | <2.0 | 9 | 2.24 | 12 |
| Giardia | (Cysts/100L) | 1.3 | 9.9 | <2.0 | 2.9 | 2.23 | 12 |
| Enteric virus | (MPN/100L) | <0.2 | <0.2 | <0.2 | NA | NA | 12 |
| Microcystin | (ng/L) | 449.6 | 2571.0 | 72.0 | 719.6 | 1.60 | 12 |
| **Lake Effluent** | | | | | | | |
| Total Coliforms | (CFU/100ml) | 1143 | 5967 | 55 | 2076 | 1.82 | 11 |
| Fecal Coliforms | (CFU/100ml) | 175 | 843 | 8 | 303 | 1.73 | 12 |
| E. coli | (CFU/100ml) | 33 | 96 | 3 | 34 | 1.01 | 12 |
| Enterococci | (CFU/100ml) | 177 | 1173 | 5 | 350 | 1.99 | 12 |
| Clostridium perfringens | (CFU/100ml) | 18 | 135 | <0.2 | 38 | 2.15 | 12 |
| Coliphage | (PFU/100ml) | 13 | 90 | <10.0 | 25 | 2.02 | 12 |
| Cryptosporidium | (Oocysts/100L) | 5 | 50 | <2.0 | 14 | 2.77 | 12 |
| Giardia | (Cysts/100L) | <2.0 | <20.0 | <2.0 | NA | NA | 12 |
| Enteric virus | (MPN/100L) | <0.2 | <0.2 | <0.2 | NA | NA | 12 |
| Microcystin | (ng/L) | 306.9 | 1488.0 | 65.0 | 425.4 | 1.39 | 12 |
| **Lake Wide** | | | | | | | |
| Total Coliforms | (CFU/100ml) | 1053 | 12733 | 30 | 2527 | 2.40 | 35 |
| Fecal Coliforms | (CFU/100ml) | 153 | 1370 | 6 | 289 | 1.89 | 36 |
| E. coli | (CFU/100ml) | 36 | 144 | 3 | 32 | 0.88 | 36 |
| Enterococci | (CFU/100ml) | 172 | 1173 | 5 | 308 | 1.79 | 36 |
| Clostridium perfringens | (CFU/100ml) | 13 | 135 | <0.2 | 23 | 1.76 | 36 |
| Coliphage | (PFU/100ml) | 21 | 180 | <10.0 | 37 | 1.73 | 36 |
| Cryptosporidium | (Oocysts/100L) | 6 | 50 | <2.0 | 11 | 1.93 | 36 |
| Giardia | (Cysts/100L) | 0.5 | 9.9 | <2.0 | 1.8 | 3.60 | 36 |
| Enteric virus | (MPN/100L) | <0.2 | <0.2 | <0.2 | NA | NA | 36 |
| Microcystin | (ng/L) | 392.0 | 3441.0 | 60.0 | 715.1 | 1.82 | 36 |

**Figure 144. Lake Monroe Microbiological Temporal Trends; Microbial Characterization**



As Figure 144 suggests, bacteria levels remained relatively consistent except for the September sampling event when they peaked for total coliforms, fecal coliforms, E. coli, and Enterococci. However, sample collection in September was unavoidably collected from shore due to the unavailability of a boat. Therefore, these samples may not represent the typical microbiological characteristics observed in the remainder of the samples. However, as earlier mentioned, sampling occurred during heavy rains, which may also have impacted the data.

Peaks in total coliforms, fecal coliforms, and E. coli occurred in the March 2003 and June 2003 events for samples in the LI and LE samples. It was determined that regrowth in the samples possibly occurred for both of these dates. Therefore, data generated by MSU for these dates was discarded. Instead, Orange County data are used for fecal coliforms and E. coli in March and June. Total coliform data (MSU analyzed) for June 2003 were discarded.

*E. coli* levels ranged from 3 to 144 CFU/100ml with an average of 24, 51, and 33 CFU/100ml for the LI, I and LE sites, respectively. Lake-wide Enterococcus spp. levels ranged from 5 to 1173 CFU/100mls with an average of 223, 116, and 177 CFU/100ml for the LI, L and LE sites, respectively. While the highest Clostridium level reached 135 CFU/100ml in November in the LE site, the values remained relatively low with less than 35 CFU/100ml for all three sites in the rest of the sampling events. Coliphage levels ranged from 0 to 180 PFU/100ml.

Lake-wide Cryptosporidium levels ranged from 0 to 50 oocysts/100L with an average of 5.8 oocysts/100L or 0.058 oocysts/L. Nearly all samples analyzed for Cryptosporidium and Giardia contained algae that looked very similar to Cryptosporidium. This made the microscopic analysis difficult and tedious because each object or organism observed that appeared to be Cryptosporidium or Giardia had to be verified and confirmed or regarded as algae. Few Giardia cysts were detected and the lake-wide average was 0.48 cysts/100L or 0.0048 cysts/L. No Giardia cysts were found at the LE site. No enteric viruses were found in any sample for any of the sites.

Lake-wide microcystin levels ranged from 60 to 3441 with an average of 392 ng/L. Levels remained below 225 until April when levels began increasing. Levels increased in May and peaked in

June to 3441, 2571, and 1448 for sites LI, I, and LE, respectively. Microcystin levels returned to previous levels or less than detectable in July when it was sampled two weeks during the AWWARF Algal Toxin Study.

Table 98 provides a comparison of averages for each sample site as well as the lake-wide average. Average total coliform, fecal coliform levels were significantly lower at the intake than at the lake influent and effluent, while E. coli levels were higher at the pilot plant intake.

*Cryptosporidium* and *Giardia* were low for all of the sites tested. Lake-wide *Cryptosporidium* and *Giardia* levels were 0.058 oocysts/L and 0.005 cysts/L, respectively. Again, Enteric viruses were below detection limits on all of the samples analyzed.

**Table 98. Lake Monroe Microbial Parameters Sample Site Comparison; Microbial Characterization**

| Parameter | Units | Lake Influent | Plant Intake | Lake Effluent | Lake-wide |
|---|---|---|---|---|---|
| Total Coliforms | (CFU/100ml) | 1723.5 | 293.4 | 1143.1 | 1053.3 |
| Fecal Coliforms | (CFU/100ml) | 166.3 | 117.2 | 175.1 | 152.8 |
| E. coli | (CFU/100ml) | 24.3 | 50.8 | 33.2 | 36.1 |
| Enterococci | (CFU/100ml) | 223.1 | 116.6 | 176.5 | 172.1 |
| Clostridium perfringens | (CFU/100ml) | 8.4 | 13.4 | 17.5 | 13.1 |
| Coliphage | (PFU/100ml) | 17.5 | 33.3 | 12.5 | 21.1 |
| Cryptosporidium | (Oocysts/L) | 0.079 | 0.042 | 0.052 | 0.058 |
| Giardia | (Cysts/L) | 0.001 | 0.013 | <0.02 | 0.005 |
| Enteric virus | (MPN/100L) | <0.2 | <0.2 | <0.2 | <0.2 |
| Microcystin | (ng/L) | 419.4 | 449.6 | 306.9 | 392 |

## Conclusions

Water quality of various central Florida streams and lakes, like streams and lakes in suburbs of cities in other states, tends to be affected by urban and agricultural runoff, generally regarded as non-point source polluters. Further, discharge from facilities, such as waste water treatment plants, are considered point source polluters, and will also affect surface water quality.

Several studies have been conducted to characterize the microbial water quality of Central Florida surface waters. In one such study, the FDEP conducted a comprehensive biological and chemical assessment of water quality in eleven tributaries of Lake Jesup, a lake slightly upstream of Lake Monroe, from 1996 to 1997. The reports concluded that stream water quality ranged from poor to quite high. Fecal coliform levels averaged from 170 CFU/100mls in Gee Creek to 1300 CFU/100mls in Black Sweetwater creek. The report concluded that these high levels were from non-point source runoff and agricultural activities.

Several other biological monitoring studies have examined various streams and lakes in Florida in order to assess their environmental health. Four studies were chosen representing tributaries of drinking water supplies located in central Florida and/or adjacent to Lake Monroe.

Two sites were located in central Florida (De Leon Springs and Wekiwa Springs) and were both analyzed for total and fecal coliforms, E. coli, and Enterococci. Average levels for De Leon and Wekiwa Springs were 200 and 260 CFU/100ml total coliforms, 24 and 30 CFU/100ml fecal coliforms, 24 and 20 CFU/100ml E. coli, and 42 and 80 CFU/100ml Enterococci, respectively.

The upper watershed of the Hillsborough River contained between 1400 and 2300 CFU/100ml total coliforms and between 20 and 160 CFU/100ml fecal coliforms, while the levels in Mill Creek, a stream that flows into the Manatee River, were 1600 and 150 CFU/100ml total and fecal coliforms, respectively. When compared to these fresh water systems, the microbiological water quality determined in the Lake Monroe study presented here was very similar.

When compared to other Florida surface waters used for drinking water (Table 99, Lake Monroe had a similar microbiological profile. Surface water quality evaluation of three Florida surface waters used for drinking water were evaluated for Cryptosporidium, Giardia, total and fecal coliforms and E. coli during the Information Collection Rule data collection period from 1997 to 1998 (EPA, 2003b). Treatment plants and sources included the Manatee County Water Treatment Plant on the Manatee River, the City of Melbourne South Water Treatment Plant on Lake Washington, and the Hillsborough River Plant on the Hillsborough River. These surface water treatment plants participated in the EPA Information Collection Rule (ICR) Program and data were reported monthly for an 18-month period.

**Table 99. Comparison of Microbiological Indicators and Pathogen Data for Lake Monroe and Select Florida Surface Waters used for Drinking Water**

| Parameter | Unit Measured | Manatee* (SD) | Melborne* (SD) | Hillsborough* (SD) | Lake Monroe** (SD) |
|---|---|---|---|---|---|
| Total Coliforms | CFU/100ml | 301 (580) | 34 (70) | 1106 (1372) | 1053 (2527) |
| Fecal Coliforms | CFU/100ml | 0.42 (0.79) | 1.3 (2.9) | 151 (365) | 153 (289) |
| E. coli | CFU/100ml | No Data | No Data | No Data | 36 (32) |
| Cryptosporidium | No./100L | 0 (0) | 0 (0) | 1.88 (6.29) | 5.76 (11.20) |
| Giardia | No./100L | 0 (0) | 0 (0) | 1.56 (6.25) | 0.48 (1.76) |
| Enteric viruses | MPN/100L | 0 (0) | 0.19 (0.57) | 0.33 (0.49) | 0 (0) |

*Samples were processed using the ICR method for Cryptosporidium and Giardia. **Samples were processed using the USEPA Method 1623 for Cryptosporidium and Giardia.

Lake Monroe data were most similar to the Hillsborough river water quality data for all the microbiological analytes tested in the ICR. Cryptosporidium and Giardia data collected under the ICR, used the ICR method while the data collected for this study used EPA Method 1623, a more robust and efficient method for detecting the pathogens (EPA Method 1623). Thus, the data reported in the ICR report may underestimate levels, compared to the levels reported in this study using Method 1623. Other studies have reported Cryptosporidium and Giardia in surface water (using the ICR method) to be 3.1 and 0.42 oocysts and cysts per 100L, respectively, in the Tampa Bypass Canal, which is used as a surface water resource by Tampa Bay Water Authority.

Since Lake Monroe could potentially be used as a surface water supply, it is important to consider the detected Cryptosporidium levels since the Long Term 2 Enhanced Surface Water Treatment Rule will request additional treatment if Cryptosporidium levels in the source water exceed a predetermined concentration (Federal Register 2003). Based on the LT2 rule, no additional treatment is required for conventional filtration treatment, direct filtration, slow sand or diatomaceous earth filtration, or alternative filtration technologies if the Cryptosporidium concentration in the source water is < 7.5 oocysts/100L as determined using grandfathered data or from 24 sampling events in a 1 to 2 year period. This study determined a mean concentration of 5.8 oocysts/100L, which is less than the EPA guideline for additional treatment. Considering the microbiological results reported here, conventional filtration could potentially be used as an adequate treatment process to produce potable water from Lake Monroe.

Comparison of algal toxins detected in this study indicated that even at the highest levels detected in Lake Monroe, toxin levels were significantly less than other reported studies. This study reports levels from 60 to 3,441 ng/L, with the majority of measurements below 225 ng/L. A guideline value was developed by the World Health Organization (WHO) to determine the level that does not result in significant health risk over a lifetime of consumption. The WHO recommended a provisional guideline for microcystin toxin in drinking water quality which is currently set at 1,000 ng/L. This level is for finished drinking water and not the source water.

# MICROBIAL CHALLENGE TESTING

Microbial challenge testing was performed as part of the St. Johns River Water Supply Project pilot testing. Challenge testing evaluated the removal efficacy of clarification, granular media filtration, and ultrafiltration. In all, eight challenges using waterborne microorganisms and pathogen surrogates were performed using the following processes:

- SuperP blanket clarifier
- Actiflo microsand ballasted clarifier
- Granular dual media filters
- Zenon ZeeWeed 500-C ultrafilter

Orange County Utilities performed the challenges that were conducted between October 2002 and March 2003. The pathogen surrogates included viruses, bacteria and Cryptosporidium size latex beads. Total and fecal coliforms, including *E. coli*, were used as surrogates for bacterial pathogens while 3 μm fluorescent latex beads were used as surrogates for *Cryptosporidium* oocysts. Pathogen surrogates were used instead of pathogens because the treated water was disposed in the sanitary sewer at the Sanford Water Reclamation Facility. Use of pathogens was avoided to reduce the risk of releasing pathogens into the reclamation distribution system. Total and fecal coliforms have been used as pathogen surrogates in treatment process studies and are well established as adequate indicators. Further, latex beads have also been reliably used as surrogates for determining *Cryptosporidium* removal.

Table 100 summarizes the challenges, surrogates, and system flow rates used to calculate removals. As the table indicates, the SuperP and Actiflo clarifiers were both challenged. Further, influent bead concentrations were such that further removals through the media filters could be analyzed. The SuperP and Actiflo systems were both challenged in parallel on October 2, 2002 to compare removal efficacy side-by-side. During these challenges, 3 µm beads were spiked to the influent of the system. Further, background levels of total and fecal coliforms were quantified in the raw, clarified, and filter effluent.

The Actiflo system was again challenged on December 11, 2002 to verify the results of the first challenge. Further, during this challenge, the media filter was challenged independently (i.e., beads were spiked prior to the filter with no chemical pretreatment). During this challenge, only beads were used for evaluation of the Actiflo system, while beads and *E. coli* were challenged to the granular media filter (without chemical pretreatment).

Finally, the Zenon ultrafilter was challenged on February 13, 2003. During this challenge, beads were challenged to the system. Background total and fecal coliforms along with *Enterococci* were again monitored in the raw water and the Zenon permeate.

**Table 100. Summary of Challenges, Surrogates, and System Flow Rates**

| Challenge # | Event Date | System Challenged | Surrogates Analyzed | Influent Flow Rate (gpm) | Effluent Flow Rate (gpm) |
|---|---|---|---|---|---|
| 1A | 10/02/2002 | SuperP Clarifier | Beads; Total Coliforms; Fecal Coliforms | 60 | 57 |
| 1B | 10/02/2002 | SuperP Granular Media Filter | Beads; Total Coliforms; Fecal Coliforms | 0.5 | 0.5 |
| 2A | 10/02/2002 | Actiflo Clarifier | Beads; Total Coliforms; Fecal Coliforms | 220 | 209 |
| 2B | 10/02/2002 | Actiflo Granular Media Filter | Beads; Total Coliforms; Fecal Coliforms | 0.5 | 0.5 |
| 3A | 12/11/2002 | Actiflo Clarifier | Beads | 220 | 209 |
| 3B | 12/11/2002 | Actiflo Granular Media Filter | Beads | 0.5 | 0.5 |
| 4 | 12/11/2002 | Granular Media Filter | Beads; *E. coli* | 0.5 | 0.5 |
| 5 | 02/13/2003 | Zenon Ultrafilter | Beads; Total Coliforms; Fecal Coliforms; *Enterococci* | 10.7 | 9.6 |

## Testing Methods and Materials

Each process was challenged with Anionic Polystyrene Fluorescent Latex Beads (3 µm diameter) (Interfacial Dynamics, Portland, Oregon) (microspheres). The beads were slightly smaller than oocysts which are approximately 4 to 6 µm diameter and negatively charged. Beads were used as non-biological surrogates for Cryptosporidium oocysts to reduce the risk of pathogen exposure to the public.

The seeded challenges were prepared by collecting 10L of influent water. Challenges on the SuperP, Actiflo, and Zenon systems used raw water from Lake Monroe, while the independent challenge of the media filter used AF clarified water. Challenge water was seeded with beads and mixed thoroughly in a sterile collapsible carboy using a pre-sterilized stir bar and stir plate for 10 minutes. Seed samples were collected from the carboy to determine the seed concentrations of beads for each challenge prior to injecting. Challenge water containing the surrogates was injected into the influent stream using a diaphragm pump (Shurflo by Cole-Palmer Instruments, Vernon Hills, Illinois) regulated to inject at a rate of one liter per minute for 10 minutes for each challenge.

Figure 145 illustrates the bead injection points and sampling locations for each of the systems challenged. As Figure 145.a indicates, beads were injected to the raw water prior to Actiflo and SuperP clarification. Samples were taken after the application point and prior to clarification to determine the influent concentration of beads, and following clarification and following filtration to determine the individual removals of the processes. Figure 145.b and Figure 145.c illustrate the spiking and sampling locations for the granular media filter and the Zenon ultrafilter, respectively. As the figure indicates, the Zenon challenge and media filter challenge were sampled only on the filter influent and effluent.

Sample collection after clarification was conducted for three hydraulic residence times (HRTs) for the clarification / filtration systems. Actiflo and SuperP samples were collected every five minutes for 15 minutes at the clarifier influent. While, clarifier effluent was sampled every 15 minutes for three HRTs or 60 and 160 minutes for the Actiflo and SuperP, respectively. Further, samples were collected every three minutes from the granular media filters filter for 60 and 160 minutes, respectively.

**Figure 145. Injection and Sampling Location Diagram**

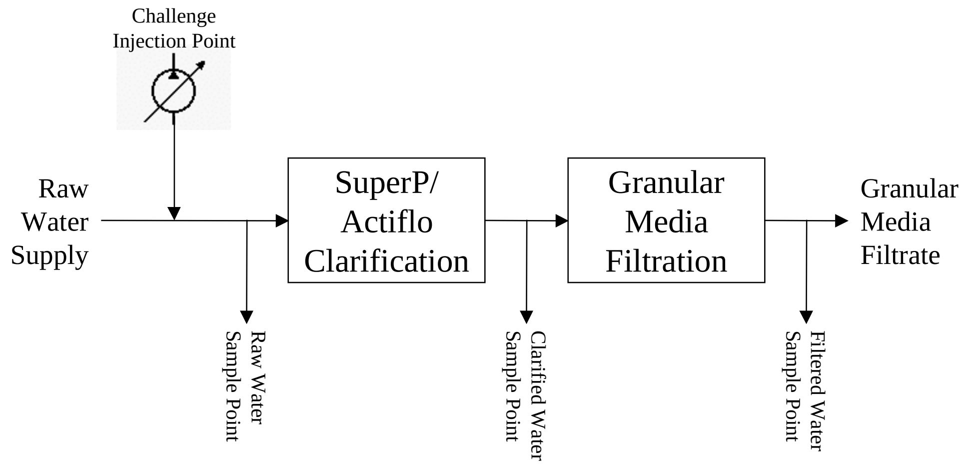



**Figure 145.a**

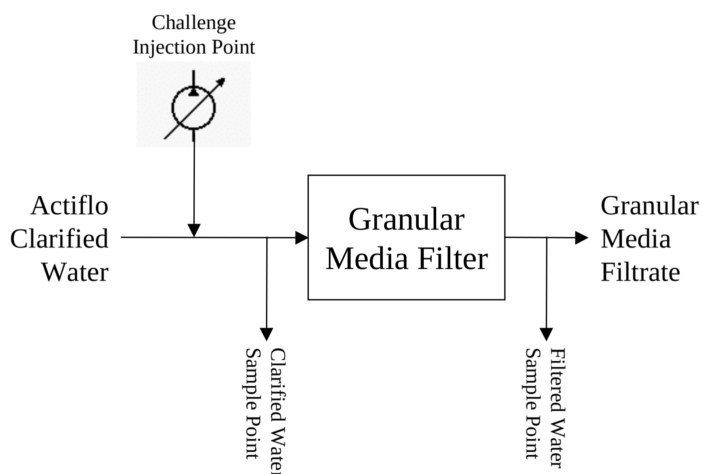



**Figure 145.b**

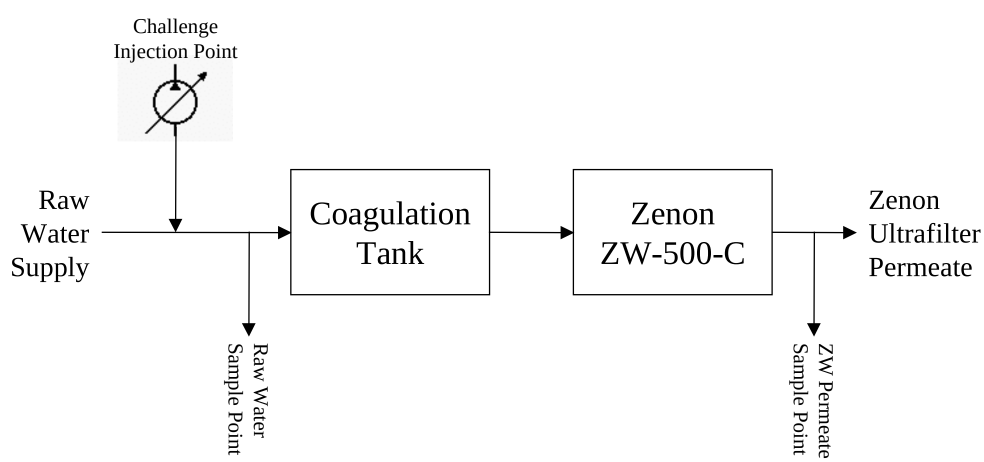



**Figure 145.c**

Influent samples were collected from the influent sampling port in sterile 15 or 50 ml polypropylene centrifuge tubes. Post clarifier samples were collected in sterile one liter containers while post filter samples were collected in sterile 10 or 20 liter containers. Post clarifier samples were processed for beads using direct centrifugation of the sample followed by membrane filtration or using the Envirochek HV filter followed by membrane filtration.

The Zenon system was operated in a continuous mode at a 20 gfd flux and 90 percent recovery. The removal efficacy of the Zenon system was expected to be high due to the absolute pore size of 0.1 µm for the membrane. Therefore, bead concentrations would be high in the process tank and bead removal from the process tank would occur via the reject pump, which had a sludge retention time of approximately 3 hours when operating at 90percent recovery.

Samples were collected from the Zenon system every 2 minutes on the influent side for 10 minutes while beads were being challenged to the system. Permeate bead samples were collected using an Envirochek HV ™ sampling capsule (Pall Gelman, Ann Arbor, MI) with a membrane pore size of 1 µm. The capsule is commonly used for detecting Cryptosporidium and Giardia (EPA Method 1623). The filter was connected to a 2 L/min side stream of the permeate. Samples were collected for two sludge retention times or approximately 6 hours. A total of 423.9L of sample was sampled through the filter and processed according to EPA Method 1623 for collection and elution of the beads.

Sample recovery efficiency was determined for all bead processing methods. Subsequently, data were corrected for the recovery efficiency. For example, processing bead samples by membrane filtration yielded a recovery efficiency of 84.5 percent. If a sample contained 400 beads/L, the value was divided by 0.845 to account for the loss associated with using membrane filtration, resulting in a corrected value of 473.4 beads/L. Similarly, bead samples processed using direct centrifugation resulted in sample recovery efficiency of 23.1 percent, while Envirochek HV sample recovery efficiency was 27.8 percent.

Table 101 summarizes the methods used to assess the microbiological and non-biological surrogates used for challenging the advanced treatment processes. Total coliforms, fecal coliforms, E. coli, and Enterococci were analyzed using membrane filtration methods described in Standard Methods. Beads were analyzed using membrane filtration onto 25mm diameter cellulose acetate filter, 0.22µm pore size membranes and enumerated under 200X magnification by epifluorescent microscopy. Maximum excitation and emission for the fluorescent beads was 458 and 540 nm, respectively.

**Table 101. Methods for Assessment of Microbiological Surrogate Challenges**

| Analyte | Method | Analyte Type | Analyte Size | Nucleic Acid Content |
|---|---|---|---|---|
| Total Coliforms | SM 9222B | Bacterium | 1 µm | DS-DNA |
| Fecal Coliforms | SM 9222D | Bacterium | 1 µm | DS-DNA |
| *E. coli* | SM9222D confirmation | Bacterium | 1 µm | DS-DNA |
| *Entercocci spp.* | USEPA Method 1600 | Bacterium | 1 µm | DS-DNA |
| Anionic Polystyrene Fluorescent Latex Beads | Membrane filtration and epifluorescent microscopy | Bead | 3 µm | NA |

DS-DNA = double stranded deoxyribonucleic acid

Data analysis was performed using Microsoft Excel. Data were entered into formulas within the spreadsheets to calculate the total load into the system and the total recovery from the system. Then the data were integrated as a function of count, flow and time changes to determine the percent and Log10 differences between the load and recovery from the system. Bead counts, system loads, system recoveries, and removals were determined using the following formulas:

**Equation 5. Influent Bead Count**

$$InfluentCount = \frac{(Q_i + Q_{i+1})}{2} * (t_{n+1} - t_n) * \frac{(Count_i + Count_{i+1})}{2}$$

**Equation 6. Effluent Bead Count**

$$EffluentCount = \frac{(Q_e + Q_{e+1})}{2} * (t_{n+1} - t_n) * \frac{(Count_e + Count_{e+1})}{2}$$

**Equation 7. Total System Load**

$$TotalLoad = \sum Counts_{Influent}$$

**Equation 8. Total System Recovery**

$$Total\,\mathrm{Re}\,\mathrm{cov}\,ery = \sum Counts_{Effluent}$$

**Equation9. Percent Bead Removal**

$$Percent\,\mathrm{Re}\,moval = \frac{(TotalLoad + Total\,\mathrm{Re}\,\mathrm{cov}\,ery)}{TotalLoad} * 100$$

**Equation 10. Log Bead Removal**

$$Log_{10}\,\mathrm{Re}\,moval = Log_{10}TotalLoad - Log_{10}Total\,\mathrm{Re}\,\mathrm{cov}\,ery$$

Where count is the number of beads counted, Q is the process flow rate in liters per minute, t is time in minutes.

## Unit Process Removals

Table 102 summarizes the SuperP challenge results. The $\log_{10}$[16] removals are highlighted in gray. The table includes clarifier removals, granular media filter removals, and total removals for total coliforms (TC), fecal coliforms (FC) and 3 µm beads. TC and FC are in units of colony forming units per milliliter (CFU / ml), while beads are a total number count (No.).

The highest level of removal occurred in the clarifier for the three analytes. The SuperP achieved approximately 2.5 log removal for TC and FC and approximately 3.5 log removal for the beads during the clarification step. Whereas, granular media filtration following clarification only achieved about 1 log removal of TC and FC and nearly 3 log removal of beads through the filter. As the table suggests, total log removals for the combined clarification / granular media filtration system were 3.6 and 3.5 for TC and FC, respectively and 6.40 or 99.99996 percent for the beads.

[16] For the purpose of this discussion, log and $\log_{10}$ will be used synonymously.

**Table 102. Challenge Results for SuperP Clarifier with Granular Media Filtration; Challenge 1A and 1B**

| Date | 10/02/2002 | 10/02/2002 | 10/02/2002 |
|---|---|---|---|
| Parameter | Total Coliforms | Fecal Coliforms | Beads |
| Reporting Unit | (CFU/ml) | (CFU/ml) | (No.) |
| Clarifier Load | 3.33E+03 | 1.63E+03 | 2.27E+10 |
| Clarifier Recovery | 12.7 | 4.4 | 6.66E+06 |
| Clarifier Removal (%) | 99.62 | 99.73 | 99.971 |
| Clarifier Removal ($Log_{10}$) | 2.42 | 2.57 | 3.53 |
| Filter Load | 12.7 | 4.4 | 1.53E+05 |
| Post Filter Recovery | 0.83 | 0.5 | 2.10E+02 |
| Post Filter Removal (%) | 93.42 | 88.64 | 99.863 |
| Filter Removal ($Log_{10}$) | 1.18 | 0.94 | 2.86 |
| Total Removal (%) | 99.97 | 99.97 | 99.99996 |
| Total Removal ($Log_{10}$) | 3.60 | 3.51 | 6.40 |

Table 103 summarizes the Actiflo challenge results. As with the SuperP results, this table includes clarifier removals, granular media filter removals, and total cumulative removals for TC, FC, and 3 μm beads. However, the Actiflo system was challenged a second time to verify the results. The SuperP was not challenged a second time because it had been removed from the site after completion of Phase 2A.

As the table suggests, for the Actiflo system, the highest bead removals occurred in the media filters, while the highest TC and FC removals occurred in the clarifier. Actiflo clarification achieved approximately 2.3 and 2.7 log removal for TC and FC, respectively, and approximately 2.8 to 3.3 log removal for the beads. While, the granular media filters only achieved about 1.5 log removal of TC and FC and nearly 3.2 to 3.6 log removal of beads.

As the table suggests, total log removals for the combined Actiflo clarification/granular media filtration system were 3.9 and 4.3 for TC and FC, respectively. For the bead challenges, there was a one log difference in removal between the two challenges. During the first challenge, the system achieved a 5.9 log removal of beads, whereas the second challenge yielded a 6.9 log removal of beads. Regardless, these levels were still at acceptable levels.

**Table 103. Challenge Results for Actiflo Clarifier with Granular Media Filtration; Challenge 2A, 2B, 3A, and 3B**

| Date | 10/02/2002 | 10/02/2002 | 10/02/2002 | 12/11/2002 |
|---|---|---|---|---|
| Parameter | Total Coliforms | Fecal Coliforms | Beads | Beads |
| Reporting Unit | (CFU/ml) | (CFU/ml) | (No.) | (No.) |
| Clarifier Load | 4.10E+03 | 2.50E+03 | 2.18E+10 | 1.36E+11 |
| Clarifier Recovery | 20.8 | 7.6 | 3.60E+07 | 6.41E+07 |
| Clarifier Removal (%) | 99.5 | 99.72 | 99.83 | 99.95 |
| Clarifier Removal ($Log_{10}$) | 2.32 | 2.71 | 2.78 | 3.33 |
| Filter Load | 20.8 | 7.6 | 9.05E+04 | 1.53E+05 |
| Post Filter Recovery | 0.6 | 0.2 | 6.46E+01 | 4.03E+01 |
| Post Filter Removal (%) | 97.11 | 97.37 | 99.93 | 99.97 |
| Filter Removal ($Log_{10}$) | 1.54 | 1.58 | 3.15 | 3.58 |
| Total Removal (%) | 99.986 | 99.9949 | 99.99988 | 99.999988 |
| Total Removal ($Log_{10}$) | 3.86 | 4.29 | 5.93 | 6.91 |

Table 104 summarizes the results of the individual granular media filter challenge. During the previous granular media filter challenges (1B, 2B, and 3B), the filters were only challenged with bead and coliform carryover from the clarification process (i.e., the filters were challenged only with the beads that were not removed during clarification). For this challenge, beads and E coli (a fecal coliform) were applied directly before the filter without any chemical pretreatment. However, the beads were mixed with Actiflo clarified water that had been pH adjusted in order to not upset the filter. As the table suggests, without chemical pretreatment of the analytes, the granular media filter was able to achieve approximately 1 log removal of E coli. and 2.9 log removal of beads.

**Table 104. Challenge Results for Granular Media Filtration; Challenge 4**

| Date | 12/11/2002 | 12/11/2002 |
|---|---|---|
| Parameter | E. coli (FC) | Beads |
| Reporting Unit | (CFU/ml) | (No.) |
| Filter Load | 2.96E+08 | 3.92E+12 |
| Post Filter Recovery | 2.63E+07 | 5.17E+09 |
| Post Filter Removal (%) | 91.13 | 99.87 |
| Filter Removal ($Log_{10}$) | 1.052 | 2.88 |

Table 105 summarizes the Zenon 500-C challenge. During this challenge, TC, FC, and *Enterococci* were removed below detection limits. However, feed concentrations were low for these parameters. As expected, bead log removal was very high for this system, with a total log removal of 8.47. This is due to the low absolute pore size (0.1 µm) of the Zenon ultrafilter compared to the size of the beads (3 µm).

**Table 105. Challenge Results for Zenon 500-C Ultrafiltration; Challenge 5**

| **Date** | **02/13/2003** | **02/13/2003** | **02/13/2003** | **02/13/2003** |
|---|---|---|---|---|
| **Parameter** | **Total Coliforms** | **Fecal Coliforms** | ***Enterococcia*** | **Beads** |
| **Reporting Unit** | **(CFU/ml)** | **(CFU/ml)** | **(CFU/ml)** | **(No.)** |
| **Filter Load** | 30.5 | 16.5 | 60 | 2.04E+10 |
| **Post Filter Recovery** | <1 | <1 | <1 | 6.97E+01 |
| **Post Filter Removal (%)** | >96.72 | >93.94 | >98.33 | 99.99999966 |
| **Filter Removal ($Log_{10}$)** | >1.48 | >1.22 | >1.78 | 8.47 |

Table 106 compares the Actiflo and SuperP clarifier removal of TC, FC, and beads during the challenges. The SuperP was only challenged once, while the Actiflo was challenged twice. The first Actiflo challenge was conducted in concurrence with the SuperP challenge, while the second Actiflo challenge was conducted several months later. The Actiflo data is therefore the average of the two challenges.

As the table suggests, TC and FC removals were comparable for both systems. Further, both clarifiers achieved greater than 3 log removal of beads. However, the SuperP had a slightly higher removal when compared to the Actiflo. One other note, as previously discussed, the Actiflo only had a 2.78 log removal during the first challenge, but had a 3.33 log removal during the second challenge which resulted in the average log removal of 3.06.

**Table 106. Actiflo and SuperP Clarifier Removal Comparison**

| **Clarifier Challenge** | **Parameter $Log_{10}$ Removal** | | |
|---|---|---|---|
| | **Total Coliforms** | **Fecal Coliforms** | **Beads** |
| **SP Clarifier-Challenge 1A** | 2.42 | 2.57 | 3.53 |
| **AF Clarifier-Challenge 2A & 3A** | 2.32 | 2.71 | 3.06* |

* Actiflo bead removal is the average removal between Challenge 2A and 3A

Table 107 summarizes the granular media filter removals for TC, FC, and beads. For the SuperP-granular media filter and Actiflo-granular media filter challenges, the feed concentration of beads to the filter resulted from beads not removed during clarification, whereas during the individual filter challenge (Challenge 4), beads and E. coli were challenged directly before the filter without chemical pretreatment.

As the table suggests, the SuperP-granular media filter and GF challenges both achieved approximately 1 log removal of TC and FC. The Actiflo-granular media filter achieved approximately 1.5 log removal of TC and FC. All three systems achieved approximately 3 log removal of beads. However, the Actiflo-granular media filter had the highest removals of TC, FC and beads.

**Table 107. Granular Media Filter Removal Comparison**

| Granular Media Filter (GF) Challenge | Parameter $Log_{10}$ Removal | | |
|---|---|---|---|
| | Total Coliforms | Fecal Coliforms | Beads |
| **SP GF-Challenge 1B** | 1.18 | 0.94 | 2.86 |
| **AF GF-Challenge 2B & 3B** | 1.54 | 1.58 | 3.37* |
| **GF-Challenge 4** | Not measured | 1.05 | 2.88 |

* Actiflo bead removal is the average removal between Challenge 2B and 3B

Table 108 summarizes the cumulative removals of TC, FC, and beads for the SP/GF, AF/GF, and the ZN-UF. The SP/GF and AF/GF systems are two step processes compared to the ZN-UF system which is a one step process. The SP/GF and AF/GF is the sum of removals of the clarifier and the granular media filter, respectively.

As the table indicates, TC and FC removals were similar for the two clarification/filtration systems, while the AF/GF system had a slightly higher level of removal. The feed concentration of TC and FC to the Zenon systems was much lower than those for the clarification/filtration challenges. Therefore, log removal of TC and FC cannot be compared to the removals of the clarification/filtration systems.

Bead removals were nearly equivalent for the AF/GF and SP/GF, with both achieving approximately 6.4 log removal. As expected, the Zenon system had a significantly higher removal compared to the clarification/filtration systems. The Zenon had a log removal of 8.47, approximately 2 logs higher than the SP/GF and AF/GF systems.

**Table 108. Zenon, SuperP with Granular Media Filtration, and Actiflo with Granular Media Filtration**

| Overall Comparison | Parameter $Log_{10}$ Removal | | |
|---|---|---|---|
| | Total Coliforms | Fecal Coliforms | Beads |
| **SP/GF-Challenge 1** | 3.6 | 3.51 | 6.40 |
| **AF/GF-Challenge 2B & 3B** | 3.86 | 4.29 | 6.42 |
| **ZW-UF-Challenge 5** | >1.48* | >1.22* | 8.47 |

* Actiflo bead removal is the average removal between Challenge 2 and 3 ** Raw water TC and FC levels during Zenon challenge were lower than during the SP and AF challenges

## Conclusions

These data suggest that under proper coagulation and treatment conditions, all three pretreatment systems were effective at removing total coliform, fecal coliform, and 3 µm beads. As expected, the Zenon system had a much higher removal of beads compared to the clarification / granular media filtration systems.

Effective removal of 3 µm beads is significant because these beads are a surrogate for Cryptosporidium, a microorganism regulated under the enhanced surface water treatment rules from EPA. *Cryptosporidium* is also one of the smaller regulated pathogens which suggest that these data also indicate that removal of the larger organisms such as *Giardia* can be achieved as well. These data provide evidence that compliance with current and future enhanced surface water treatment rules will be possible.

In addition, these data also indicate the log removals for the combined processes such as coagulation / clarification followed by media filtration or membrane filtration were very high. These combined removals ranged up to 6 to 8 log removal of the 3 µm bead surrogate.

# EMERGING CONTAMINANTS

Recent decades have brought increasing concerns for potential adverse human and ecological health effects resulting from the production, use, and disposal of numerous chemicals that offer improvements in industry, agriculture, medical treatment, and even common household conveniences. Research has shown that many such compounds can enter the environment, disperse, and persist to a greater extent than first anticipated.

Additional water quality sampling was, therefore conducted to ensure that a surface water plant on the St. Johns River would be able to meet existing as well as new regulations. Algal toxins, wastewater and endocrine disrupting compounds/ pharmaceuticals, NDMA, and boron are all target contaminants for possible future regulation.

## ALGAL TOXINS

The occurrence of algae and the subsequent toxins produced by the algae in Lake Monroe, and other surface waters, is important regarding any plant that could be constructed in this research of the St. Johns River. Research for the AWWARF tailored collaboration research project is currently being conducted on the treatability of algal toxins using oxidation, adsorption, and NF/RO membranes. Algal toxin occurrence is being evaluated by Dr. Joan Rose (Michigan State University), membrane treatment of algal toxins is being evaluated by Dr. Jim Taylor, and oxidation and adsorption of the toxins is being assessed by CH2M HILL at the CH2M HILL Applied Sciences lab in Corvallis, Oregon. This research is being conducted to assess the occurrence and subsequent removal of algal toxins during treatment.

Samples at Lake Monroe and several other central Florida lakes are currently being collected twice per month and shipped to the Michigan State University for analysis. Analyses to characterize the algae present in the source water are currently underway. Further, cyanobacteria are being cultured for use in bench-scale removal studies.

The NF/RO membrane challenge studies will be conducted with bench and field experimentation. Challenge tests will be conducted with algal toxins at varying concentrations and for different operating conditions. Further, challenge studies with chlorides or another inorganic solute will be done to determine the time constant and the time to steady state for each membrane system. Variations of concentration, flux, and recovery will allow determination of the primary rejection mechanism. While variation of charge by major ion concentration will allow determination of charge effect on diffusion or size exclusion.

Ozone testing will evaluate the effectiveness of ozone in oxidizing algal toxins. Dose requirements will be developed with as well as toxin decay constants that relate the ozone dose to the amount of decay. Further, rapid small-scale column tests will be used to define the shape of the adsorption wavefront for GAC adsorption.

The testing for this study will be completed in 2004 and the published AWWARF report will be available in 2005.

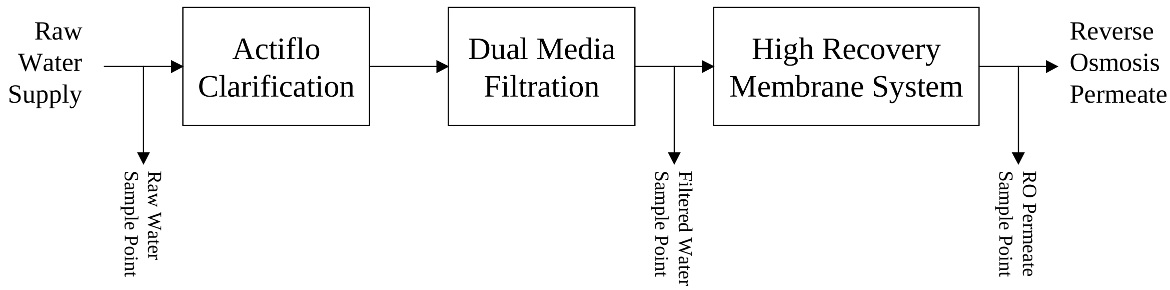
## WASTEWATER AND ENDOCRINE DISRUPTING COMPOUNDS

Sampling was conducted during March 2003 for wastewater and endocrine disrupting compounds. Samples were taken from at the raw water supply, after pretreatment by Actiflo-granular media filtration, and after RO membrane treatment, to demonstrate the removal of these compounds throughout the treatment processes.

Samples were taken for both wastewater and endocrine disrupting compounds. However, hormone concentrations are not reported since the laboratory QA/QC identified low level blank contamination for three of the four hormones analyzed.

Figure 146 illustrates the basic process flow diagram for EDR and wastewater compound sampling. As the figure suggests, samples were collected in the raw water prior to clarification (and chemical addition). Samples were also collected following the dual media filter and after RO membrane treatment.

**Figure 146. Basic Process Flow Diagram**




During sampling, the Actiflo system was operated at a coagulation pH of approximately 4.2, a ferric sulfate dosage of 125 mg/L, and polymer dosage of 0.5 mg/L. The dual media filtration loading rate was 5 gpm/$ft^2$ and filtration pH was approximately 6.5. Prior to filtration, chloramines were added at a concentration or 1.8 mg/L as $Cl_2$. RO membrane flux and recovery was 12 gfd and 85 percent recovery, respectively.

Table 109 summarizes the wastewater compounds analyzed for this segment of testing and the subsequent reporting limits for the given methods. As the table indicates, testing for 76 different wastewater compounds was conducted. For an explanation of the methods for analysis, see Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance[17].

Table 110 summarizes the results from wastewater compound testing. The table only summarizes positive results for compounds. Compounds not listed in Table 110 were below detectable limits for all three samples. The letter "P" indicates the compound was present but not at levels which could be quantified using the current available methods. However, the presence of these constituents was confirmed by the examination of mass spectra. As the table suggests, only 10 compounds were detected as present in either the raw or filtered water. These compounds were not detected in the RO filtered water, indicating the effectiveness of membrane treatment.

[17]Cahill, J.D. Furlong, E.T. Burkhardt, M. R. Kolpin, D.W. and Anderson, L.R. 2003. Determination of Pharmaceutical Compounds in Surface and Groundwater Samples by Solid Phase Extraction and High Performance Liquid Chromotography/Electrospray-Ionization Mass Spectrometry. Submitted to the Journal of Chromatography.

## Table 109. Selected Wastewater Compounds and Reporting Limits

| Waste Water Analyte | Detection Limit (µg/L) |
|---|---|
| Tetrachloroethylene | 0.5 |
| Bromoform | 0.5 |
| Cumene | 0.5 |
| Phenol | 0.5 |
| 1,4-dichlorobenzene | 0.5 |
| D-limonene | 0.5 |
| Acetophenone | 0.5 |
| Para-cresol | 1 |
| Isophorone | 0.5 |
| Camphor | 0.5 |
| Isoborneol | 0.5 |
| Menthol | 0.5 |
| Naphthalene | 0.5 |
| Methyl salicylate | 0.5 |
| Dichlorvos | 1 |
| Isoquinoline | 0.5 |
| 2-methylnapthalene | 0.5 |
| Indole | 0.5 |
| 3,4-dichlorophenyl isocyanate | 0.5 |
| 1-methylnapthalene | 0.5 |
| Skatol | 1 |
| 2,6-dimethylnapthalene | 0.5 |
| BHA | 5 |
| N,N-diethyltoluamide (DEET) | 0.5 |
| 5-methyl-1H-benzotriazle | 2 |
| Diethyl phthalate | 0.5 |
| 4-tert-octylphenol | 1 |
| Benzophenone | 0.5 |
| Tributylphosphate | 0.5 |
| Ethyl citrate | 0.5 |
| Cotinine | 1 |
| Para-nonylphenol-total | 5 |
| Prometon | 0.5 |
| Pentachlorophenol | 2 |
| Atrazine | 0.5 |
| Tri(2-chloroethyl)phosphate | 0.5 |
| 4-n-octylphenol | 1 |
| Diazinon | 0.5 |

| Waste Water Analyte | Detection Limit (µg/L) |
|---|---|
| Phenanthrene | 0.5 |
| Anthracene | 0.5 |
| Tonalide (AHTN) | 0.5 |
| Caffeine | 0.5 |
| Carbazole | 0.5 |
| Galaxolide (HHCB) | 0.5 |
| OPEO1 | 1 |
| 4-cumylphenol | 1 |
| Carbaryl | 1 |
| Metalaxyl | 0.5 |
| Bromacil | 0.5 |
| Metolachlor | 0.5 |
| Chlorpyrifos | 0.5 |
| Anthraquinone | 0.5 |
| NPEO1-total | 5 |
| Fluoranthene | 0.5 |
| Triclosan | 1 |
| Pyrene | 0.5 |
| OPEO2 | 1 |
| Bisphenol A | 1 |
| NPEO2-total | 5 |
| Tri(dichlorisopropyl)phosphat | 0.5 |
| Triphenyl phosphate | 0.5 |
| Ethanol,2-butoxy-,phosphate | 0.5 |
| PBDE4-1 | 10 |
| PBDE4-2 | 10 |
| Diethylhexyl phthalate | 0.5 |
| PBDE4-3 | 10 |
| PBDE5-1 | 10 |
| PBDE5-2 | 10 |
| Benzo(a)pyrene | 0.5 |
| PBDE5-3 | 10 |
| PBDE6-1 | 10 |
| PBDE6-2 | 10 |
| 3-beta-coprostanol | 2 |
| Cholesterol | 2 |
| Beta-sitosterol | 2 |
| Stigmastanol | 2 |

**Table 110. Positive Results for Tested Wastewater Compounds**

| Waste Water Analyte | Sample Location | | |
|---|---|---|---|
| | Raw water | Filtered water | RO Permeate |
| | (µg/L) | (µg/L) | (µg/L) |
| Bromoform | < 0.500 | **P** | **P** |
| Phenol | **P** | < 0.500 | < 0.500 |
| 3,4-dichlorophenyl isocyanate | **P** | < 0.500 | < 0.500 |
| Pentachlorophenol | < 2.000 | **P** | < 2.000 |
| Atrazine | **P** | **P** | < 0.500 |
| Caffeine | **P** | **P** | < 0.500 |
| Bromacil | **0.690** | **P** | < 0.500 |
| Anthraquinone | < 0.500 | **P** | < 0.500 |
| Fluoranthene | < 0.500 | **P** | < 0.500 |
| Ethanol,2-butoxy-,phosphate | **P** | **P** | < 0.500 |

P = presence of material verified, but not quantified

As the table suggests, as expected bromoform was not present in the raw water, but was present in the filtered water and RO permeate. However, it was not formed at levels which could be quantified. Bromoform is a disinfection by-product formed from the reaction of chlorine with NOM. Although chloramines are more stable than free chlorine, small amounts of bromoform can still form. The presence of bromoform are a result of the chloramines being used for biofouling control on the membranes.

Phenol is found naturally in decaying dead organic matter. However, phenol can also be man made and is used in versatile resins and nylon. Further, phenol is a powerful disinfectant and can be used in ointments and lotions. Phenol was detected in the raw water but was below detectable limits in the filtered water and the RO permeate. This suggests that the phenol may have been removed during coagulation.

3,4-dichlorophenyl isocyanate is a white crystal solid and is mainly used for dye, chemicals, and pesticides. 3,4-dichlorophenyl isocyanate was detected in the raw water but was not detected in the filtered water or the RO permeate.

Pentachlorophenol was widely used as a pesticide and wood preservative. Since 1984, the purchase and use of pentachlorophenol has been restricted to certified applicators. It is still used industrially as a wood preservative for utility poles, railroad ties, and wharf pilings. Pentachlorophenol does not occur naturally, but can be formed through the reaction of chlorine with phenol. Pentachlorophenol was not detected in the raw water, but was detected in the filtered water. As previously discussed, phenol was present in the raw water. This phenol may have reacted with chlorine during the chloramination process. However, the compound was removed during RO treatment to below detection .

Atrazine is a white, crystalline solid organic compound widely used as a herbicide for control of broadleaf and grassy weeds. Atrazine was estimated to be the most heavily used herbicide in the United States in 1987/89. However, in 1993 its uses were greatly restricted. Atrazine was detected in the raw and filtered water but was removed below detectable limits during RO membrane treatment.

Caffeine is both a naturally occurring and a commercially produced organic compound used in soft drinks, medicines and other consumer products. It is a natural substance that is present in the leaves, seeds or fruits of more than sixty plant species worldwide. Many food and beverage products made with these ingredients naturally contain caffeine. In addition, caffeine is sometimes added to foods and beverages during the manufacturing process in order to enhance flavor or, in the case of medications, to enhance effectiveness. The general population will be exposed to caffeine by the ingestion of foods, medicines or consumer products in which it is contained which may result in the release to the environment in wastewater effluent. If release to water, caffeine will not volatilize from water to the atmosphere. Caffeine was also present in the raw and filtered water but was removed below detectable limits during RO treatment.

Bromacil is one of a group of compounds called substituted uracils. These materials are broad spectrum herbicides used for nonselective weed and brush control on non-cropland, as well as for selective weed control on a limited number of crops, such as citrus fruit and pineapple. Bromacil was present in the raw water at a concentration of 0.690 µg/L, and it was partially removed during coagulation and filtration. As expected, the concentration was removed to below detectable limits during RO membrane treatment.

Anthraquinone is a light yellow to green crystalline (sand-like) substance used in the manufacture of dyes and paper, as a medication, and as a bird repellent. Anthraquinone was not present in the raw water. However, it was unexpectedly present in the filtered water, possibly due to sample contamination. The contaminant was removed to below detectable levels during RO membrane treatment.

Fluoranthene is a product of combustion of organic matter and is present in fossil fuel products. Both in air and water it is largely associated with particulate matter. Aerosols and particulate matter containing sorbed fluoranthene is sufficiently stable to be transported long distances while being subject to gravitational settling and rainout. When released into water, it will rapidly become adsorbed to sediment and particulate matter and bioconcentrate into aquatic organisms. Because it is strongly adsorbed to soil, it can be stable in sediment for decades or more. Fluoranthene was below detectable limits in the raw water but was detected in the filtered water, possibly due to contamination via exposure to the ambient air. Fluoranthene was not detected in the RO permeate.

Ethanol-2-butoxy-phosphate is used in floor polishes, as a plasticizer in rubber and plastics, and as a flame retardant. Most potential exposure of the general population arises from the use of ethanol-2-butoxy-phosphate in packaging materials for food and from the possible contamination of drinking-water from synthetic rubbers used in plumbing washers. Ethanol-2-butoxy-phosphate was detected in the raw water and filtered water. As expected, it was removed to below detectable limits after RO membrane treatment.

Therefore, as illustrated above, the treatment processes tested were removed the EDR compounds analyzed. The RO membranes proved to be especially effective in rejecting these compounds.

# NDMA

NDMA was not among the chemicals listed in the Contaminant Candidate List published by the USEPA in 1998; hence, it would appear that its regulation as a drinking water contaminant is not imminent. However, USEPA classifies NDMA as a “probable human carcinogen”, and has estimated its $10^{-6}$ cancer risk level in drinking water at 2 ng/L. However, since the principle concern about NDMA has been as an air contaminant, drinking water MCLG or MCL have not been established at this time.

NDMA is a disinfection byproduct and appears to be formed by several different reactions, depending on the water matrix and chemicals used. Among other sources, chloramination, cationic polymers, and detention times appear to be factors that may increase the levels of NDMA. Chloramination provides nitrogen species that may trigger the formation of NDMA, while some cationic polymers may be releasing precursors of NDMA into the water.

As previously discussed, the Actiflo and SuperP clarification processes require cationic polymer for proper operation. Further, chloramines are necessary to control biological fouling on the reverse osmosis membranes. Both of these chemicals contribute to the formation of NDMA. Therefore, samples for NDMA were taken from the RO membrane feed and permeate.

Two sets of samples were collected and analyzed for NDMA. The RO membrane feed was Actiflo-granular media filtered water. Chloramine concentrations were 1.8 mg/L as $Cl_2$ for both sampling events. The polymer used for Actiflo clarification was the Ciba® Magnafloc® LT22S, a medium charge density cationic polymer. The polymer dosage was 0.55 mg/L for both tests.

During the first sampling event, NDMA was below the detection limit of 2 ng/l for both the membrane feed and membrane permeate. The second sampling event resulted in some formation of NDMA in the membrane feed. The concentration of NDMA prior to membrane treatment was 3.9 ng/l, lower than the proposed California action level of 10 ng/l. Membrane treatment was, however, successful in removing NDMA to below detectable limits. Therefore, based on the detection limit of the method used, the RO membranes achieved <u>at least</u> 49 percent removal of NDMA.

# BORON

Boron is a naturally occurring element commonly found in soils and water, particularly sea water. Boron in surface waters may originate from the residues of detergent formulations present in treated sewage effluents. Some boron naturally occurs in ground water, although its concentration varies widely among aquifers. Boron compounds have long been used in eyewashes, mouthwashes, burn ointments, baby ointments, and baby powders. Most people are regularly exposed to small amounts of boron in food. Generally, the amounts pose no harm because boron is regularly excreted in feces and urine during a period of several days. However, boron has been eliminated from use, particularly those uses involving children and infants, given a growing recognition that boron can pose health hazards.

A biological role has been suggested for boron in animal systems; however, the essential nature of this element has not yet been proven. Some investigations suggest that high concentrations of boron may be toxic to the male reproductive system. Infants and children who have received boron-containing medication can become acutely ill with nausea, vomiting, diarrhea, circulatory collapse, skin rash, and confusion. Fatal poisonings often involve kidney failure. Acute poisonings are rare and are generally associated with deliberate use of concentrated boron products. Other adverse effects that do not include any immediate symptoms of illness can occur when smaller amounts of boron are used on a regular basis. These injuries are not as well known but involve stunted growth (in experimental animals) and infertility in human beings. Other symptoms that have been linked to long-term overexposure to boron include loss of appetite, vomiting, diarrhea, loss of hair, skin rashes, anemia, and convulsions.

Currently, there is no mandatory maximum limit for boron in drinking water in the U.S., but the EPA is considering adopting 0.5 ppm as the standard. The World Health Organization and several European countries have adopted or recommended drinking water limits for boron of 0.3 ppm.

Since boron is a naturally occurring element, it does not degrade or disappear from the environment. It may change its form physically and chemically, but it always remains as boron. Since it exists primarily dissolved in water, the most effective removal process is by distillation or membrane treatment.

Several samples were analyzed for boron at the CH2M HILL Applied Sciences Lab in Corvallis, Oregon. Samples were analyzed using the EPA 200.7 analysis method with a maximum detection limit of 100 µg/L. Raw water samples were sampled and analyzed in October 2002, March 2003, and November 2003. All three samples had boron levels below the detectable limit.

# EXPECTED FINISHED WATER QUALITY

## EXPECTED FILTER AND RO PERMEATE WATER QUALITY

This section summarizes the expected filter and RO permeate water quality based on pilot testing from August 2001 to April 2003. Further, disinfection by-product formation and taste and odor removal were evaluated at the Applied Sciences Lab in Corvallis, OR.

### Pilot Testing Water Quality Summary

Samples were collected and analyzed by UCF students and CH2M HILL staff at the site daily. Further, samples were collected by UCF for further analysis in the lab. Samples were collected from the raw water, pretreatment systems, RO membrane permeate and RO membrane concentrate. Only the results from the pretreatment systems and the RO membrane permeate are summarized in this section.

Table 111 summarizes field samples for major water quality parameters for the pretreatment systems—AF/GF, SP/GF, and ZN-UF. The RO membrane permeate is also summarized in the far right column of the table. The table summarizes average expected pH, turbidity, color, and alkalinity for the listed systems.

The pH of all three pretreatment systems was 6.6, required to precipitate soluble iron from the water. Alkalinity for the AF/GF and SP/GF was approximately 25 mg/L as $CaCO_3$, while the alkalinity for the ZN-UF 9 mg/L as $CaCO_3$. The alkalinity of the ZN-UF was significantly lower due stripping of $CO_2$ during aeration of the Zenon membrane for solids removal. The pH of the RO permeate was 5.7 with an alkalinity of 1 mg/L as $CaCO_3$.

As the table indicates, all systems had turbidity below the current and future turbidity levels of the LT1 and LT2 Enhanced Surface Water Treatment Rules. Further, the color of the water was well below the secondary standard of 15 Pt-Co for all of the systems. However, the ZN-UF had significantly higher pH due to the higher coagulation pH requirements.

Additional finished water quality data is summarized in the RO pilot testing section based on the laboratory samples collected by UCF. These data include TOC data which indicate the average permeate TOC levels were less than 0.5 mg/L.

## Table 111. Average Finished Water Quality during Pilot Testing

| Analyte | Units | Pretreatment Systems | | | RO Membrane Treatment |
|---|---|---|---|---|---|
| | | Actiflo/Granular Media Filtration | SuperP/Granular Media Filtration | Zenon Ultrafiltration | |
| pH | | 6.6 | 6.6 | 6.6 | 5.7 |
| Turbidity | (NTU) | 0.05 | 0.06 | 0.05 | 0.04 |
| Color | (Pt-Co) | 2 | 1 | 8 | 0 |
| Alkalinity | (mg/L as $CaCO_3$) | 25 | 24 | 9 | 1 |

## Projected RO Permeate Water Quality

RO permeate water quality will vary depending on the feed water quality, especially with respect to dissolved ionic species concentrations and feed temperature. Permeate water quality was, therefore, estimated using Filmtec Corporation's ROSA (Reverse Osmosis System Analysis) design software, which estimates permeate water quality based on feed water quality.

This analysis is intended to supplement the pilot data and demonstrate how this RO system can be modeled for future planning purposes.

Feed water parameters were determined using USGS raw water quality data, feed water quality data collected during pilot testing, and estimated feed water quality. The average feed water quality was estimated using the average levels for the parameters during a typical year (i.e., non-drought conditions, while minimum levels represent  the lowest levels based on wet weather conditions). The maximum feed levels were estimated based on peak drought conditions during the summer of 2001.

Table 112 summarizes these various ionic water quality parameters for the RO permeate based on these expected feed levels.

As the table suggests, permeate TDS levels are expected to range between 4.8 mg/L and 33.6 mg/L with an average of 16.2. All of the other parameters have similar ranges between minimum and maximum levels. While there is a high degree of variation between the minimum and maximum levels, these RO permeate levels are vary low when compared to typical ground and surface water levels in the central Florida region.

## Table 112. Estimated RO Permeate Water Quality

| Parameter | Location | Units | Average | Minimum | Maximum |
|---|---|---|---|---|---|
| TDS | Feed | (mg/L) | 750 | 202 | 1500 |
| | Permeate | (mg/L) | 16.2 | 4.8 | 33.6 |
| Chloride | Feed | (mg/L) | 352 | 90 | 711 |
| | Permeate | (mg/L) | 8.0 | 2.0 | 16.8 |
| Sodium | Feed | (mg/L) | 178 | 40 | 365 |
| | Permeate | (mg/L) | 4.2 | 0.9 | 8.8 |
| Potassium | Feed | (mg/L) | 8.25 | 5.5 | 12 |
| | Permeate | (mg/L) | 0.5 | 0.3 | 0.7 |
| Magnesium | Feed | (mg/L) | 25 | 7 | 50 |
| | Permeate | (mg/L) | 0.3 | 0.1 | 0.6 |
| Calcium | Feed | (mg/L) | 52 | 17 | 100 |
| | Permeate | (mg/L) | 1.0 | 0.4 | 2.0 |
| Sulfate | Feed | (mg/L) | 117 | 27 | 240 |
| | Permeate | (mg/L) | 1.3 | 0.3 | 2.8 |

## Safe Drinking Water Act Sampling Events

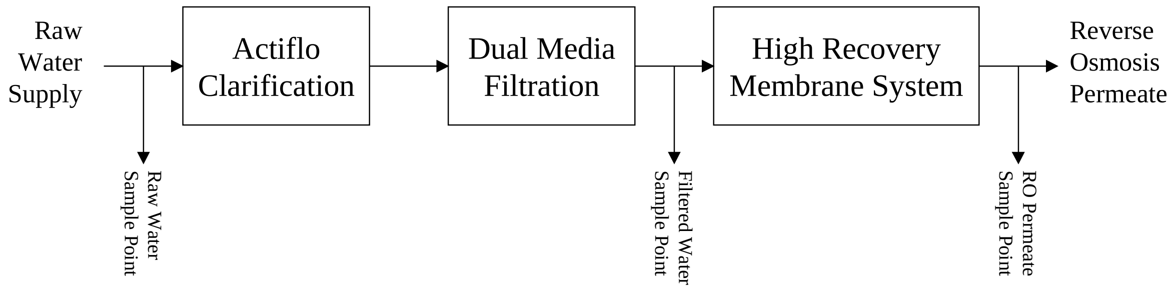
Regulatory sampling was conducted to demonstrate that a surface water plant on this reach of the St. Johns River would be able to meet the existing regulatory requirements of the EPA and the FDEP using the treatment technologies tested.

### Methods

Two sampling events were conducted on the raw water, filtered water, and RO permeate. Sampling was conducted on December 11, 2002 and March 25, 2003. Phase II and V Inorganic Compounds, Phase 1 Volatile Organic Compounds, Phase II and V Synthetic Organic Compounds, secondary standards, and Group I, II, and III Unregulated contaminants were monitored as a part of this testing.

Figure 147 illustrates the basic process flow diagram for SDWA regulatory sampling. As the figure suggests, samples were collected in the raw water prior to clarification (and chemical addition). Samples were also collected following the dual media filter and after RO membrane treatment.

**Figure 147. Basic Process Flow Diagram**




During both sampling events, the Actiflo system was operated at a coagulation pH of approximately 4.2, a ferric sulfate dosage of 125 mg/L, and polymer dosage of 0.5 mg/L. Dual media filtration loading rates were 5 gpm/ft$^2$ and filtration pH was approximately 6.5. Prior to filtration, chloramines were added at a concentration or 1.8 mg/L as $Cl_2$. RO membrane flux and recovery was 12 gfd and 85 percent recovery, respectively.

Table 113 through Table 118 summarizes the methods, maximum contaminant level, and maximum detection limits for these compounds. As the tables suggest, maximum detection the MDL of a contaminant often varied between the two sampling events due to the recovery efficiency of the method.

**Table 113. Inorganic Analyses; Methods, Maximum Contaminant Levels, and Maximum Detection Limits; 62-550.310(1)**

| Contaminant | MCL (mg/L) | Analysis Method | MDL-12/11/02 (mg/L) | MDL-03/25/03 (mg/L) |
|---|---|---|---|---|
| Antimony | 0.006 | EPA 200.9 | 0.0004 | 0.0004 |
| Arsenic | 0.05 | EPA 200.9 | 0.0002 | 0.0002 |
| Barium | 2 | EPA 200.7 | 0.0005 | 0.0005 |
| Beryllium | 0.004 | EPA 200.7 | 0.0005 | 0.0005 |
| Cadmium | 0.005 | EPA 200.7 | 0.0006 | 0.0006 |
| Chromium | 0.1 | EPA 200.7 | 0.0006 | 0.0006 |
| Cyanide | 0.2 | EPA 335.4 | 0.01 | 0.01 |
| Fluoride | 0.4 | EPA 300.0 | 0.02 | 0.02 |
| Lead | 0.015 | EPA 200.9 | 0.0002 | 0.0002 |
| Mercury | 0.002 | EPA 245.1 | 0.00004 | 0.00004 |
| Nickel | 0.1 | EPA 200.7 | 0.002 | 0.002 |
| Nitrate | 10 | EPA 300.0 | 0.004 | 0.004 |
| Nitrite | 1 | EPA 300.0 | 0.01 | 0.01 |
| Selenium | 0.05 | SM3113B | 0.0004 | 0.0004 |
| Sodium | 160 | EPA 200.7 | 0.044 | 0.044 |
| Thallium | 0.002 | EPA 200.9 | 0.0004 | 0.0004 |

**Table 114. Secondary Chemical Analyses; Methods, Maximum Contaminant Levels, and Maximum Detection Limits; 62-550.320**

| Contaminant | MCL | Analysis Method | MDL-12/11/02 | MDL-03/25/03 |
|---|---|---|---|---|
| | (mg/L) | | (mg/L) | (mg/L) |
| Aluminum | 0.2 | EPA 200.7 | 0.013 | 0.013 |
| Chloride | 250 | EPA 300.0 | 0.03 | 0.03 |
| Color | 15 cu | SM2120B | 1 | 1 |
| Copper | 1 | EPA 200.7 | 0.0008 | 0.0008 |
| Fluoride | 2 | EPA 300.0 | 0.02 | 0.02 |
| Iron | 0.3 | EPA 200.7 | 0.00065 | 0.00065 |
| Manganese | 0.05 | EPA 200.7 | 0.0002 | 0.0002 |
| MBAS | 0.5 | EPA 425.1 | 0.02 | 0.02 |
| Odor | 3 TON | SM2150B | 1 | 1 |
| pH | 6.5-8.5 | EPA 150.1 | 0.01 | 0.01 |
| Silver | 0.1 | EPA 200.7 | 0.0014 | 0.0014 |
| Sulfate | 250 | EPA 300.0 | 0.04 | 0.04 |
| Total Dissolved Solids | 500 | EPA 160.1 | 1 | 1 |
| Zinc | 5 | EPA 200.7 | 0.001 | 0.001 |

**Table 115. Trihalomethane Analyses; Methods, Maximum Contaminant Levels, and Maximum Detection Limits; 62-550.310(2)(a)**

| Contaminant | MCL | Analysis Method | MDL-12/11/02 | MDL-03/25/03 |
|---|---|---|---|---|
| | (μg/L) | | (μg/L) | (μg/L) |
| Total Trihalomethanes | 100 | EPA 524.2 | 0.71 | 0.24 |

**Table 116. Volatile Organic Analyses; Methods, Maximum Contaminant Levels, and Maximum Detection Limits; 62-550.310(2)(b)**

| Contaminant | MCL (μg/L) | Analysis Method | MDL-12/11/02 (μg/L) | MDL-03/25/03 (μg/L) |
|---|---|---|---|---|
| 1,1,1-Trichloroethane | 200 | EPA 524.2 | 0.08 | 0.08 |
| 1,1,2-Trichloroethane | 5 | EPA 524.2 | 0.07 | 0.07 |
| 1,1-Dichloroethylene | 7 | EPA 524.2 | 0.09 | 0.09 |
| 1,2,4-Trichlorobenzene | 70 | EPA 524.2 | 0.06 | 0.06 |
| 1,2-Dichloroethane | 3 | EPA 524.2 | 0.07 | 0.07 |
| 1,2-Dichloropropane | 5 | EPA 524.2 | 0.11 | 0.11 |
| Benzene | 1 | EPA 524.2 | 0.09 | 0.09 |
| Carbon tetrachloride | 3 | EPA 524.2 | 0.11 | 0.11 |
| cis-1,2-Dichloroethylene | 70 | EPA 524.2 | 0.08 | 0.08 |
| Dichloromethane | 5 | EPA 524.2 | 0.08 | 0.08 |
| Ethylbenzene | 700 | EPA 524.2 | 0.06 | 0.06 |
| Monochlorobenzene | 100 | EPA 524.2 | 0.06 | 0.06 |
| o-Dichlorobenzene | 600 | EPA 524.2 | 0.05 | 0.05 |
| para-Dichlorobenzene | 75 | EPA 524.2 | 0.08 | 0.08 |
| Styrene | 100 | EPA 524.2 | 0.1 | 0.1 |
| Tetrachloroethylene | 3 | EPA 524.2 | 0.09 | 0.09 |
| Toluene | 1000 | EPA 524.2 | 0.09 | 0.09 |
| trans-1,2-Dichloroethylene | 100 | EPA 524.2 | 0.1 | 0.1 |
| Trichloroethylene | 3 | EPA 524.2 | 0.08 | 0.08 |
| Vinyl chloride | 1 | EPA 524.2 | 0.1 | 0.1 |
| Xylenes (total) | 10000 | EPA 524.2 | 0.11 | 0.11 |

## Table 117. Pesticides and PCB Chemical Analyses; Methods, Maximum Contaminant Levels, and Maximum Detection Limits; 62-550.310(2)

| Contaminant | MCL (μg/L) | Analysis Method | MDL-12/11/02 (μg/L) | MDL-03/25/03 (μg/L) |
|---|---|---|---|---|
| 1,2-Dibromo-3-chloropropane | 0.2 | EPA 504.1 | 0.006 | 0.006 |
| 2,4,5-TP (Silvex) | 50 | EPA 515.1 | 0.05 | 0.07 |
| 2,4-D | 70 | EPA 515.1 | 0.11 | 0.07 |
| Alachlor | 2 | EPA 525.2 | 1.2/0.29* | 0.32/0.08* |
| Atrazine | 3 | EPA 525.2 | 0.32/0.08* | 0.76/0.19* |
| Benzo(a)pyrene | 0.2 | EPA 525.2 | 0.36/0.09* | 0.4/0.1* |
| Bis(2-ethylhexyl) phthalate | 6 | EPA 525.2 | 7.8/2* | 0.64/0/16* |
| Carbofuran | 40 | EPA 531.1 | 0.77 | 0.77 |
| Chlordane (Technical) | 2 | EPA 508.1 | 1.94/0.35* | 0.7/0.35* |
| Dalapon | 200 | EPA 515.1 | 0.48 | 0.53 |
| Di(2-ethylhexyl)adipate | 400 | EPA 525.2 | 0.28/0.07* | 0.24/0.06* |
| Dinoseb | 7 | EPA 515.1 | 0.1 | 0.06 |
| Diquat | 20 | EPA 549.2 | 0.45 | 0.75/0.45* |
| Endothall | 100 | EPA 548.1 | 7.8 | 7.8 |
| Endrin | 2 | EPA 508.1 | 0.44/0.08* | 0.02/0.01* |
| Ethylene dibromide | 0.02 | EPA 504.1 | 0.006 | 0.006 |
| Glyphosate | 700 | EPA 547 | 5.3 | 5.3 |
| Heptachlor | 0.4 | EPA 508.1 | 0.67/0.12* | 0.02/0.01* |
| Heptachlor epoxide | 0.2 | EPA 508.1 | 0.17/0.03* | 0.04/0.02* |
| Hexachlorobenzene | 1 | EPA 508.1 | 0.28/0.05* | 0.08/0.04* |
| Hexachlorocyclopentadiene | 50 | EPA 525.2 | 0.52 | 1/0.25* |
| Lindane | 0.2 | EPA 508.1 | 0.17/0.03* | 0.04/0.02* |
| Methoxychlor | 40 | EPA 508.1 | 0.39/0.07* | 0.2/0.1* |
| Oxamyl (Vydate) | 200 | EPA 531.1 | 1.41 | 1.41 |
| PCB | 0.5 | EPA 508 | 0.19 | 0.19 |
| Pentachlorophenol | 1 | EPA 515.1 | 0.04 | 0.04 |
| Picloram | 500 | EPA 515.1 | 0.06 | 0.03 |
| Simazine | 4 | EPA 525.2 | 0.32/0.08* | 0.32/0.08* |
| Toxaphene | 3 | EPA 508 | 0.64 | 0.64 |

*Raw water detection limit was different than filtered water and RO permeate detection limits

**Table 118. Group I, II, and III Unregulated Contaminants Analyses; Methods, Maximum Contaminant Levels, and Maximum Detection Limits; 62-550.405, 62-550.410, & 62-550.415**

| Contaminant | MCL (µg/L) | Analysis Method | MDL-12/11/02 (µg/L) | MDL-03/25/03 (µg/L) |
|---|---|---|---|---|
| Group I | | | | |
| 3-Hydroxycarbofuran | NA | EPA 531.1 | 1.93 | 1.93 |
| Aldicarb | NA | EPA 531.1 | 0.5 | 0.5 |
| Aldicarb Sulfone | NA | EPA 531.1 | 0.7 | 0.7 |
| Aldicarb Sulfoxide | NA | EPA 531.1 | 0.72 | 0.72 |
| Aldrin | NA | EPA 525.2 | 0.76/0.19* | 0.16/0.04* |
| Carbaryl | NA | EPA 531.1 | 0.31 | 0.31 |
| Dicamba | NA | EPA 515.1 | 0.06 | 0.01 |
| Dieldrin | NA | EPA 508.1 | 0.44/0.08* | 0.02/0.01* |
| Methomyl | NA | EPA 531.1 | 0.29 | 0.29 |
| Metolachlor | NA | EPA 525.2 | 0.72/0.18* | 0.28/0.07* |
| Metribuzin | NA | EPA 525.2 | 1.4/0.36* | 1.4/0.36* |
| Propachlor | NA | EPA 525.2 | 0.36/0.09* | 1.5/0.38* |
| Group II | | | | |
| 1,1,1,2-Tetrachloroethane | NA | EPA 524.2 | 0.08 | 0.08 |
| 1,1,2,2-Tetrachloroethane | NA | EPA 524.2 | 0.05 | 0.05 |
| 1,1-Dichloroethane | NA | EPA 524.2 | 0.12 | 0.12 |
| 1,1-Dichloropropylene | NA | EPA 524.2 | 0.11 | 0.11 |
| 1,2,3-Trichloropropane | NA | EPA 524.2 | 0.06 | 0.06 |
| 1,3-Dichloropropane | NA | EPA 524.2 | 0.05 | 0.05 |
| 1,3-Dichloropropene | NA | EPA 524.2 | 0.11 | 0.11 |
| 2,2-Dichloropropane | NA | EPA 524.2 | 0.11 | 0.11 |
| Bromobenzene | NA | EPA 524.2 | 0.06 | 0.06 |
| Bromodichloromethane | NA | EPA 524.2 | 0.09 | 0.07 |
| Bromoform | NA | EPA 524.2 | 0.31 | 0.07 |
| Bromomethane | NA | EPA 524.2 | 0.19 | 0.19 |
| Chloroethane | NA | EPA 524.2 | 0.12 | 0.12 |
| Chloroform | NA | EPA 524.2 | 0.09 | 0.06 |
| Chloromethane | NA | EPA 524.2 | 0.12 | 0.12 |
| Dibromochloromethane | NA | EPA 524.2 | 0.22 | 0.04 |
| Dibromomethane | NA | EPA 524.2 | 0.06 | 0.06 |
| Dichlorodifluoromethane | NA | EPA 524.2 | 0.15 | 0.15 |
| m-Dichlorobenzene | NA | EPA 524.2 | 0.08 | 0.08 |
| Methyl-tert-butyl-ether | NA | EPA 524.2 | 0.09 | 0.09 |
| o-Chlorotoluene | NA | EPA 524.2 | 0.08 | 0.08 |
| p-Chlorotoluene | NA | EPA 524.2 | 0.06 | 0.06 |
| Trichlorofluoromethane | NA | EPA 524.2 | 0.51 | 0.51 |
| Group III | | | | |
| 2,4,6-Trichlorophenol | NA | EPA 625 | 4.7 | 4.7 |
| 2,4-Dinitrotoluene | NA | EPA 525.2 | 0.48/0.12* | 0.2/0.05* |
| 2-Chlorophenol | NA | EPA 625 | 4.1 | 4.1 |
| 2-Methyl-4,6-dinitrophenol | NA | EPA 625 | 4 | 4 |
| Bis(2-ethylhexyl) phthalate | NA | EPA 525.2 | 7.8/2* | 0.64/0.16* |
| Butyl benzyl phthalate | NA | EPA 525.2 | 0.6/0.15* | 0.2/0.05* |
| Diethyl phthalate | NA | EPA 525.2 | 1.1/0.28* | 0.16/0.04* |
| Dimethyl phthalate | NA | EPA 525.2 | 0.36/0.09* | 0.28/0.07* |
| Di-n-butyl phthalate | NA | EPA 525.2 | 1.4/0.36* | 0.24/0.06* |
| Isophorone | NA | EPA 525.2 | 0.16/0.04* | 0.28/0.07* |
| Phenol | NA | EPA 625 | 2.6 | 2.6 |

*Raw water detection limit was different than filtered water and RO permeate detection limits

### Results

Table 119 summarizes the inorganic analysis results for the two sampling events for the raw and filtered water as well as the RO treated water. As the figure indicates, concentrations of parameters were below the maximum contaminant level (MCL) for all of the streams during the two sampling events. Further, as expected, compounds present in the raw and filtered water were significantly removed during RO treatment. For example, arsenic, present in the second sampling event, was reduced from 0.0016 mg/L in the filtered water to 0.00083 mg/L in the RO permeate. Sodium was reduced from filtered concentrations of approximately 100 mg/L to below 5 mg/L following RO treatment.

**Table 119. Inorganic Analyses Results**

| Contaminant | MCL (mg/L) | 12/11/2002 Concentration (mg/L) | | | 03/25/2003 Concentration (mg/L) | | |
|---|---|---|---|---|---|---|---|
| | | Raw | Filtered | RO Perm. | Raw | Filtered | RO Perm. |
| Antimony | 0.006 | < 0.0004 | < 0.0004 | < 0.0004 | < 0.0004 | < 0.0004 | 0.00064 |
| Arsenic | 0.05 | < 0.0002 | < 0.0002 | < 0.0002 | 0.0019 | 0.0016 | 0.00083 |
| Barium | 2 | 0.026 | 0.023 | < 0.0005 | 0.018 | 0.018 | < 0.0005 |
| Beryllium | 0.004 | < 0.0005 | < 0.0005 | < 0.0005 | < 0.0005 | < 0.0005 | < 0.0005 |
| Cadmium | 0.005 | < 0.0006 | < 0.0006 | < 0.0006 | < 0.0006 | < 0.0006 | < 0.0006 |
| Chromium | 0.1 | < 0.0006 | < 0.0006 | < 0.0006 | 0.0007 | < 0.0006 | < 0.0006 |
| Cyanide | 0.2 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 |
| Fluoride | 0.4 | 0.122 | 0.114 | < 0.02 | 0.108 | 0.106 | < 0.02 |
| Lead | 0.015 | < 0.0002 | < 0.0002 | < 0.0002 | 0.001 | < 0.0002 | < 0.0002 |
| Mercury | 0.002 | < 0.00004 | < 0.00004 | < 0.00004 | < 0.00004 | < 0.00004 | < 0.00004 |
| Nickel | 0.1 | < 0.002 | < 0.002 | < 0.002 | < 0.002 | < 0.002 | < 0.002 |
| Nitrate | 10 | 0.29 | 0.298 | 0.038 | 0.242 | 0.261 | 0.064 |
| Nitrite | 1 | < 0.01 | < 0.01 | < 0.01 | 0.02 | 0.041 | < 0.01 |
| Selenium | 0.05 | < 0.0004 | < 0.0004 | < 0.0004 | 0.0021 | 0.0027 | 0.0038 |
| Sodium | 160 | 98 | 95 | 2.7 | 76 | 102 | 3.6 |
| Thallium | 0.002 | < 0.0004 | < 0.0004 | < 0.0004 | < 0.0004 | < 0.0004 | < 0.0004 |

Table 120 summarizes the secondary analysis results for the two sampling events for the raw, filtered and RO treated water. Values highlighted in gray indicate exceedences of the maximum contaminant levels. Raw water iron and color exceeded the MCL during both sampling events. However, these contaminants were both significantly reduced during filtration, which followed chemical clarification. Also, the levels for these contaminants were further reduced during RO membrane treatment.

Aluminum and odor exceeded the MCL during the second sampling event. Following treatment by filtration and RO membranes, both of these contaminants were reduced to below detectable limits.

As the figure indicates, concentrations of total dissolved solids (TDS) were slightly below the MCL (500 mg/L) for the raw water during both sampling events. However, during the second sampling event, TDS levels were higher than the regulatory limit. As expected, TDS levels in the RO were reduced to below 10 mg/L.

**Table 120. Secondary Chemical Analysis Results**

| Contaminant | MCL (mg/L) | 12/11/2002 Concentration (mg/L) | | | 03/25/2003 Concentration (mg/L) | | |
|---|---|---|---|---|---|---|---|
| | | Raw | Filtered | RO Perm. | Raw | Filtered | RO Perm. |
| Aluminum | 0.2 | 0.16 | < 0.013 | < 0.013 | 0.25 | 0.046 | < 0.013 |
| Chloride | 250 | 200 | 201 | 3 | 167 | 169 | 3.45 |
| Color | 15 cu | 200 | 8 | 8 | 200 | 5 | < 1 |
| Copper | 1 | 0.007 | 0.004 | < 0.0008 | 0.003 | 0.002 | 0.002 |
| Fluoride | 2 | 0.122 | 0.114 | < 0.02 | 0.108 | 0.106 | < 0.02 |
| Iron | 0.3 | 0.48 | < 0.00065 | < 0.00065 | 0.76 | 0.042 | 0.038 |
| Manganese | 0.05 | 0.018 | 0.029 | < 0.0002 | 0.018 | 0.038 | 0.0006 |
| MBAS | 0.5 | 0.06 | 0.04 | 0.04 | 0.03 | 0.03 | 0.02 |
| Odor | 3 TON | 1 | ND | ND | 4 | 2 | ND |
| pH | 6.5-8.5 | 7.53 | 6.37 | 5.44 | 7 | 7.31 | 6.59 |
| Silver | 0.1 | < 0.0014 | 0.003 | 0.002 | < 0.0014 | < 0.0014 | < 0.0014 |
| Sulfate | 250 | 44.2 | 146 | 0.25 | 41 | 138 | 0.56 |
| Total Dissolved Solids | 500 | 497 | 522 | < 1 | 495 | 406 | 9 |
| Zinc | 5 | 0.012 | 0.019 | < 0.001 | 0.013 | 0.015 | 0.006 |

Table 121 summarizes the TTHM monitoring results. As expected, TTHM levels were below detectable levels in the raw water. However, TTHMs were detected in the filtered water due to the addition of chloramines prior to filtration. TTHM values were well below the MCL of 100 μg/L and were removed during RO treatment. While TTHMs are a dissolved gas and expected to pass through RO membranes, the compounds may have been volatilized during pumping from the break tanks to the RO system or during high pressure pumping of the water through the membranes.

**Table 121. Trihalomethane Analysis Results**

| Contaminant | MCL (μg/L) | 12/11/2002 Concentration (μg/L) | | | 03/25/2003 Concentration (μg/L) | | |
|---|---|---|---|---|---|---|---|
| | | Raw | Filtered | RO Perm. | Raw | Filtered | RO Perm. |
| Total Trihalomethanes | 100 | < 0.71 | 15.19 | < 0.71 | < 0.24 | 0.85 | < 0.24 |

Table 122 summarizes the results of Volatile Organic, Pesticides, PCBs, and Group I, II, and III Unregulated Contaminants Analyses. All Volatile Organics parameters and Group I Unregulated contaminates were below detectable limits for all of the samples collected. Bis(2-ethylhexyl) phthalate (DEHP) and Dalapon were present in samples analyzed as a part of Pesticides and PCB Monitoring. Bromodichloromethane, bromoform, chloroform and dibromochloromethane were present in samples collected as a part of the Group II Unregulated Contaminants. Di-n-butyl phthalate was present as a Group III Unregulated Contaminant during both sampling events.

**Table 122. Volatile Organic, Pesticides, PCBs, and Group I, II, and III Unregulated Contaminants Analyses**

| Contaminant | MCL (μg/L) | 12/11/2002 Concentration (μg/L) | | | 03/25/2003 Concentration (μg/L) | | |
|---|---|---|---|---|---|---|---|
| | | Raw | Filtered | RO Perm. | Raw | Filtered | RO Perm. |
| Pesticides and PCBs | | | | | | | |
| Bis(2-ethylhexyl)phthalate | 6 | 11 | < 2.0 | < 2.0 | 5.7 | 1.8 | 0.58 |
| Dalapon | 200 | < 0.48 | < 0.48 | 4.1 | < 0.53 | < 0.53 | < 0.53 |
| Volatile Organics | NA | All results BDL | | | All results BDL | | |
| Unregulated Group I | NA | All results BDL | | | All results BDL | | |
| Unregulated Group II | | | | | | | |
| Bromodichloromethane | NA | < 0.09 | 1.01 | < 0.09 | < 0.07 | 0.09 | < 0.07 |
| Bromoform | NA | < 0.31 | 5.77 | < 0.31 | < 0.07 | 0.4 | < 0.07 |
| Chloroform | NA | < 0.09 | < 0.09 | < 0.09 | < 0.06 | 0.14 | < 0.06 |
| Dibromochloromethane | NA | < 0.22 | 8.41 | < 0.22 | < 0.04 | 0.22 | < 0.04 |
| Unregulated Group III | | | | | | | |
| Bis(2-ethylhexyl) phthalate | NA | 11 | < 2.0 | < 2.0 | 5.7 | 1.8 | 0.58 |
| Di-n-butyl phthalate | NA | 8 | < 0.36 | < 0.36 | 0.78 | 0.21 | 0.15 |

As the table indicates, Dalapon was unexpectedly present in the RO permeate of the first sampling event. It was not, however, present in any raw or filtered water, suggesting sample contamination. Dalapon is a herbicide used to control grasses in a wide variety of crops, including fruit trees, beans, coffee, corn, cotton and peas. It is also registered for use in a number of non-crop applications such as lawns, drainage ditches, along railroad tracks, and in industrial areas. Dalapon is marketed as the sodium salt or as a mixture of the sodium and magnesium salts.

DEHP was present during both sampling events. For the first sampling event, it was present at levels above the MCL, while for the second sampling event it was present at concentrations near the MCL. During the first sampling event it was removed below detectable limits during filtration. For the second sampling event it was partially removed during filtration, and further removed during RO membrane treatment. DEHP is used in the production of polyvinyl chloride (PVC). PVC was used in construction of water lines at the pilot plant. Subsequently, DEHP contamination may have been a result of the material of construction rather than actual contamination of Lake Monroe, the raw water source.

As expected, bromodichloromethane, bromoform, chloroform and dibromochloromethane were present in samples collected during testing. These compounds are disinfection byproducts and are the parts of the sum of TTHMs. Again, these compounds are formed when free chlorine and NOM react. They are monitored as a part of the Group II Unregulated Contaminants.

Di-n-butyl phthalate was present as a Group III Unregulated Contaminant during both raw water sampling events. However, significantly removed during filtration and RO membrane treatment. Di-n-butyl phthalate is used to make plastics more flexible and is also in carpet backings, paints, glue, insect repellents, hair spray, nail polish, and rocket fuel. It is commonly found in the environment and can be a common source of contamination during sampling.

### Conclusions

Volatile organics or Group I or Group II Unregulated Contaminants were not present in the raw water during the two sampling events and, therefore, were not present in the finished water.

Trace levels of 2 compounds including Pesticides, PCBs, and Group III contaminants were present in the raw water. The coagulation/filtration and RO membrane tehnologies removed these compounds to below the regulatory limit.

Some inorganics and Secondary contaminants were present in the raw water. However, pretreatment with coagulation/clarification followed by filtration, as well as treatment with the RO membranes were able to remove all of these compounds to below the regulatory limits.

Therefore, in summary, the finished water produced from pretreatment with coagulation/clarification and filtration, followed by RO membranes, met or exceeded all current USEPA regulatory standards as well as anticipated future regulatory standards.

# RECOMMENDATIONS AND COSTS

The St. Johns River at Lake Monroe is characteristic of a typical Florida surface water with low turbidity and high dissolved organics. In addition, the lake periodically becomes brackish from saline groundwater inflow during low rainfall periods. Total dissolved solids and chloride levels often exceed 1,200 mg/L and 500 mg/L, respectively.

To meet drinking water regulations, it is necessary to remove organics and turbidity to regulatory limits regardless of the TDS and chloride concentrations. During periods of elevated TDS and chloride it is also necessary to reduce these contaminants with RO membranes. This study evaluated the capabilities of different treatment configurations to meet regulatory requirements based on removal of ambient organic and turbidity concentrations as well as low and high TDS and chloride concentrations. Treatment for organics and turbidity consisted of chemical coagulation followed by clarification and filtration. The same treatment process configuration is required prior to RO membrane treatment as pretreatment to prevent organic and turbidity fouling of the RO membranes. As a result, potable water treatment evaluations of low TDS water and high TDS waters involved the same process configurations for organics and turbidity removal followed by RO if necessary for TDS and chloride removal. The pilot plant studies focused on treatment for organics and turbidity removal as well as pretreatment capabilities as measured by RO membrane response.

Based on the above requirements and a stakeholder selection process the following 5 treatment alternatives were selected for evaluation as stand alone treatment and RO pretreatment options:

- Actiflo ballasted sand clarifier followed by dual media filtration
- SuperP blanket clarifier followed by dual media filtration
- Zenon ultrafilter operating in direct filtration mode (coagulation in tank)
- Actiflo ballasted sand clarifier followed by Zenon ultrafilter
- Actiflo ballasted sand clarifier followed by Memcor microfilter

The pilot testing was conducted in 5 phases. Phase 1A was conducted to select the best RO pretreatment which would then be used for the remainder of the testing to evaluate stand alone treatment as well as pretreatment capabilities. However, all three pretreatment processes worked well in Phase 1A. Therefore, based on this result, all 5 of the pretreatment processes were used in the subsequent phases as follows:

| | |
|---|---|
| Phase 1A | SuperP, Actiflo, and Zenon Ultrafilter |
| Phase 1B | Super P and Zenon Ultrafilter |
| Phase 2A | Super P and Zenon Ultrafilter |
| Phase 2B | Actiflo and Zenon Ultrafilter |
| Phase 3 | Actiflo, Zenon Ultrafilter, and Memcor Microfilter |

In addition, the following RO membranes were evaluated during this study for salt and TDS removal from the pretreated water:

- Osmonics SG Brackish Water Membrane
- Hydranautics Low Fouling Composite (LFC1) Membrane
- TriSep X-20 Membrane
- Filmtec BW30FR Membrane
- Filmtec BW30LE Membrane

The following summarizes the treatment recommendations based on the pilot data as well as the costs for these treatment processes.

# TESTING RESULTS SUMMARY

## Pretreatment Results

Pilot testing results indicated that all 5 of the treatment systems are capable of meeting regulatory requirements for producing potable water from low TDS waters as well as being acceptable as pretreatment for RO.

The treatments demonstrated stable operation throughout testing and consistently produced high quality water. When dissolved solids were within regulatory limits, the pretreatment produced potable water without RO membrane treatment. Organics removal by each pretreatment exceeded regulatory requirements and the filtered water turbidity was significantly below the future turbidity standards of 0.10 NTU. However, this level of treatment may not meet all of the water quality and operating goals established by the stakeholders. Criteria in addition to the regulations included the desire to use free chlorine as a residual disinfectant and have the capabilities to remove emerging contaminants such as algal toxins and endocrine disrupters. The option of these treatment processes for stand-alone treatment is discuss further at the end of this section.

In each testing phase, these five pretreatments provided acceptable treated water for RO membrane desalting. The suitability of a pretreatment configuration was evaluated based on changes in RO performance parameters, including NPF, DPC, and NSP. In addition, each pretreatment system provided RO feed water with low levels of turbidity and with low SDI values.

There were some differences between a few of the processes. As expected, Ultra-filtration and Micro-filtration (i.e., Zenon and Memcor) consistently provided a lower and more consistent feed water SDI compared to granular media filtration. While the differences in SDIs did not translate into distinct differences in single element fouling rates, pretreatment with MF or UF can be expected to reduce fouling rates in a full scale system.

## RO Treatment Results

Membrane testing results indicated that the BWFR30 was the best performing membrane. It had the smallest changes in all three performance parameters of NPF, DPC, and NSP, when operated on any of the pretreated feed waters.

The membrane displaying the next best performance was the X-20. Although the X-20 performance had a less stable performance than the BW30FR, it was to acceptable levels. Both the BW30FR membrane and X-20 membrane can be recommended for use on this source water.

The LFC1 and SG membranes encountered the most dramatic changes in NSP. This was especially evident when operating with a chloraminated feed water. They were also the most sensitive to fouling, most likely due to the smaller feed spacer used with these two elements. Further, the BW30LE membrane was not acceptable for consideration at full-scale based on poor performance relative to the NPF, DPC, and NSP parameters.

The RO membrane evaluation indicated that some form of biofouling control is necessary. Chloramines were found to be the best approach for biofouling control. BioGuard was tested and found to be less effective as a biofouling control agent for this source water.

BioGuard, the only NSF-approved chemical currently available, was tested as an alternative to chloramines because chloramines are a suspected oxidant of RO membranes. However, the use of BioGuard in place of chloramines resulted in rapid differential pressure increases for both the RO membranes and the 5 µm cartridge prefilters. Therefore, chloramines are recommended for full-scale use on this source water at a dosage of -0.75 to 2 mg/L as $Cl_2$. This chloramine dosage did not result in unacceptable membrane oxidation as measured by the low increases in salt passage. The recommended chloramine application point is prior to filtration.

Optimization could be conducted to further evaluate lower chloramine levels to offset potential membrane degradation and increased salt passage., Lower chloramine dosages (below the 0.74 mg/L level tested in this study) could be evaluated to determine if effective biofouling control could be maintained a lower dose. However, the incremental reduction in NSP that may be realized from lower chloramine levels below 0.74 mg/L needs be assessed regarding the ability to effectively control the residual at those low levels.

Testing determined that a flux rate of 15 gfd is feasible. However, to provide for a conservative design on this relatively undeveloped source water, a flux of 12 gfd is initially recommended. Further, based on projection software analysis of the feed water, a RO membrane system recovery of 85 percent is recommended. With respect to membrane fouling, both biofilms and iron oxides can be effectively controlled with respect to all three performance parameters (NPF, DTC, and NSP) with chloramines.

Flux data was developed while using polymer in the Actiflo and SuperP pretreatment systems. This was considered necessary to assess the possible adverse effects of polymer carryover. Adverse effects were not observed.

Final recommendations have also been developed regarding membrane cleaning frequency and replacement frequency. Based on the high recovery RO test data and optimum operating configuration (i.e., chloramines and high pH/low pH cleaning regime), the RO cleaning frequency is estimated at 2,000 hours or greater. Membrane fouling by both biofilms and iron oxides can be effectively controlled with respect to all three performance parameters (NPF, DTC and NSP) using the optimum operating configuration.

To determine membrane replacement based on salt passage, an analysis was performed to estimate the maximum allowable salt passage rate of increase to allow a 5 year membrane life. To calculate this increase several assumptions were made:

- Maximum allowable TDS in the permeate is 200 mg/L.
- Maximum raw water TDS is 1,500 mg/L based on historical data collected by the USGS during the drought of 1,400 mg/L TDS plus chemical addition during pretreatment of 100 mg/L TDS
- Minimum allowable membrane replacement of 5 years.
- An initial salt passage of 1.5 percent.

Based on the max allowable permeate TDS and max feed water TDS, the maximum allowable salt passage is 13.3 percent (200 mg/L – 1,500 mg/L) through the RO membranes. This translates to a maximum allowable annual rate of increase of 2.4 percent assuming 100 percent treatment capacity.

Therefore, the rate of 0.75 percent increase per year for the SP/AF BW30FR single element is acceptable for a 5 year replacement frequency based on the above feed water and permeate water TDS levels. Further, the higher rate of salt passage increase of 2.1 percent per year for the high recovery system would also be acceptable based on the above feed and permeate water qualityThe TriSep X-20 element operating at low recovery had a decrease in salt passage suggesting it would likely not increase to unacceptable levels within 5 years.

Therefore, both the BW30FR and X-20 membrane can realize up to 5 years of operating life before the salt passage increase due to both fouling and chloramine addition becomes unacceptable.

Note that this analysis was conducted under very conservative conditions which included a feed water TDS of 1,500 mg/L which has only occurred during the 100-year drought event as well as a low permeate TDS level of 200 mg/L.

## Taste and Odor Results

Taste and odor also needs to be controlled for this source water. For evaluating control of taste and odor causing compounds, specifically 2-methylisoborneol (MIB) and geosmin, PAC and membrane flat sheet tests were performed on Lake Monroe water spiked with MIB and geosmin. A PAC dosage of 40 mg/L achieved 40 percent removal of MIB and nearly 70 percent removal of geosmin at a 15 minute contact time. This detention time is achievable in the Actiflo. The SuperP is capable of much longer detention times, which can result in a slight reduction on PAC dose to achieve the same level of treatment.

Flat sheet membrane testing resulted in more than 93 percent removal of both compounds, although membrane degradation due to chloramines may result in more passage of these taste and odor compounds over time, any decrease in rejection of these compounds by the membranes can be mitigated with higher PAC dosages. Therefore, the use of PAC in conjunction with the RO membranes is an effective approach for taste and odor control for this source water.

## Disinfection

Final recommendations were also developed for disinfection based on the DBP testing conducted. Testing was performed on two finished waters, the RO permeate and on filtered water which had been pretreated by Actiflo clarification (clarified/filtered). These two waters were tested to illustrate the recommended disinfection strategy for a number of reasons. First, a number of different end uses are possible for this treated water. The final blend characteristics of this water with other utilities will not be determined at this time. The intent of this testing is to evaluate the two extreme conditions, the highest organic levels with no desalting (clarified/filtered water) and then the lowest organic levels (RO permeate). The premise is to identify the available contact time for each alternative as well as if chlorine or chloramines can be used as the residual disinfectant.

Based on the DBP formation, if split stream RO is used (75 percent membrane treatment for TDS reduction or higher, not including 100 percent) virus inactivation will be done with free chlorine with *Giardia* and *Cryptosporidium* inactivation being accomplished with UV. Since a significant level of organics will be present in the finished water, chloramines will have to be used for a residual disinfectant.

Due to the concerns of emerging contaminants and the conversion many utilities will face if chloramines have to be used as the residual disinfectant, 100 percent membrane treatment is likely the preferred alternative for desalting. The primary disinfectant for the RO permeate with 100 percent membrane treatment will be free chlorine. Free chlorine can also be used as the residual disinfectant in the distribution system. UV can also be used on the RO permeate for *Cryptosporidium* inactivation if the membranes have to be bypassed during a maintenance event or shutdown.

# TREATMENT ALTERNATIVES

All of the treatment alternatives tested proved to treat the St. Johns River water: 1) to high quality potable standards with out the RO membranes (for low TDS conditions), and 2) to acceptable pretreatment levels for RO membranes. In addition, the Filmtec BW30FR and TriSep X-20RO membranes were determined to be suitable for desalting this source water

Considering the use of the MF/UF membrane used either for direct filtration or filtration after clarification, as well as the percentage of desalting with RO membranes, the following six potential treatment combinations can be recommended for treating this water based on the pilot results:

1. Zenon ZW-500-C (direct filtration) with 100 percent RO treatment
2. Zenon ZW-500-C (direct filtration) with 75 percent RO treatment
3. Actiflo/Granular Media Filtration with 75 percent RO treatment
4. SuperP/Granular Media Filtration with 75 percent RO treatment
5. Actiflo/Memcor CMF-S or Zenon 1000 with 100 percent RO treatment
6. Super-P/Memcor CMF-S or Zenon 1000 with 100 percent RO treatment

These six alternatives include the average benefit and cost alternatives with clarification and partial desalting (Alternatives 3 and 4), as well as the highest benefit and highest cost dual membrane alternatives with 100 percent desalting (Alternatives 1, 5, and 6). These represent the range of technologies and range of cost benefits selected by the stakeholders at the beginning of the study.

Figures 148, 149, 150, and 151 summarize the process flow schematics for these 6 potential treatment alternative recommendations. These schematics include the unit process flow descriptions, orientation, and chemical feed locations. The schematics are based on the data and operating observations from the pilot study.

**Figure 148. Process Flow Diagram; Zenon ZW-500-C Direct Filtration (UF) with 100% RO Treatment (Alt. 1)**

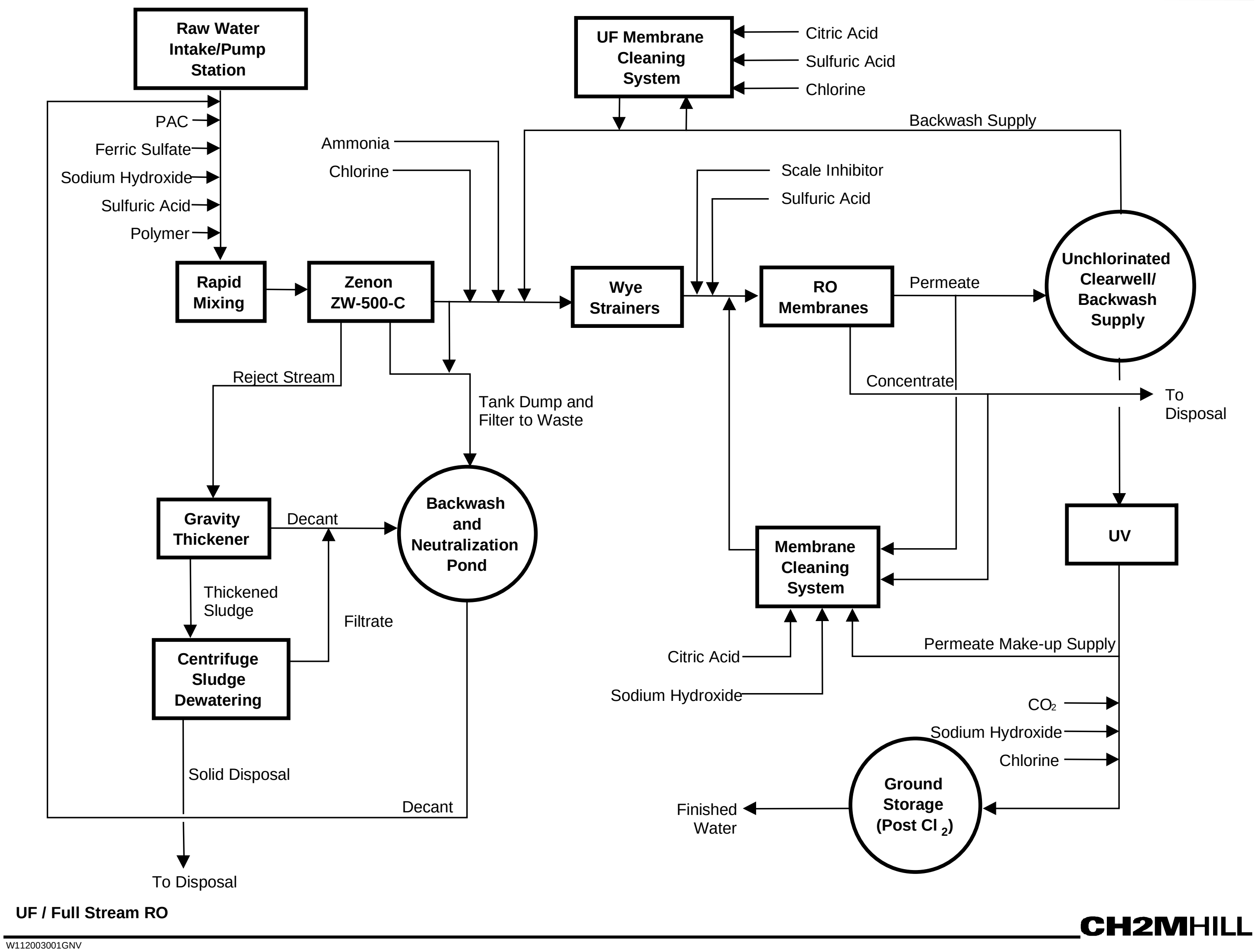


**Figure 149. Process Flow Diagram; Zenon ZW-500-C Direct Filtration (UF) with Partial RO Treatment (Alt. 2)**

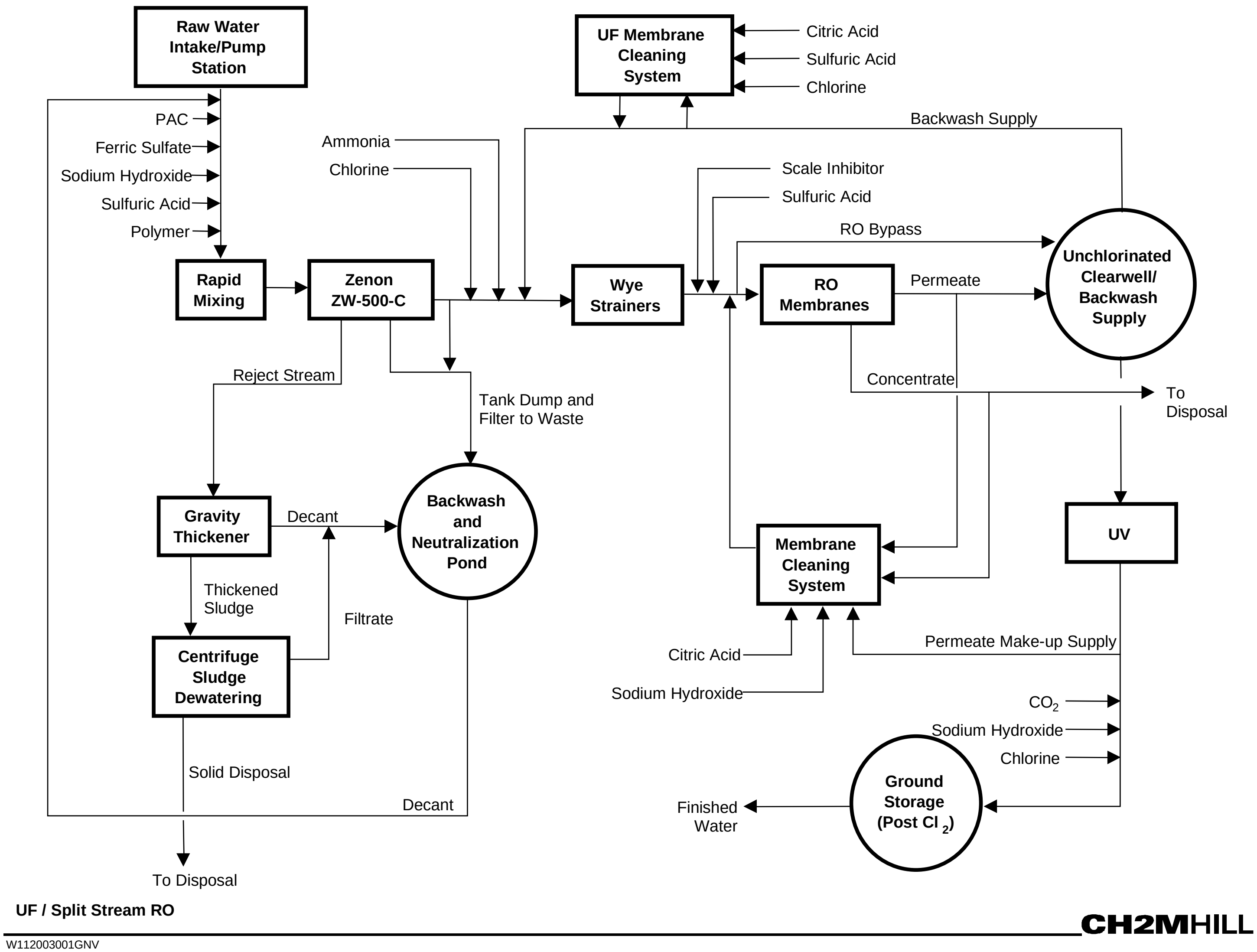


**Figure 150. High Rate Clarification and Granular Media Filtration with Partial RO Treatment (Alt. 3 and 4)**

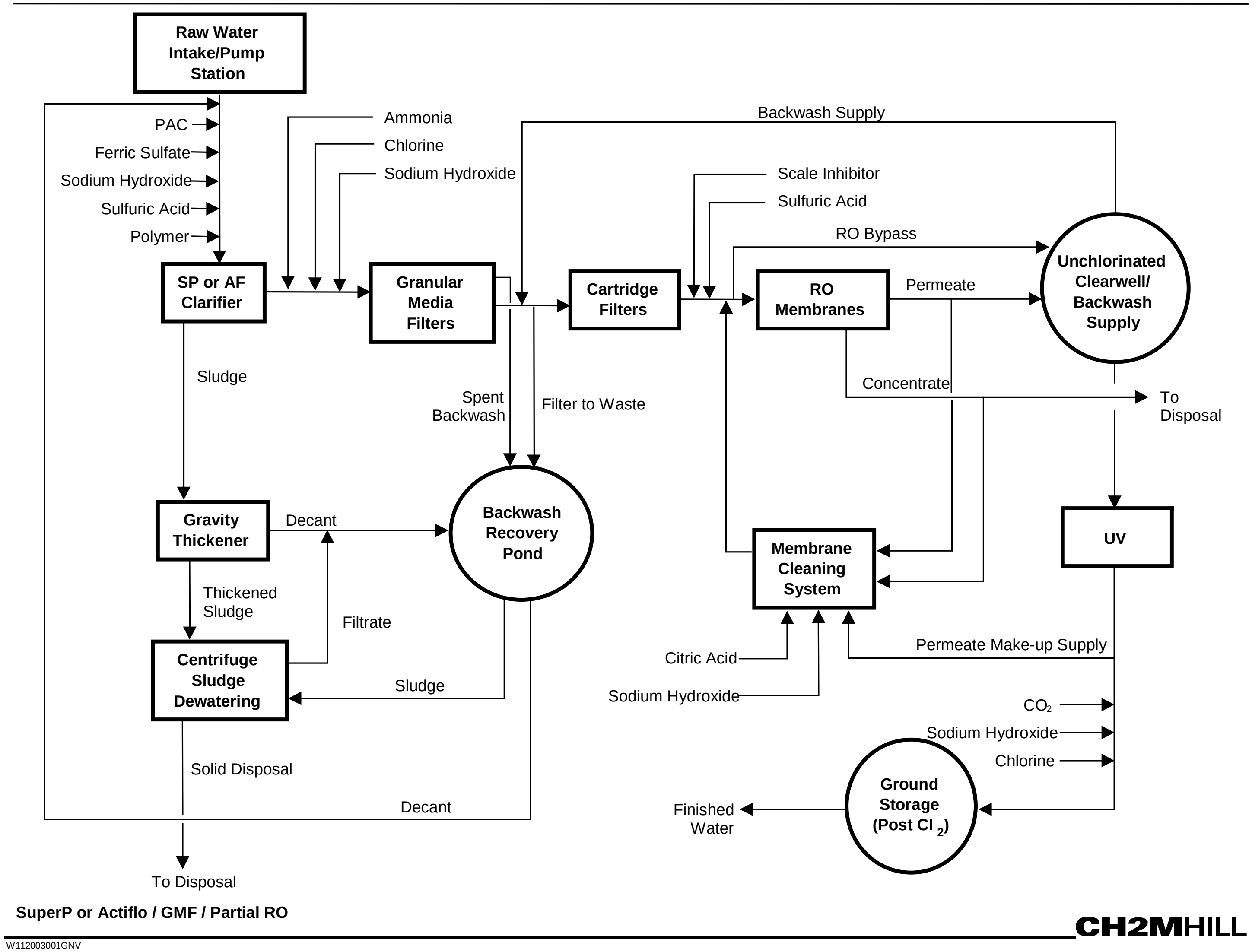
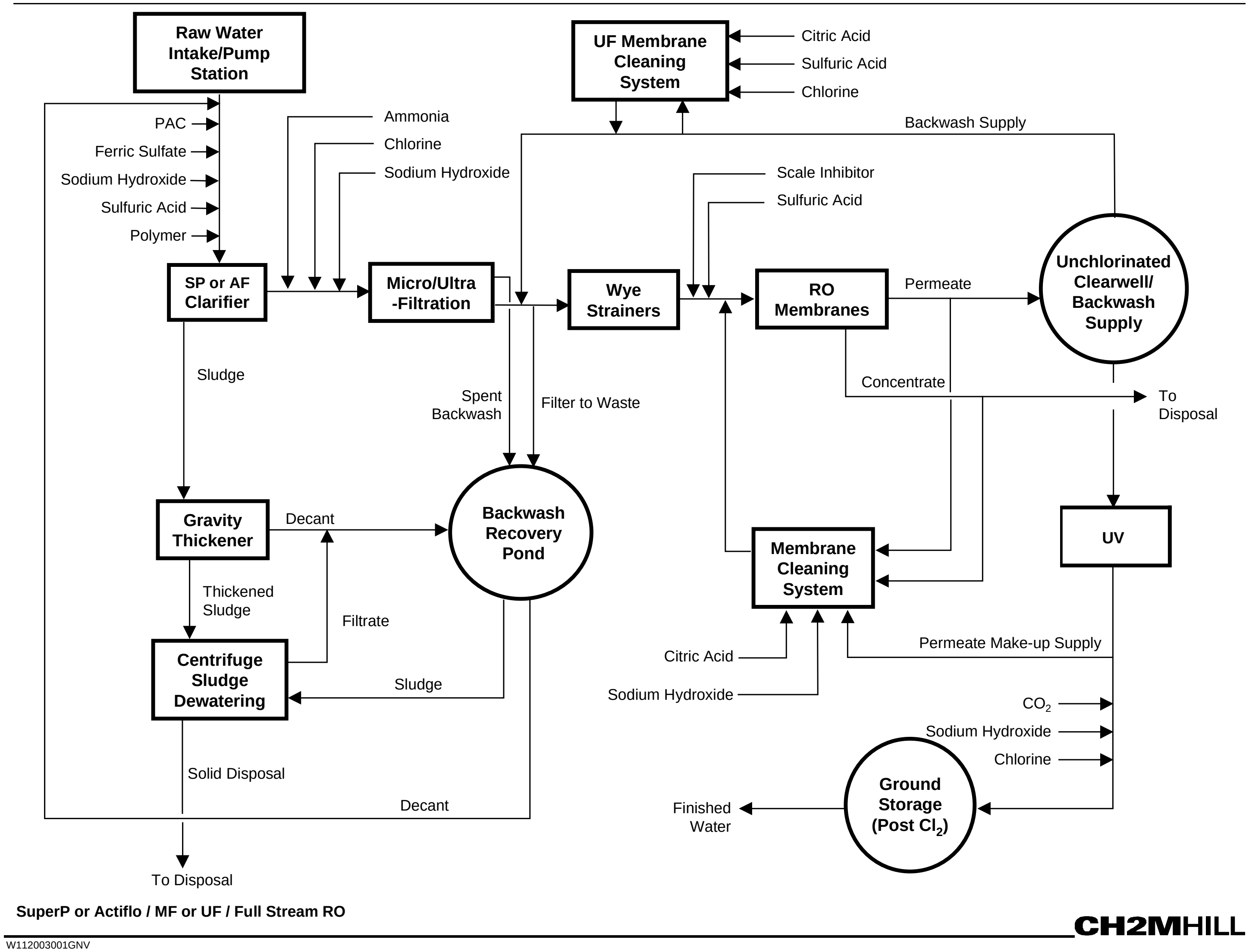


**Figure 151. High Rate Clarification and Micro or Ultra Filtration with 100% RO Treatment (Alt. 5 and 6)**



# PRELIMINARY UNIT PROCESS DESIGN

## Process Flow Schematics and Preliminary Design Criteria

Tables 123 through 131 are the design summary tables for the six process trains presented above. The tables were developed using operational data from 19 months of pilot testing. Some of the design information was developed jointly with the specificequipment manufacturers. These preliminary design tables can be used with the above process flow schematics to assess design conditions for these alternatives.

### Table 123. Actiflo High Rate Clarifier Preliminary Design

| Parameter | Criteria | Comment |
|---|---|---|
| **Rise Rate** | 16 gpm/ft$^2$ | Higher rise rates may be possible based on current full-scale installations in Florida. |
| **Ferric Sulfate Dosage** | 69 - 289 mg/l | Dosage dependant primarily on raw water color and NOM levels. |
| **Coagulation pH** | 4.0 - 5.0 | Low coagulation pH required for enhanced coagulation and more efficient NOM removal. |
| **Polymer Dosage** | 0.40 - 0.75 mg/l | Polymer dosage primarily dependant on solids loading to the system. |
| **PAC Dosage** | 0 - 60 mg/l | PAC will be required for taste and odor control and will need to be dosed seasonally. PAC needed 6 months per year. |
| **Sodium Hydroxide Dosage** | 0 - 92 mg/l | Dosage dependant on raw water alkalinity and ferric sulfate dosage. Low alkalinity and/or high coagulant dosages result in high sodium hydroxide dosages. Sodium hydroxide needed 10 months per year. |
| **Sulfuric Acid Dosage** | 0 - 43 mg/l | Dosage dependant on raw water alkalinity and ferric sulfate dosage. High alkalinity and/or low coagulant dosages result in high sulfuric acid dosages. Sulfuric acid needed 2 months per year. |
| **Dry Sludge Production** | 1,200 lbs/MG | Assumes max coagulant dosage. |
| **Sludge % Dry Solids from Clarifier** | 0.25% | |
| **Gravity Thickener** | | Typically 2 units |
| **Hydraulic Loading Rate** | 100-300 gpd/sf | |
| **Solids Loading Rate** | 5-10 lb/sf/d | |
| **Centrifuge** | 200-325 gpm | Number of centrifuges dependant on final plant size |

## Table 124. SuperP High Rate Clarifier Preliminary Design

| Parameter | Criteria | Comment |
|---|---|---|
| **Rise Rate** | 3.6 gpm/$ft^2$ | Rise rate for SuperP Type U clarifier. |
| **Ferric Sulfate Dosage** | 69 - 289 mg/l | Dosage dependant primarily on raw water color and NOM levels. |
| **Coagulation pH** | 4.0 - 5.0 | Low coagulation pH required for enhanced coagulation and more efficient NOM removal. |
| **Polymer Dosage** | 0.47 - 0.98 mg/l | Polymer dosage primarily dependant on solids loading to the system. |
| **PAC Dosage** | 0 - 20 mg/l | PAC will be required for taste and odor control and will need to be dosed seasonally. PAC needed 6 months per year. |
| **Sodium Hydroxide Dosage** | 0 - 92 mg/l | Dosage dependant on raw water alkalinity and ferric sulfate dosage. Low alkalinity and/or high coagulant dosages result in high sodium hydroxide dosages. Sodium hydroxide needed 10 months per year. |
| **Sulfuric Acid Dosage** | 0 - 43 mg/l | Dosage dependant on raw water alkalinity and ferric sulfate dosage. High alkalinity and/or low coagulant dosages result in high sulfuric acid dosages. Sulfuric acid needed 2 months per year. |
| **Dry Sludge Production** | 1,200 lbs/MG | Assumes max coagulant dosage. |
| **Sludge % Dry Solids from Clarifier** | 0.50% | |
| **Gravity Thickener** | | Typically 2 units |
| **Hydraulic Loading Rate** | 100-300 gpd/sf | |
| **Solids Loading Rate** | 5-10 lb/sf/d | |
| **Centrifuge** | 200-325 gpm | Number of centrifuges dependant on final plant size |

## Table 125. Pre-filtration Chemical Feed Preliminary Design

| Parameter | Criteria | Comment |
|---|---|---|
| **Filtration pH** | 6.5 - 7.0 | Filtration pH must be increased after clarification to convert soluble iron carryover to insoluble iron for removal on the filter |
| **Sodium Hydroxide Dosage** | 15 - 51 mg/l | Dosage primarily dependant on clarification pH and inorganic concentrations. |
| **Chloramine Dosage** | 1 - 2 mg/l as $Cl_2$ | Required for biofouling control on the RO membranes. Minimize dosage to reduce membrane degradation; however, dose sufficient chloramines to control biofouling. |
| **Ammonia Dosage** | 0.25 - 1.00 mg/l as $NH_3$-N | Estimate $Cl_2$:$NH_3$-N of 4:1. Need to maintain 0.1 mg/l $NH_3$-N free residual to prevent degradation of RO membranes by free chlorine. |
| **Chlorine Dosage** | 0.5 - 2.0 mg/l as $Cl_2$ | Minimize chlorine dosage to reduce membrane degradation. Dose sufficient chlorine |

## Table 126. Granular Media Filtration Preliminary Design

| Parameter | Criteria | Comment |
|---|---|---|
| **Filter Loading Rate** | 6 gpm/ft$^2$ | Based on results of filtration testing with SuperP and Actiflo. |
| **Filter Media** | 60" GAC/12" Sand | Standard design. |

## Table 127. Zenon ZW-1000 UF Filtration Preliminary Design (after clarification)

| Parameter | Criteria | Comment |
|---|---|---|
| **Instantaneous Flux** | 20 gfd | Result based on correlation of ZW 500-C data to ZW-1000 and conservative recommendation by Zenon. Higher design flux may be possible. |
| **Recovery** | 92 percent | |
| **Filter Run Duration** | 15 minutes | |
| **Backwash/pulse duration** | 60 seconds | |
| **Cleaning Interval** | | |
| **Temp < 60 °F** | 4 weeks | Temperature greater than 60°F approximately 10 months per year. |
| **Temp > 60 °F** | 6 weeks | Temperature less than 60°F approximately 2 months per year. |
| **Maintenance Cleaning** | 7 Cleans/Week | Full tank deconcentration with either a chlorinated or citric acid maintenance clean. |
| **Chlorinated Clean** | 5 with 50 mg/L as $Cl_2$ | |
| **Citric Acid Clean** | 2 with 1 g/L Citric Acid | Adjust pH to 2 with sulfuric acid after citric acid addition. |
| **Recovery Clean** | Chlorine/Citric Acid | Chlorinated clean followed by citric acid clean. |
| **Clean Frequency** | ~10 Times per Year | |
| **Chlorinated Recovery Clean** | | Primarily for organics removal. |
| **Backpulse Concentration** | 1000 mg/l as $Cl_2$ | |
| **Soak Concentration** | 250 mg/l as $Cl_2$ | |
| **Soak Duration** | 4-6 hours | |
| **Citric Acid Recovery Clean** | | Primarily for metals/iron removal. |
| **Backpulse Concentration** | 4 g/l | Adjust pH to 2 with sulfuric acid after citric acid addition. |
| **Soak Concentration** | 1 g/l | Adjust pH to 2 with sulfuric acid after citric acid addition. |
| **Soak Duration** | 4-6 hours | |

## Table 128. Memcor CMF-S MF Filtration Preliminary Design (after clarification)

| Parameter | Criteria | Comment |
|---|---|---|
| **Instantaneous Flux** | 39 gfd | |
| **Recovery** | 94 percent | |
| **Filter Run Duration** | 30 minutes | |
| **Backwash/pulse duration** | 60 seconds | |
| **Cleaning Interval** | 6 weeks | Temperature less than 60°F approximately 2 months per year. |
| **Maintenance Cleaning** | 7 Cleans/Week | Chlorinated clean only. |
| **Chlorine Concentration** | 200 mg/L as $Cl_2$ | |
| **Recovery Clean** | Chlorine/Citric Acid | Chlorinated clean followed by citric acid clean. |
| **Clean Frequency** | ~10 Times per Year | |
| **Chlorinated Recovery Clean** | | Primarily for organics removal. |
| **Concentration** | 400 mg/l as $Cl_2$ | |
| **Duration** | 3 hours | |
| **Citric Acid Recovery Clean** | | Primarily for metals/iron removal. |
| **Concentration** | 2 percent | |
| **Duration** | 3 hours | |

## Table 129. Zenon 500-C Ultrafiltration (Direct Filtration Mode) Preliminary Design

| Parameter | Criteria | Comment |
|---|---|---|
| **Instantaneous Flux** | 20 gfd | |
| **Recovery** | 90 percent | |
| **Ferric Sulfate Dosage** | 153-218 mg/l | Dosage dependant primarily on raw water color and NOM levels. |
| **Coagulation pH** | 5.7 - 6.1 | Optimize pH to maximize NOM removal and minimize soluble iron in the membrane permeate. |
| **Sodium Hydroxide Dosage** | 0 - 100 mg/l | Sodium hydroxide dosage primarily dependant on solids loading to the system. Sodium hydroxide required 11 months per year. |
| **Sulfuric Acid Dosage** | 0 - 15 mg/l | Sulfuric acid primarily dependant on solids loading to the system. Sulfuric acid required 1 month per year. |
| **Filter Run Duration** | 15 minutes | |
| **Backwash/pulse duration** | 15 seconds | |
| **Aeration** | 10 sec on/10 sec off | Cyclic aeration with 10 seconds of aeration followed by 10 seconds of no aeration. |
| **Cleaning Interval** | 6 weeks | |
| **Maintenance Cleaning Strategy** | 7 Tank Drains/Week | Full tank deconcentration with a chlorinated maintenance clean. |
| **Chlorinated Clean** | 250 mg/L as $Cl_2$ | |
| **Recovery Clean** | Chlorine/Citric Acid | Chlorinated clean followed by citric acid clean. |
| **Clean Frequency** | 9 Times per Year | |
| **Chlorinated Clean** | | Primarily for organics removal. |
| **Backpulse Concentration** | 1000 mg/l as $Cl_2$ | |
| **Soak Concentration** | 250 mg/l as $Cl_2$ | |
| **Soak Duration** | 4-6 hours | |
| **Citric Acid Clean** | | Primarily for metals/iron removal. |
| **Backpulse Concentration** | 4 g/l | Adjust pH to 2 with sulfuric acid. |
| **Soak Concentration** | 1 g/l | Adjust pH to 2 with sulfuric acid. |
| **Soak Duration** | 4-6 hours | |

## Table 130. Reverse Osmosis System Preliminary Design

| Parameter | Criteria | Comment |
|---|---|---|
| **Flux** | 12 gfd | Based on conservative design for treating surface water |
| **Recovery** | 88 percent | |
| **Treated Flow per Train** | 2.5 mgd | |
| **Sulfuric Acid** | 8.5 - 34 mg/l | Minimize insoluble iron in concentrate |
| **Scale Inhibitor** | 0 - 2.5 mg/l | Dependant on feed water conditions |
| **Stages** | 3 | Based on analysis by Reverse Osmosis System Analysis program by the Filmtec corporation |
| **Stage 1** | 56 pressure vessels | Assumes 6 elements per vessel |
| **Stage 2** | 24 pressure vessels | Assumes 6 elements per vessel |
| **Stage 3** | 15 pressure vessels | Assumes 6 elements per vessel |
| **Operating Pressure** | 140 - 240 psi | Based on analysis by Reverse Osmosis System Analysis program by the Filmtec corporation |
| **Cleaning Frequency** | 12 weeks | |
| **Cleaning Methodology** | High pH followed by low pH | |
| **High pH** | pH 11 - 12 RO permeate solution | Follow manufacturer guidelines |
| **Low pH** | pH 2 RO permeate solution | Follow manufacturer guidelines |
| **Membrane Replacement Frequency** | 5 years | |

## Table 131. UV Disinfection Preliminary Design

| Parameter | Criteria | Comment |
|---|---|---|
| **Transmittance** | 98 percent | Based on UVT analysis of RO permeate water. Will be lower if blending with RO feed water. |
| **Dose** | 40 $mJ/cm^2$ | Assumes 2.0 - 2.5 log inactivation of *Cryptosporidium* |

## Chemical Feed Design

A number of different chemical feeds are required for treatment of this source water. Table 132 presents, average, maximum, and minimum dosage ranges for each chemical feed as well as duration per year of the chemical feed since some are seasonal. In addition, chemicals for stabilization of the finished water prior to blending have been identified. These include soda ash, caustic soda, carbon dioxide ($CO_2$), and lime. Dosing will be unique to the needs of a specific utility. Based on the required water quality, the necessary chemicals and dosages to stabilize the blend can be estimated.

### Table 132. Chemical Feed System Requirements

| Dosing Location | Units | Average | Max | Min | Months per Year |
|---|---|---|---|---|---|
| Raw Water Prior to Clarification | | | | | |
| Ferric Sulfate | (mg/L) | 150 | 289 | 69 | 12 |
| Sodium Hydroxide | (mg/L) | 44.6 | 91.5 | 0 | 10 |
| Sulfuric Acid | (mg/L) | 26 | 43 | 0 | 2 |
| PAC (SP) | (mg/L) | 10 | 20 | 0 | 6 |
| PAC (AF) | (mg/L) | 40 | 70 | 0 | 6 |
| Polymer (SP) | (mg/L) | 0.65 | 0.98 | 0.47 | 12 |
| Polymer (AF) | (mg/L) | 0.38 | 0.75 | 0.15 | 12 |
| Clarified Effluent Prior to Filtration | | | | | |
| Ammonia | (mg/L as N) | 0.50 | 1.00 | 0.25 | 12 |
| Chlorine | (mg/L as $Cl_2$) | 1.0 | 2.0 | 0.5 | 12 |
| Sodium Hydroxide | (mg/L) | 27 | 51 | 15 | 12 |
| Filtered Water Prior to Reverse Osmosis Treatment | | | | | |
| Sulfuric Acid | (mg/L) | 21 | 34 | 8.5 | 12 |
| Antiscalant | (mg/L) | 1.7 | 2.5 | 0 | 8 |
| RO Permeate Prior to Distribution/Blending/ASR | | | | | |
| Soda Ash | (mg/L as $CaCO_3$) | Specific to blend water | | | 12 |
| Caustic Soda | (mg/L) | Specific to blend water | | | 12 |
| CO2 | (mg/L) | Specific to blend water | | | 12 |
| Lime | (mg/L as $CaCO_3$) | Specific to blend water | | | 12 |
| Chlorine | (mg/L as $Cl_2$) | Specific to blend water | | | 12 |

*Doses are as pure product except where noted

## Land Requirements

Land requirements for this facility have been estimated and are included in Table 133. For planning purposes, both the land requirements for a large and small facility have been provided, 22 mgd and 44 mgd, respectively. The capacities for the large and small facilities are based on the demand center projections and the management of the alternative supply (e.g., ASR, intermittent source, etc.). These projections and flow estimated are summarized later in this section. The land requirements are also based on the largest size unit processes such as those with the lowest loading rates and largest footprints.

### Table 133. Land Requirements

| Unit Process | 29 MGD Plant | | | 65 MGD Plant | | |
|---|---|---|---|---|---|---|
| | Unit Process Flow (mgd) | Width x Length (ft x ft) | Area*** ($ft^2$) | Unit Process Flow (mgd) | Width x Length (ft x ft) | Area*** ($ft^2$) |
| Raw water screening/pump station | 39 | 27x36 | 2632 | 87 | 44x36 | 3584 |
| Rapid Mixing | 39 | 76x15 | 3360 | 87 | 67x31 | 4437 |
| Flow splitting structure | 39 | 49x23 | 2967 | 87 | 49x23 | 3741 |
| SuperP Clarification | 39 | 157x84 | 18408 | 87 | 272x110 | 37960 |
| Granular Media Filtration | 37 | 209x97 | 26793 | 82 | 350x103 | 45510 |
| RO | 34 | 54x546 | 41884 | 76 | 54x1215 | 91390 |
| Clearwell | 34 | 353x716 | 274528 | 76 | 528x1066 | 595128 |
| UV | 34 | 45x58 | 5070 | 76 | 55x99 | 8925 |
| High service pump station | 34 | 29x28 | 2352 | 76 | 44x28 | 3072 |
| Chemical feed/storage | Var | 528x68 | 48224 | Var | 828x70 | 76320 |
| Backwash Supply | Var | 28x25 | 2160 | Var | 40x29 | 2940 |
| Gravity thickener | 5 | 306x168 | 61288 | 11 | 460x240 | 124800 |
| Centrifuge solids dewatering | 5 | 30x46 | 3300 | 11 | 30x46 | 3300 |
| Decant Pond* | 5 | 220x440** | 110400 | 11 | 320x590** | 207400 |
| Administration Building | NA | 80x190 | 21000 | NA | 80x240 | 26000 |
| Subtotal Area (ft2) | | | 624366 | | | 1234507 |
| Subtotal Area (acres) | | | 14.3 | | | 28.3 |
| Parking and Roads (acres) | 15% | | 2.2 | 15% | | 4.3 |
| Stormwater Requirements (acres) | 13% | | 1.9 | 13% | | 3.7 |
| Landscaping and Buffering (acres) | 5% | | 0.7 | 5% | | 1.4 |
| Additional Items (acres) | 5% | | 0.7 | 5% | | 1.4 |
| Total Area (acres) | | | 19.8 | | | 39.1 |

*Assumes one day detention time.

**Assumes 6' depth.

***Includes an additional 20 feet on each side of each unit process for spacing.

# RECOMMENDED ALTERNATIVES

The recommended alternatives include both the average benefit and lowest cost processes as well as the highest cost and highest benefit processes. To assess this cost difference based on the final pilot data, both construction costs and yearly O&M costs were estimated for each alternative assuming a 19 mgd facility. This 19 mgd size was selected from the one of the demand scenarios discussed later and was chosen for comparison purposes only.

The comparative costs for treatment Alternatives 1 through 6 are summarized in Table 134.

**Table 134. Comparative Treatment Plant Capital and O&M Costs at 19 MGD ADF/22 MGD MDF**

| Alt. No. | Treatment System | Plant Cost ($) | Yearly O&M ($) |
|---|---|---|---|
| 1 | Zenon ZW-500-C with 100% RO | $ 131,876,969 | $ 13,044,020 |
| 2 | Zenon ZW-500-C with 75% RO | $ 123,632,133 | $ 11,966,681 |
| 3 | Actiflo/Granular Media Filtration with 75% RO | $ 93,034,600 | $ 9,760,222 |
| 4 | SuperP/Granular Media Filtration with 75% RO | $ 92,147,077 | $ 9,712,800 |
| 5 | Actiflo/Memcor CMF-S with 100% RO | $ 115,848,998 | $ 12,325,464 |
| 6 | SuperP/Memcor CMF-S with 100% RO | $ 114,961,474 | $ 12,278,042 |

Includes raw water screening and pump station, rapid mixing, flow splitting structure, clearwell, high service pump station, chemical feed and storage, UV disinfection, on-site sodium hypochlorite generation, gravity thickeners, and centrifuge solids dewatering.

Alternatives 1 and 2 include the Zenon ZW-500-C direct filtration with full and partial RO treatment. These options include the high benefit alternatives due to the use of the ultrafilter membrane as well as 100 percent RO. However, these options are 15 percent to 42 percent higher in cost than the other alternatives. The reason for this higher cost is that the flux for the Zenon membrane is very low due to this high organic water. Low flux translates intoincreased membrane cost. Although this is the highest cost alternative, it is less operationally intensive since it has less equipment without the clarifier (i.e., higher benefit). It should also be noted that Alternative 1, with 100 percent RO, can be further optimized to minimize coagulation requirements and allow more orgainic removal with the RO membranes.

Alternatives 3 and 4 include high rate clarification, granular media filtration, and split stream RO. These options include the average benefit alternatives since they do not include membrane filtration and only implement partial RO for TDS reduction. However, as expected, the average benefit alternatives have the lowest capital and operating cost.

Alternative 5 and 6 optimizes performance of the UF/MF membranes by clarifying the water prior to filtration with the membrane, thus lowering the organics and increasing the acceptable flux rate. By optimizing the use of the membrane filter, alternatives 5 and 6 can still have the high benefit of the dual membrane process with 100 percent RO, vis-à-vis Alternative 1, but with 14 percent lower cost. Alternatives 5 and 6 represent the highest benefit alternative (as does Alternative 1), but with medium cost, making it the best cost-benefit option. Alternatives 5 and 6 use the Memcor CMF-S membrane due cost issues. The Zenon 1000 membrane can also be used in this application but was significantly higher in cost at the time of this report. The Zenon cost can be revisited before implementation.

As mentioned earlier, all of the alternatives can be recommended for treatment of this source water. The major difference in these processes is the use of the membranes. Based on stakeholder input and issues of public perception that were noted during the facility tours, a significant emphasis has been placed on the use of dual membrane systems with 100 percent RO to produce the highest quality water. The reasons for this type of system are for treatment of emerging contaminants as well as to remove greater than 90 percent of the organics in the water. This high organic removal will allow the stakeholder utilities to continue using free chlorine as the residual disinfectant. The cost of increasing from 75 percent RO to 100 percent RO is about a 6 percent. If the source water to be treated requires this level of RO treatment, especially as it relates to treatment of emerging contaminants, the 6 percent cost increase in construction is reasonable. However, if a much lower RO capacity is needed to produce acceptable TDS water only, it may be more cost effective to use partial treatment and chloramines as a residual disinfectant.

Although all six alternatives can be recommended for this study (based on the pilot data), for the sake of simplicity, only one alternative will be carried forward to conduct the affordability analysis. Carrying forward more than one alternative into the affordability analysis would result in an additional level of complexity and number of scenarios that would not provide any benefit to the reader.

Cost estimates for Alternatives 5 and 6 will be used for the remainder of the evaluation and affordability analysis. These are the high rate clarification, membrane filtration, and 100 percent RO alternatives. There is a minimal cost difference between the Actiflo and the SuperP high rate clarifier, so the cost estimates will not be distinguished between the two.

This alternative was selected because it provides for a best-case scenario for water treatment with the dual membrane and 100 percent RO system. The alternative also considers the stakeholder issues of emerging contaminants removal and organic removal to maintain the use of free chlorine. This represents the maximum benefit scenario and higher cost alternative to carry forward into the costing and affordability analyses.

Therefore, the costs estimates presented in this report, as well as those in the affordability estimates, will include the higher cost alternative of the high rate clarification dual membrane system (membrane filtration followed by RO) with 100 percent RO that has the highest benefit with treatment for emerging contaminants and organic removal.

## DEMAND CENTER AND WATER SUPPLY SCENARIOS

To develop a representative range of costs estimates for the study, representative demand centers and water supply alternatives were identified. Three demand centers and three water supply scenarios were selected for evaluation. The demand centers include: 1) an "All Volusia" demand center serving all of the County, 2) an "All Seminole" demand center serving all of the County, and 3) a "Seminole and South Volusia" demand center serving a combination of the two. It is important to note that scenario 3 is a combination of Seminole and South Volusia only, not all of Volusia.

It is assumed that each demand center is served from one surface water treatment facility. The source of the demand center average daily flows (ADF) is from the report *Affordability Analysis of Alternative Water Supplies* (Burton and Associates, 2004).

In addition to the demand centers, three water supply scenarios are being considered: 1) intermittent river supply with ASR that can only have seasonal withdraw, 2) reliable source with ASR, and 3) reliable source without ASR. Table 135 summarizes the water supply scenarios as well as the resulting demand center flows.

The main difference in these scenarios is the application of ASR for system storage as well as the use of the river as a seasonally intermittent or reliable year round source. The Intermittent

Source with ASR" scenario has the highest ASR capacity since it assumes that the river source will only be available during high flow conditions and not during low flow conditions. This higher ASR capacity is to provide a reliable supply of treated water from a seasonally unreliable source. The other two scenarios consider a year round reliable source where ASR is used to offset the treatment plant capacity reuired to meet max day flows and is not used in the final scenario resulting in a larger capacity plant.

These max day factors were developed considering a larger regional facility.

**Table 135. Water Supply and Demand Center Scenarios**

| Demand Center | | Demand | Intermittent Source w/ASR (1.5 ASR Factor) | Reliable Source w/ASR (0.5 ASR Factor) | Reliable Source w/o ASR |
|---|---|---|---|---|---|
| | | ADF | MDF = 1.32 * ADF | MDF = 1.15 * ADF | MDF = 1.50 * ADF |
| | | (MGD) | (MGD) | (MGD) | (MGD) |
| All Volusia | Initial Demand | 26 | 34 | 30 | 39 |
| | Ultimate Demand | 34 | 45 | 39 | 51 |
| | ASR Capacity | | 51 | 17 | 0 |
| Seminole | Initial Demand | 19 | 25 | 22 | 29 |
| | Ultimate Demand | 25 | 33 | 29 | 38 |
| | ASR Capacity | | 38 | 13 | 0 |
| Seminole and South Volusia | Initial Demand | 32 | 42 | 37 | 48 |
| | Ultimate Demand | 43 | 57 | 49 | 65 |
| | ASR Capacity | | 65 | 22 | 0 |

ADF - Average daily flow; MDF - Max day factor; ASR - Aquifer storage and recovery factor

# TREATMENT PLANT COSTS FOR RECOMMENDED ALTERNATIVES

The treatment plant costs for the nine recommended alternatives and water supply scenarios (recommended for the affordability analysis) discussed earlier are summarized in Tables 136 to 138. The detailed treatment plant construction cost estimates for the nine alternatives are included in Appendix F.

Each scenario is presented with two sites. These sites were identified in the Siting Study report by HDR (TM D2B *Surface Water Treatment Plant Siting Study*, HDR, 2004). The maps and locations for these sites can be referenced in the HDR report.

The difference between the sites is the distance of piping for the raw water pipeline, the finished water pipeline, and the concentrate disposal pipeline. The differences in total costs for each site can be identified in the pipeline costs. The differences in cost between scenarios are due to the capacity of the plant based on the source and use of ASR. Those factors as well as the mark-up percentages to calculate the capital costs are summarized at the bottom of each table.

## Table 136. Costs for Intermittent Source with ASR

| Demand Center | Ultimate Design | Ultimate Design |
|---|---|---|
| | Site G | Site E |
| **All Volusia** | **ADF 34 mgd** | **ADF 34 mgd** |
| | **Max Day 45 mgd** | **Max Day 45 mgd** |
| **Capital Costs** | | |
| Plant | $204,082,896 | $204,082,896 |
| Raw Water Pipeline | $890,400 | $26,022,000 |
| Finished Water Pipeline | $55,836,000 | $59,517,600 |
| Concentrate Disposal Pipeline | $7,392,000 | $10,803,600 |
| ASR | $31,620,000 | $31,620,000 |
| Plant Land Cost | $510,000 | $750,000 |
| Pipeline Land Cost | $4,141,000 | $6,055,000 |
| **Total** | **$304,472,296** | **$338,851,096** |
| **Annual O&M Cost** | **$28,708,952** | **$28,708,952** |
| | Site B | Site K |
| **Seminole** | **ADF 25 mgd** | **ADF 25 mgd** |
| | **Max Day 33 mgd** | **Max Day 33 mgd** |
| **Capital Costs** | | |
| Plant | $155,551,638 | $155,551,638 |
| Raw Water Pipeline | $2,024,878 | $8,590,139 |
| Finished Water Pipeline | $46,631,791 | $50,313,345 |
| Concentrate Disposal Pipeline | $261,883 | $4,188,291 |
| ASR | $23,250,000 | $23,250,000 |
| Plant Land Cost | $1,300,000 | $0 |
| Pipeline Land Cost | $3,453,000 | $4,816,000 |
| **Total** | **$232,473,190** | **$246,709,414** |
| **Annual O&M Cost** | **$18,600,835** | **$18,600,835** |
| | Site K | Site E |
| **Seminole and South Volusia** | **ADF 43 mgd** | **ADF 43 mgd** |
| | **Max Day 57 mgd** | **Max Day 57 mgd** |
| **Capital Costs** | | |
| Plant | $248,485,006 | $248,485,006 |
| Raw Water Pipeline | $10,625,833 | $28,841,679 |
| Finished Water Pipeline | $144,966,427 | $144,966,427 |
| Concentrate Disposal Pipeline | $5,275,636 | $12,529,204 |
| ASR | $39,990,000 | $39,990,000 |
| Plant Land Cost | $0 | $750,000 |
| Pipeline Land Cost | $8,840,000 | $10,680,000 |
| **Total** | **$458,182,903** | **$486,242,316** |
| **Annual O&M Cost** | **$37,585,862** | **$37,585,862** |

| Construction Markups: | | Capital Mark-ups: | | Design Flow Factors: | |
|---|---|---|---|---|---|
| Overhead | 10% | Permittng | 3% | Max Day | 1.32 * ADF |
| Profit | 5% | Engineering/SDC | 16% | ASR | 1.5 * ADF |
| Mob/Bond | 3% | Start-up | 2% | | |
| Contingency | 30% | Legal | 3% | | |

## Table 137. Costs for Reliable Source with ASR

| Demand Center | Ultimate Design | Ultimate Design |
|---|---|---|
| | Site G | Site E |
| **All Volusia** | **ADF 34 mgd** | **ADF 34 mgd** |
| | **Max Day 39 mgd** | **Max Day 39 mgd** |
| **Capital Costs** | | |
| Plant | $183,408,393 | $183,408,393 |
| Raw Water Pipeline | $890,400 | $26,022,000 |
| Finished Water Pipeline | $55,836,000 | $59,517,600 |
| Concentrate Disposal Pipeline | $7,392,000 | $10,803,600 |
| ASR | $10,540,000 | $10,540,000 |
| Plant Land Cost | $510,000 | $750,000 |
| Pipeline Land Cost | $4,141,000 | $6,055,000 |
| **Total** | **$262,717,793** | **$297,096,593** |
| **Annual O&M Cost** | **$26,836,052** | **$26,836,052** |
| | Site B | Site K |
| **Seminole** | **ADF 25 mgd** | **ADF 25 mgd** |
| | **Max Day 29 mgd** | **Max Day 29 mgd** |
| **Capital Costs** | | |
| Plant | $139,456,224 | $139,456,224 |
| Raw Water Pipeline | $2,024,878 | $8,590,139 |
| Finished Water Pipeline | $46,631,791 | $50,313,345 |
| Concentrate Disposal Pipeline | $261,883 | $4,188,291 |
| ASR | $7,750,000 | $7,750,000 |
| Plant Land Cost | $1,300,000 | $0 |
| Pipeline Land Cost | $3,453,000 | $4,816,000 |
| **Total** | **$200,877,776** | **$215,114,000** |
| **Annual O&M Cost** | **$17,965,501** | **$17,965,501** |
| | Site K | Site E |
| **Seminole and South Volusia** | **ADF 43 mgd** | **ADF 43 mgd** |
| | **Max Day 49 mgd** | **Max Day 49 mgd** |
| **Capital Costs** | | |
| Plant | $221,288,669 | $221,288,669 |
| Raw Water Pipeline | $10,625,833 | $28,841,679 |
| Finished Water Pipeline | $144,966,427 | $144,966,427 |
| Concentrate Disposal Pipeline | $5,275,636 | $12,529,204 |
| ASR | $13,330,000 | $13,330,000 |
| Plant Land Cost | $0 | $750,000 |
| Pipeline Land Cost | $8,840,000 | $10,680,000 |
| **Total** | **$404,326,566** | **$432,385,979** |
| **Annual O&M Cost** | **$34,367,175** | **$34,367,175** |

| Construction Markups: | | Capital Mark-ups: | | Design Flow Factors: | |
|---|---|---|---|---|---|
| Overhead | 10% | Permittng | 3% | Max Day | 1.15 * ADF |
| Profit | 5% | Engineering/SDC | 16% | ASR | 0.50 * ADF |
| Mob/Bond | 3% | Start-up | 2% | | |
| Contingency | 30% | Legal | 3% | | |

## Table 138. Costs for Reliable Source without ASR

| Demand Center | Ultimate Design | Ultimate Design |
|---|---|---|
| | Site G | Site E |
| **All Volusia** | **ADF 34 mgd** | **ADF 34 mgd** |
| | **Max Day 51 mgd** | **Max Day 51 mgd** |
| **Capital Costs** | | |
| Plant | $224,810,074 | $224,810,074 |
| Raw Water Pipeline | $890,400 | $26,022,000 |
| Finished Water Pipeline | $55,836,000 | $59,517,600 |
| Concentrate Disposal Pipeline | $7,392,000 | $10,803,600 |
| ASR | $0 | $0 |
| Plant Land Cost | $510,000 | $750,000 |
| Pipeline Land Cost | $4,141,000 | $6,055,000 |
| **Total** | **$293,579,474** | **$327,958,274** |
| **Annual O&M Cost** | **$30,844,123** | **$30,844,123** |
| | **Site B** | **Site K** |
| **Seminole** | **ADF 25 mgd** | **ADF 25 mgd** |
| | **Max Day 38 mgd** | **Max Day 38 mgd** |
| **Capital Costs** | | |
| Plant | $171,301,478 | $171,301,478 |
| Raw Water Pipeline | $2,024,878 | $8,590,139 |
| Finished Water Pipeline | $46,631,791 | $50,313,345 |
| Concentrate Disposal Pipeline | $261,883 | $4,188,291 |
| ASR | $0 | $0 |
| Plant Land Cost | $1,300,000 | $0 |
| Pipeline Land Cost | $3,453,000 | $4,816,000 |
| **Total** | **$224,973,030** | **$239,209,254** |
| **Annual O&M Cost** | **$19,601,801** | **$19,601,801** |
| | **Site K** | **Site E** |
| **Seminole and South Volusia** | **ADF 43 mgd** | **ADF 43 mgd** |
| | **Max Day 65 mgd** | **Max Day 65 mgd** |
| **Capital Costs** | | |
| Plant | $278,906,715 | $278,906,715 |
| Raw Water Pipeline | $10,625,833 | $28,841,679 |
| Finished Water Pipeline | $144,966,427 | $144,966,427 |
| Concentrate Disposal Pipeline | $5,275,636 | $12,529,204 |
| ASR | $0 | $0 |
| Plant Land Cost | $0 | $750,000 |
| Pipeline Land Cost | $8,840,000 | $10,680,000 |
| **Total** | **$448,614,612** | **$476,674,025** |
| **Annual O&M Cost** | **$41,371,847** | **$41,371,847** |

| Construction Markups: | | Capital Mark-ups: | | Design Flow Factors: | |
|---|---|---|---|---|---|
| Overhead | 10% | Permittng | 3% | Max Day | 1.50 * ADF |
| Profit | 5% | Engineering/SDC | 16% | ASR | 0.0 * ADF |
| Mob/Bond | 3% | Start-up | 2% | | |
| Contingency | 30% | Legal | 3% | | |

The capital costs and O&M costs in Tables 136 through 138 were used as the basis for the Affordability Analysis conducted by Burton and Associates. The impact these plant costs have on local rate structures and affordability can be found in the report, *Affordability Analysis of Alternative Water Supplies* (Burton and Associates, 2004).

As mentioned earlier, it should be noted that the above costs provided for the affordability analysis are based on Alternatives 5 and 6. This was done to assess the maximum limits of affordability with the highest benefit and higher cost alternatives. Other alternatives can be implemented, such as Alternatives 3 and 4, that are about 25 percent to 30 percent lower in capital cost.

All costs presented in these tables, as well as Appendix F, are planning level costs as defined by the American Association of Cost Engineers and have an accuracy of +50 to –30 percent.

## ASSESSING PARTIAL TREATMENT APPLICATIONS

A final requirement of this study was to evaluate any other potential uses for this brackish surface water other than potable use. Treatment of St. Johns River water to less than drinking water standards for non-potable uses is also an option available to East-Central Florida water supply utilities. In this case, the partially treated non potable water could be used to help offset potable demands. Non potable uses may include the following.

- Direct irrigation
- Augmentation of reclaimed water irrigation systems
- Re-hydration of impacted lakes and wetlands
- Artificial recharge via Rapid Infiltration Basins (RIBs)

Direct artificial recharge via injection wells currently requires meeting all primary and secondary drinking water standards and would require full treatment. It is, therefore, not among the partial treatment alternatives. Each of the above potential non-potable applications may require slightly different levels of treatment for a given site specific applications. However, in general, if the partially treated surface water meets public access reuse standards, it should be suitable for most of the above non potable applications.

Florida regulations (Rule 62-610.472) require that surface water supplies used to supplement reclaimed water supply be treated to fecal coliform and TSS limits established for high level disinfection of wastewater. These limits are non-detect of fecal coliform and 5 mg/L TSS. These limits must be met before combining with reclaimed water. In general, for St. Johns River raw water, the Public Access Reuse limits can be meet by a combination of pre treatment and high level disinfection.

In addition, when considering irrigation uses with reuse, other inorganic standards may need to be considered depending on the application. Because of the seasonally high levels of TDS found in the St. Johns River, salt tolerant applications will be most viable.

To further investigate the use of Lake Monroe as a Public Access Reuse source, jar tests were performed to simulate treatment with the clarification technologies. Further, following jar testing, the coagulated/settled water was filtered through Wattman 400 filter paper to simulate media filtration.

The Lake Monroe water was characterized for the major analytes that can be considered for reuse applications.

Jar testing was performed at two ferric sulfate dosages to simulate different treatment scenarios with the clarification technologies and assess the required treatment scenario to remove TDS. The first dosage, considered a near optimum dosage for high levels of organics and suspended solids removal, was evaluated as a baseline representing coagulation conditions when treating to drinking water standards. For comparison, a 20 percent lower dosage was evaluated to observe the lower level of organic removal and assess the impact on TSS levels. The basis for this test was to determine if lower levels of treatment can achieve the reuse standards for TSS. In addition to evaluating organic and suspended solids removal, increases in inorganic parameters such as TDS and sulfate were evaluated.

The data from this evaluation is summarized in Table 139. As expected, the higher coagulant dosage effectively removed the TSS to 2 mg/L which is below the regulatory limit of 5 mg/L. The 20 percent lower coagulant dosage was able to achieve the regulatory requirement and meet the 5 mg/L level. These data verify the concept that lower coagulant doses can be used to meet the FDEP reuse criteria for TDS while avoiding excess chemical use in removing organics to unnecessary levels.

Although lower coagulant dosages than what are applied for potable water treatment can be used to remove TSS to reuse levels, the background chloride and sulfate levels in this source water limit the range of uses for this source without additional treatment. Based on the pilot data, the average chloride concentrations in the raw water were 285 mg/L with a maximum of 560 mg/L, and a minimum of 81 mg/L. Since this water is not being sold to customers as potable water would be, it would be difficult to justify the cost-benefit of using membranes to reduce these salt levels.

It should be further noted that if membranes were to be used to reduce these salt levels, the pretreatment requirements for these membranes would require that the raw water be treated to potable standards to avoid fouling the membranes. This high level of treatment would certainly preclude this water being used for reuse applications after pretreatment and membrane desalting.

In summary, lower levels of pretreatment coagulation can be used to meet the FDEP public access reuse standard of 5 mg/L TSS. Based on the inorganic levels in the river, at times of the year, significant blending volumes will be necessary to utilize this water after TSS removal. Therefore, the specific application must be examined closely for sensitivity to chloride and other ions and this could greatly limit the potential for development of non-potable applications. Opportunities for blending with other low chloride non-potable sources, or seasonal use, should also be explored.

**Table 139. Raw Water and Jar Test Data Summary**

| Analyte | Units | Detection Limit | Raw Water | 55 mg/L $Fe_2(SO_4)_3$ Dosage* | | 70 mg/L $Fe_2(SO_4)_3$ Dosage* | |
|---|---|---|---|---|---|---|---|
| | | | | Clarified | Filtered | Clarified | Filtered |
| Alkalinity | mg/L as $CaCO_3$ | 5 | 68 | <5 | <5 | <5 | <5 |
| $BOD_5$ | mg/L | 2 | U | U | U | U | U |
| Chloride | mg/L | 1 | 321 | | | | |
| $Color_{Apparent}$ | color units | 5 | 150 | 50 | 30 | 25 | 15 |
| COD | mg/L | 5 | 65 | 20 | 16 | 15 | 5 |
| pH | pH | --- | 7.9 | 4.6 | 4.6 | 4.4 | 4.5 |
| Sulfate | mg/L | 0.1 | 65.9 | 121 | | 121 | |
| TDS | mg/L | 5 | 666 | 676 | | 622 | |
| TSS | mg/L | 2 | 11 | 5 | 4 | <2 | 2 |
| TOC | mg/L | 2.5 | 23.1 | 6.3 | 5.8 | 4.6 | 4.4 |
| Turbidity | NTU | 0.1 | 6.5 | 3.0 | 1.8 | 1.6 | 0.8 |
| $UV_{254}$ | abs/cm | 0.009 | 0.687 | 0.100 | 0.098 | 0.076 | 0.074 |

*Dosages are as pure ferric sulfate

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# Appendix A
# Technical Memorandum C2 and C3
# Development of Treatment Goals and Evaluation and Selection of Treatment Processes

FINAL

# Surface Water Treatability and Demineralization Study

# District Project No. SE 406AA

# Development of Treatment Goals and Evaluation and Selection of Treatment Processes to be Piloted

Technical Memorandum
TM C.2 AND TM C.3

by

CH2M HILL

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April 2002
161983.A3.PM

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AOC | assimilable organic carbon |
| FDEP | Florida Department of Environmental Protection |
| NF | nanofiltration |
| PAC | powdered activated carbon |
| RO | reverse osmosis |
| SMART | Simple Multiattribute Utility Technique |
| T&O | taste and odor |
| TM | technical memorandum |
| TOC | total organic carbon |
| UV | ultraviolet |

# EXECUTIVE SUMMARY

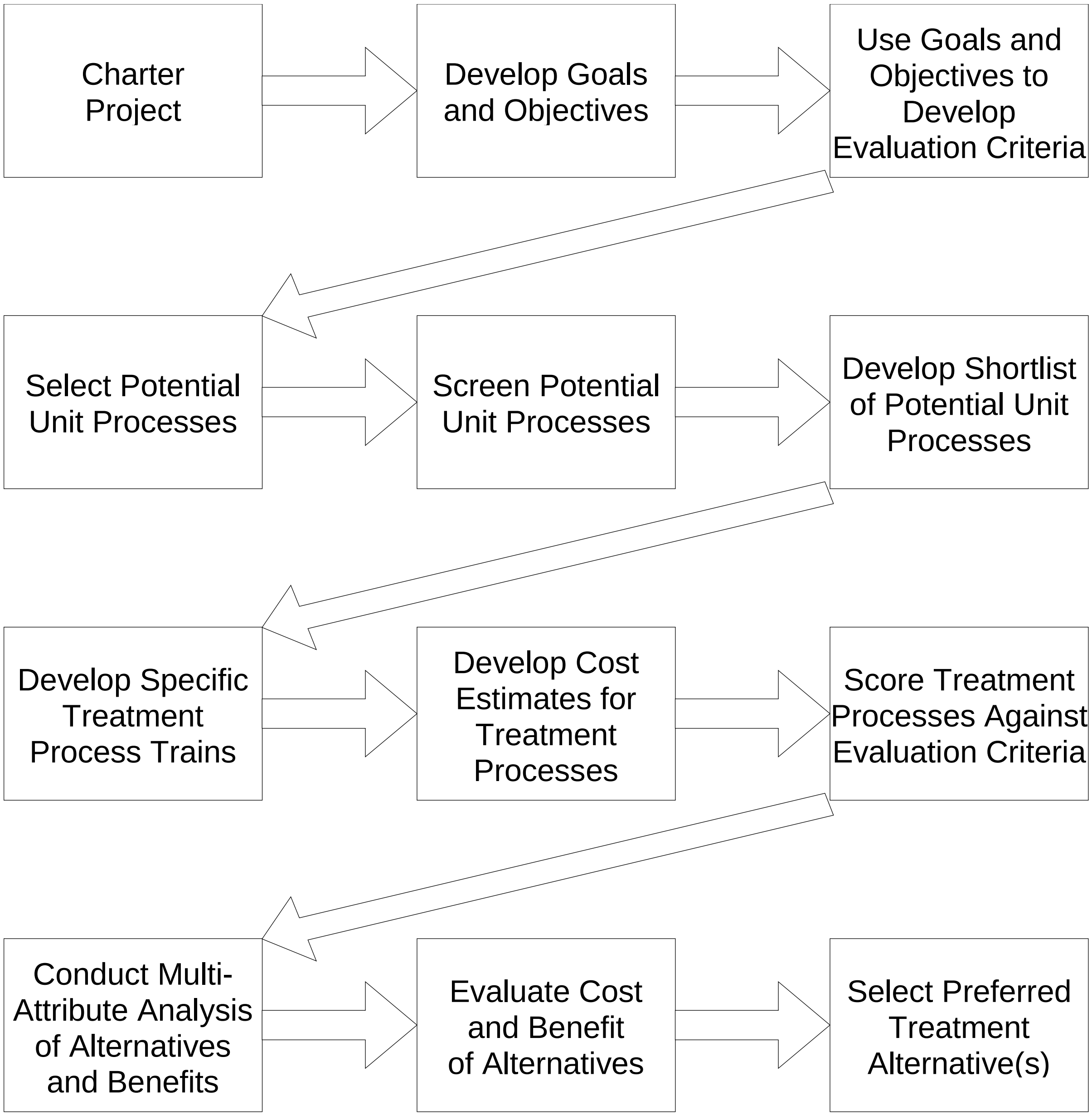
The purpose of the pilot testing for the Treatability and Demineralized Concentrate Study (District Project SE406AA) is to assess the required treatment technology to produce potable water from the middle St. Johns River. As a first step in this program, the appropriate treatment technologies to test in this study needed to be selected. This evaluation and selection process initially began with over 30 treatment processes which were then screened down to three final technology combinations for testing.

The purpose of this technical memorandum (TM) is to summarize the treatment technology selection process used for this project. This process included stakeholder input on goals and criteria, development of the treatment alternatives, multi-attribute computer modeling of the benefits and costs, and finally ranking and selection of the alternatives to be tested. The steps used in this evaluation process are illustrated in Figure ES-1. The steps in this process begin with project chartering and end with selection of preferred treatment alternatives. This process was conducted over three (3) meetings with the stakeholders and the District; Goal Meeting 1 and 2, and Evaluation Meeting 1. The stakeholders included local government officials and utility staff from east-central Florida cities and counties as well as regulatory officials from the Florida Department of Environmental Protection (FDEP) and one county health department.

Goal Meeting 1 was conducted to charter the project, develop the goals and objectives of the study, and develop the evaluation criteria and subcriteria for the selection process. These are the first 3 steps illustrated in Figure ES-1. Based on input from the stakeholders, the following five criteria with their corresponding sub-criteria were developed for the evaluation process.

1. **Regulatory Compliance**
   A. Disinfection By-products
   B. Pathogens
   C. Inorganics
   D. Organics
2. **Aesthetics** (consumer expectations beyond regulations)
   A. Taste and Odor
   B. Color
3. **Other Water Quality Goals** (beyond regulations)
   A. Algal Toxins

**Figure ES-1. Evaluation Process**



B. Chlorides
C. TOC
D. Regrowth
E. Sodium

**4. Environmental Issues**

A. Residuals-Solids
B. Traffic
C. Plant Odors
D. Sustainability (e.g., power and chemicals)
E. Environmental Hazards (chemical release)
F. Residuals-Liquid
G. Foot Print
H. Navigational Impairment
I. Noise

**5. Plant Operability**

A. Automation
B. Maintenance
C. Operating Complexity
D. Flexibility to handle degradation of water quality
E. Interruptible operations

Goal Meeting 2 was conducted to weight and rank the criteria, discuss the conceptual treatment processes (more than 30), screen the processes, develop a shortlist of treatment processes using a fatal flaw analysis, and develop the specific treatment processes to be evaluated. These are the next four steps illustrated in Figure ES-1. Through the fatal flaw analysis, the conceptual treatment processes were reduced from more than 30 down to 15 treatment alternatives. The fatal flaw analysis eliminated any technology that did not meet current regulations or that was not a proven technology for this type of water source. All treatment alternatives included organic removal and filtration for pretreatment before the desalting membranes followed by partial or full desalination, and disinfection. These processes were required since this is a highly organic surface water that is seasonally brackish and requires pretreatment before any desalting step.

The remaining steps in this process were completed with the stakeholders in Evaluation Workshop 1. To evaluate and rank the remaining 15 treatment alternatives, the weighted evaluation criteria developed by the stakeholders were used with a multi-attribute decision model designed to rank the alternatives with respect to relative benefit. Once the relative benefits were assigned using the model, the alternatives were ranked and plotted with comparative costs. Processes that had a lower relative benefit for a higher cost were eliminated.

From this evaluation step, five process combinations were selected by the stakeholders for pilot study which resulted in the following three treatment process combinations for the pilot testing:

1. SuperP clarification with granular media filtration for pretreatment followed by reverse osmosis membranes for salt removal.
2. Actiflo clarification with granular media filtration for pretreatment followed by reverse osmosis membranes for salt removal.
3. Ultrafiltration for pretreatment followed by reverse osmosis membranes for salt removal.

These three treatment process alternatives were selected to include two alternatives with average relative benefit and average cost and one alternative with the highest relative benefit and highest cost. By evaluating these three alternatives in the pilot testing, the stakeholders will have a choice between a range of benefit and costs to be used when making the decision for potential implementation.

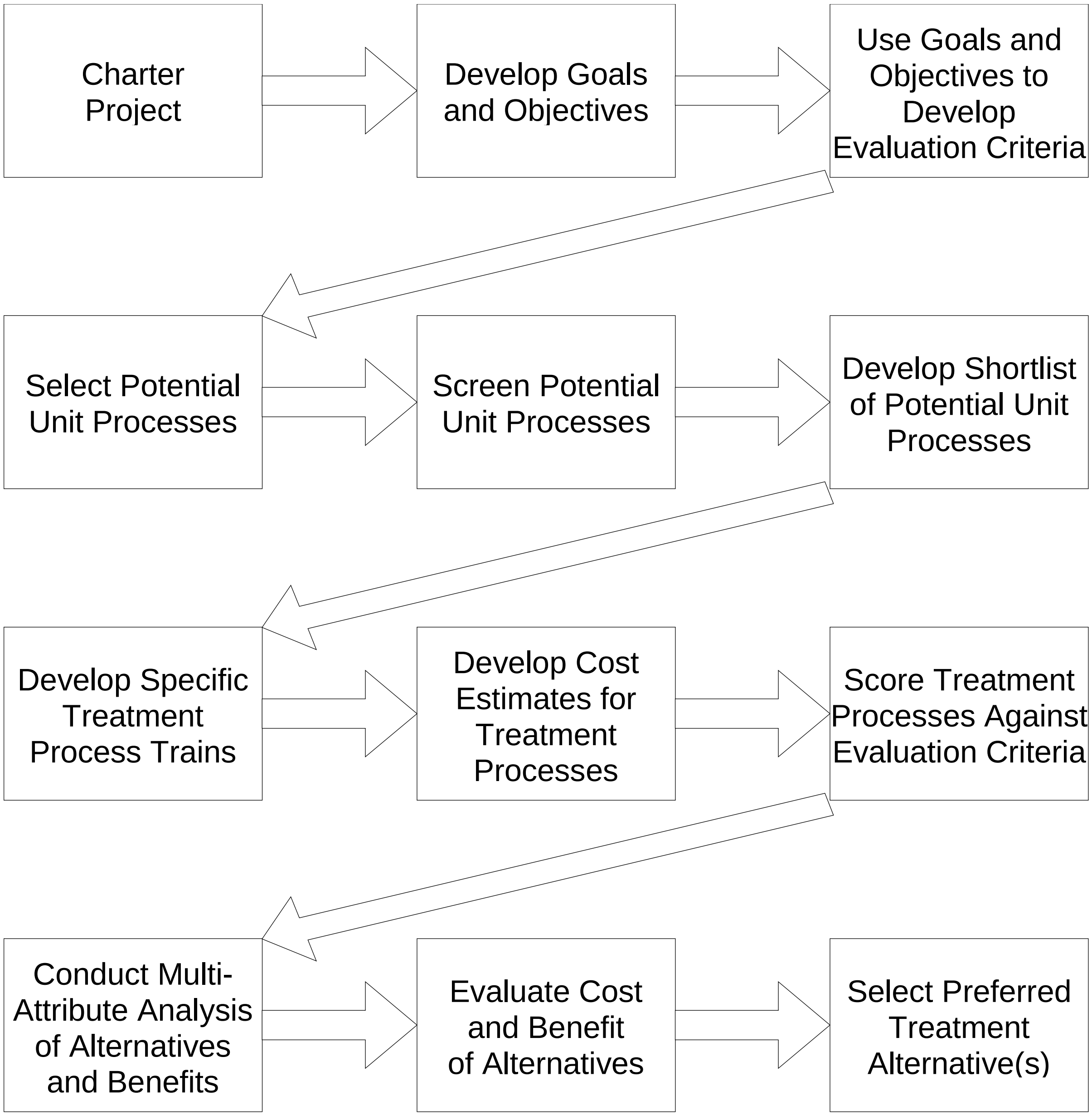
# GOAL AND CRITERIA DEVELOPMENT

As illustrated in Figure 1, the first step of the process evaluation and selection was to develop the goals and criteria with the stakeholders. The stakeholders included local government officials and utility staff from east Central Florida cities and counties as well as regulatory officials from the FDEP. The goal and criteria development was conducted in two meetings with the stakeholders, Goal Meetings 1 and 2.

Goal Meeting 1 was conducted to charter the project, develop the goals and objectives of the study, and develop the evaluation criteria and subcriteria for the selection process. These are the first 3 steps illustrated in Figure 1. Based on input from the stakeholders, the following five criteria with their corresponding sub-criteria were developed for the evaluation process.

1. **Regulatory Compliance**
   - A. Disinfection By-products
   - B. Pathogens
   - C. Inorganics
   - D. Organics
2. **Aesthetics** (consumer expectations beyond regulations)
   - A. Taste and Odor
   - B. Color
3. **Other Water Quality Goals** (beyond regulations)
   - A. Algal Toxins
   - B. Chlorides
   - C. TOC
   - D. Regrowth
   - E. Sodium
4. **Environmental Issues**
   - A. Residuals-Solids
   - B. Traffic
   - C. Plant Odors
   - D. Sustainability (e.g., power and chemicals)
   - E. Environmental Hazards (chemical release)
   - F. Residuals-Liquid
   - G. Foot Print
   - H. Navigational Impairment
   - I. Noise

**Figure 1. Evaluation Process**



5. **Plant Operability**
   A. Automation
   B. Maintenance
   C. Operating Complexity
   D. Flexibility to handle degradation of water quality
   E. Interruptible Operation

Table 1 summarizes the five primary criteria and corresponding sub-criteria along with the individual goals developed by the stakeholders.

Goal Meeting 2 was conducted to weight and rank the criteria, discuss the conceptual treatment processes, screen the processes, develop a shortlist of treatment processes using a fatal flaw analysis, and develop the specific treatment processes to be evaluated. These are the next four steps illustrated in Figure 1. To weight the criteria, the stakeholders discretely compared each primary criteria and determined which criteria was most important when directly compared to another. For example, if "Aesthetics" was <u>more</u> important than "Environmental Issues," then "Aesthetics" was scored with a higher preference when directly compared to "Environmental Issues." This process is continued until all of the criteria have been compared. The weighting factors were then calculated as the percentage of cases where a primary criteria was determined to be more important than other primary criteria divided by the number of comparisons. Table 2 summarizes the criteria ranking from this process. Through this process, the stakeholders identified the criteria, "Plant Operability", as the most important factor (27 percent) for process selection followed by "Enhanced Regulatory Compliance" and "Aesthetics" which both scored equally (23 percent). "Other Water Quality Goals" and "Environmental Issues" were last in order of importance (13 percent).

Following the ranking process, the group was asked to score by ballot the five primary criteria using a scale of 0 to 100 with 0 being least important and 100 being most important. Participants were not allowed to score a lower ranked criteria above a higher ranked criteria. The results of this scoring are summarized in Table 3 which includes the maximum and minimum score for a given criteria as well as the standard deviation in score for a given alternative. These results are illustrated in Figure 2. This relative weight scoring could then be used in the decision model to evaluate and compare relative benefits of the selected processes.

## Table 1. Treatment Criteria and Goals

| Category | Criteria | Goal |
|---|---|---|
| **Enhanced Regulatory Compliance** | **Disinfection By-products** | |
| | THMs | Meet Regulations |
| | HAAs | Meet Regulations |
| | Bromate | Meet Regulations |
| | Chlorite | Meet Regulations |
| | **Pathogens** | |
| | Giardia | Meet Regulations |
| | Crypto | Meet Regulations |
| | Virus | Meet Regulations |
| | **Inorganics** | |
| | Total Dissolved Solids | Meet Regulations |
| | Chloride | Meet Regulations |
| | Corrosion Control | Meet Regulations |
| | **Organics** | |
| | TOC | Meet Regulations |
| | SOCs/VOCs | Meet Regulations |
| **Aesthetics** | Taste and Odor | Meet Regulations |
| | Color | Meet Regulations |
| **Other Water Quality Goals** | Algal Toxins | Minimize |
| | Chloride | <250 |
| | TOC | Minimize |
| | Regrowth | Minimize |
| | Sodium | Minimize |
| **Environmental Issues** | Residuals-Solids | Minimize |
| | Traffic | Minimize |
| | Plant Odors | Minimize |
| | Sustainable | Maximize |
| | Environmental Hazards | Minimize |
| | Residuals-Liquid | Minimize |
| | Foot Print | Minimize |
| | Navigational Impairment | Minimize |
| | Noise | Minimize |
| **Plant Operability** | Automation | Maximize |
| | Maintenance | Minimize |
| | Operating Complexity | Minimize |
| | Flexibility to handle WQ degradation | Maximize |
| | Interruptible operations | Maximize |

## Table 2. Forced Ranking Results

| Criteria | Two Criteria Comparison | | | | | Sum | % | | Forced Order |
|---|---|---|---|---|---|---|---|---|---|
| Aesthetics | A | a/b | a | a/d | a/e | 3.5 | 23% | 2 | 2 |
| Other Water Quality Goals | | B | b/c | d | e | 2 | 13% | 3 | 4 |
| Enviromental Issues | | | C | d | c/e | 2 | 13% | 3 | 5 |
| Plant Operability | | | | D | d/e | 4 | 27% | 1 | 1 |
| Enhanced Regulatory Compliance | | | | | E | 3.5 | 23% | 2 | 3 |

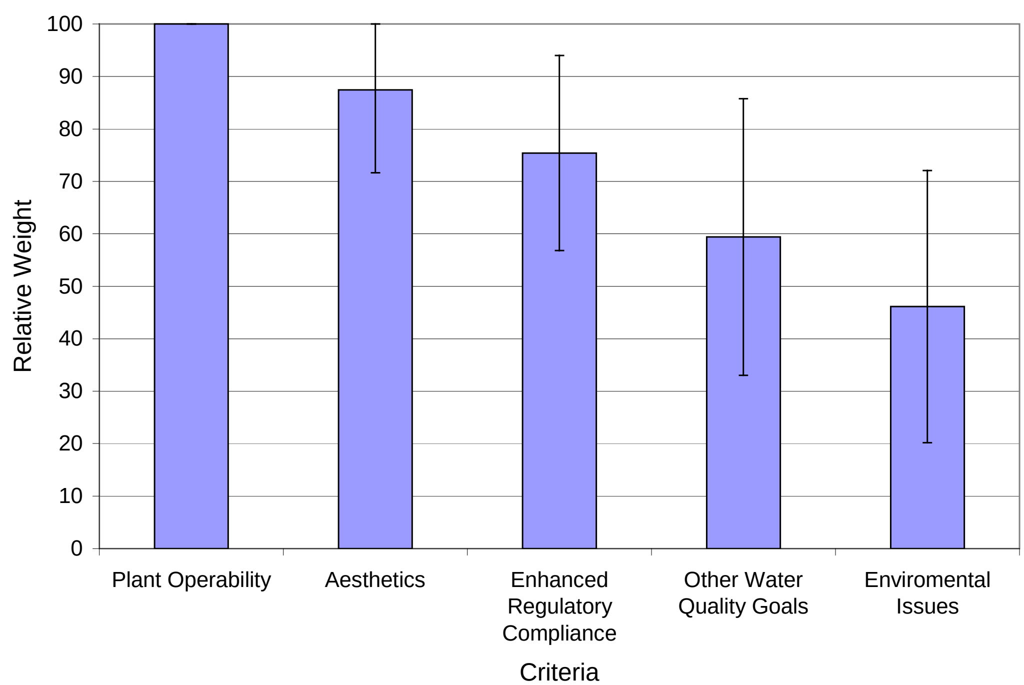
Note: Each criteria was assigned a letter, A-E. The scoring was done with each starting with 1-point and then tallying the score in each row. If the letter is solely in the box, it has 1-point; if split with another letter, then it has 0.5 points.

For example, A: 1 + 0.5 + 1 + 0.5 + 0.5 = 3.5

## Table 3. Ballot Scoring for Primary Criteria

| Criteria | Weighting Statistics | | | |
|---|---|---|---|---|
| | Average | Min | Max | Standard Deviation |
| Aesthetics | 100 | 100 | 100 | 0 |
| Other Water Quality Goals | 87 | 50 | 99 | 16 |
| Enviromental Issues | 75 | 50 | 99 | 19 |
| Plant Operability | 59 | 10 | 97 | 26 |
| Enhanced Regulatory Compliance | 46 | 9 | 85 | 26 |

## Figure 2. Criteria Weighting Bar Chart



# DEVELOP TREATMENT PROCESSES FOR MODEL

As Figure 1 illustrates, the next steps in the evaluation process with the stakeholders involved developing treatment processes for the model evaluation. These steps included developing and screening potential unit processes, then developing a shortlist of potential unit processes based on a fatal flaw analysis. From this shortlist, specific treatment process trains and corresponding costs were developed to be evaluated by the stakeholders with the multiattribute decision model. These evaluation steps are summarized in the following sections.

All treatment alternatives considered were required to meet all current water quality regulations and the Stage 2 Disinfection By-Product Rule and the Long Term Enhanced Surface Water Treatment Rules. In addition, each alternative was required to meet all of the goals and criteria set forth by the stakeholders in this process.

## POTENTIAL UNIT PROCESS SCREENING

Selection of the most appropriate water treatment technologies for this pilot program began with the evaluation of the commonly known water treatment technologies. A list of approximately 30 treatment approaches and processes were developed and screened according to the known ability of each alternative to achieve the desired water quality and meet the criteria developed during Goal Meeting No. 1.

In order to screen these treatment processes, a fatal flaw analysis was conducted. The fatal flaw analysis for these treatment processes was conducted with two criteria:

1. Any unit treatment process that would be unable to meet current and future regulations would be eliminated.

2. Technologies that had not yet been proven for these types of source waters in the United States (high organics and high TDS) would be eliminated.

Using the fatal flaw analysis, the field of over 30 unit treatment processes was narrowed to 15 and is summarized in Table 4. This table lists the proven technologies considered most applicable to the St. Johns River water quality and is divided into four sections:

1. Pretreatment Clarification and Filtration
2. Desalting
3. Taste and Odor/Organics Removal
4. Disinfection

### Pretreatment Clarification and Filtration

Pretreatment requires clarification using coagulation for solids and TOC (total organic carbon) removal followed by filtration. Clarification technologies listed in Table 4 include the SuperP and Actiflo, both of which have been proven and tested on these types of surface waters. Any alternatives which involve the SuperP include the use of powdered activated carbon (PAC) which can achieve some TOC removal as well as taste and odor (T&O) control. Filtration technologies include granular media filtration and ultrafiltration. Regarding pretreatments for this study, river bank filtration was considered during the treatment process screening. However, any plant built as a result of this study could be sited anywhere along the St. Johns River from Sanford to DeLand. Therefore, all technologies tested had to be applicable at any point along this reach of the river. Due to the site-specific nature of river bank filtration, based on variable geology, testing for riverbank filtration would have to be done at the actual site for a potential plant. For example, testing riverbank filtration on a reach of the river in Sanford would not necessarily prove or disprove the applicability of riverbank filtration in Deland.

### Desalting

As listed in Table 4, reverse osmosis (RO) and/or nanofiltration (NF) membranes must be used for salt removal. Depending on the desired salt and organics removal, partial or full desalination by RO, NF, or a combination of both RO and NF could be used. The advantage of full stream treatment is that over 98 percent of the TOC is removed as well as over 98% of the dissolved solids and salts. This decision of percent membrane treatment would be based on the increased high pressure pumping costs to the membranes (full stream vs. partial stream) vs. the enhanced water quality as well as increased concentrate production.

### Taste & Odor/Organics Removal

For control of T&O, Table 4 lists several alternatives. These include activated carbon filtration or ozonation following membrane treatment. If ozone is used, an activated carbon step must be employed to remove the assimilable organic carbon (AOC). Alternatives that involve full stream treatment by RO may not require a T&O removal step.

### Disinfection

Finally, Table 4 lists the disinfection alternatives available for use given the St. John's River water quality. Disinfection includes chlorine, chloramine, and/or ultraviolet (UV) disinfection and ozone. Due to the high organics in this source water, chlorine can

## Table 4. Initial Treatment Approach Screening

| Treatment Processes | Comments |
|---|---|
| **Pretreatment Clarification*** | |
| Actiflo and conventional filtration | Requires a smaller footprint than all other clarification processes. Responds quickly to changes in raw water quality. Has been successfully used on similar waters. |
| SuperP with PAC and conventional filtration | Requires a smaller footprint than most other clarification processes. Utilizes PAC which removes some T&O and organics. Creates a higher solids percentage sludge than most clarification processes. |
| **Pretreatment Filtration** | |
| Conventional filtration | Most common form of filtration used. Relatively low construction and O&M cost. |
| Membrane ultrafiltration | Absolute barrier to particles (especially viruses). Relatively simple to operate. Higher treatment costs due to increased pumping costs. |
| Membrane ultrafiltration with coagulation | Absolute barrier to particles (especially viruses). Relatively simple to operate. Higher treatment costs due to increased pumping costs. Coagulation allows for higher organics rejection. |
| **Desalting** | |
| Partial treatment by RO | Treats portion of stream thus reducing pumping costs. Lowest membrane cost for treatment. |
| Full treatment by RO | Treats full stream of pretreated water. Highest pumping costs. Removes majority of TOC and dissolved solids. |
| Full treatment by RO and NF | Treats full stream of pretreated water. Percentage of stream treated by RO membranes with remaining treated by NF membranes. Lower treatment cost due to lower pumping costs associated with NF membranes. |
| **T&O / Organics Removal** | |
| Ozone/BAC | Ozone disinfects as well as oxidizes T&O compounds. BAC removes some oxidized material. Ozone may cause higher bromate levels. |
| GAC with 60 day regeneration | Removes T&O and all TOC. High cost due to frequent regeneration. |
| GAC with 120 day regeneration | Removes T&O and some TOC. High cost due to frequent regeneration. |
| GAC with 2 year regeneration | Removes T&O. Lower cost due to less frequent regeneration. |
| **Disinfection** | |
| Chloramines | Low DBP formation potential. Cannot be used for primary disinfection. |
| Chlorine | High DBP formation potential. Provides good disinfection. |
| Ozone | Need to consider bromate formation. Provides good disinfection. Removes T&O Cannot be used as a residual disinfectant. |
| UV | No DBP formation. Provides excellent disinfection. Does not provide a residual. |

**All pretreatment technologies assume coagulation with a metal salt.*

only be used as a residual disinfectant with processes that remove a high percentage of TOC (i.e., full treatment by RO or full treatment by GAC (60 day regeneration)). Primary disinfection can also be achieved by ozone which also removes T&O or UV. Without greater than 95 percent TOC removal, chloramines would have to be used as the residual disinfectant.

## DEVELOP SPECIFIC TREATMENT ALTERNATIVES FOR MODEL

As illustrated in Figure 1, the next step in the evaluation process was development of specific treatment alternatives for the model using the unit processes that were screened. A technology matrix was developed with the screened processes listed in Table 4. This matrix is illustrated in Figure 3. Process flow lines are included to illustrate how these unit processes would be used in a multibarrier treatment approach. Each combination represents a possible treatment alternative.

Using this matrix, the stakeholders could identify 17 treatment configurations. Treatment configurations were developed based on a multibarrier approach to water treatment as well as the need for at least partial desalination of the water. These 17 multibarrier alternatives are summarized in Table 5.

For use in the model, and for subsequent figures and tables, the acronyms of the screened unit processes are summarized in Table 6.

Once the 17 different multibarrier alternatives were developed, the next step was to develop costs for each of the treatment systems.

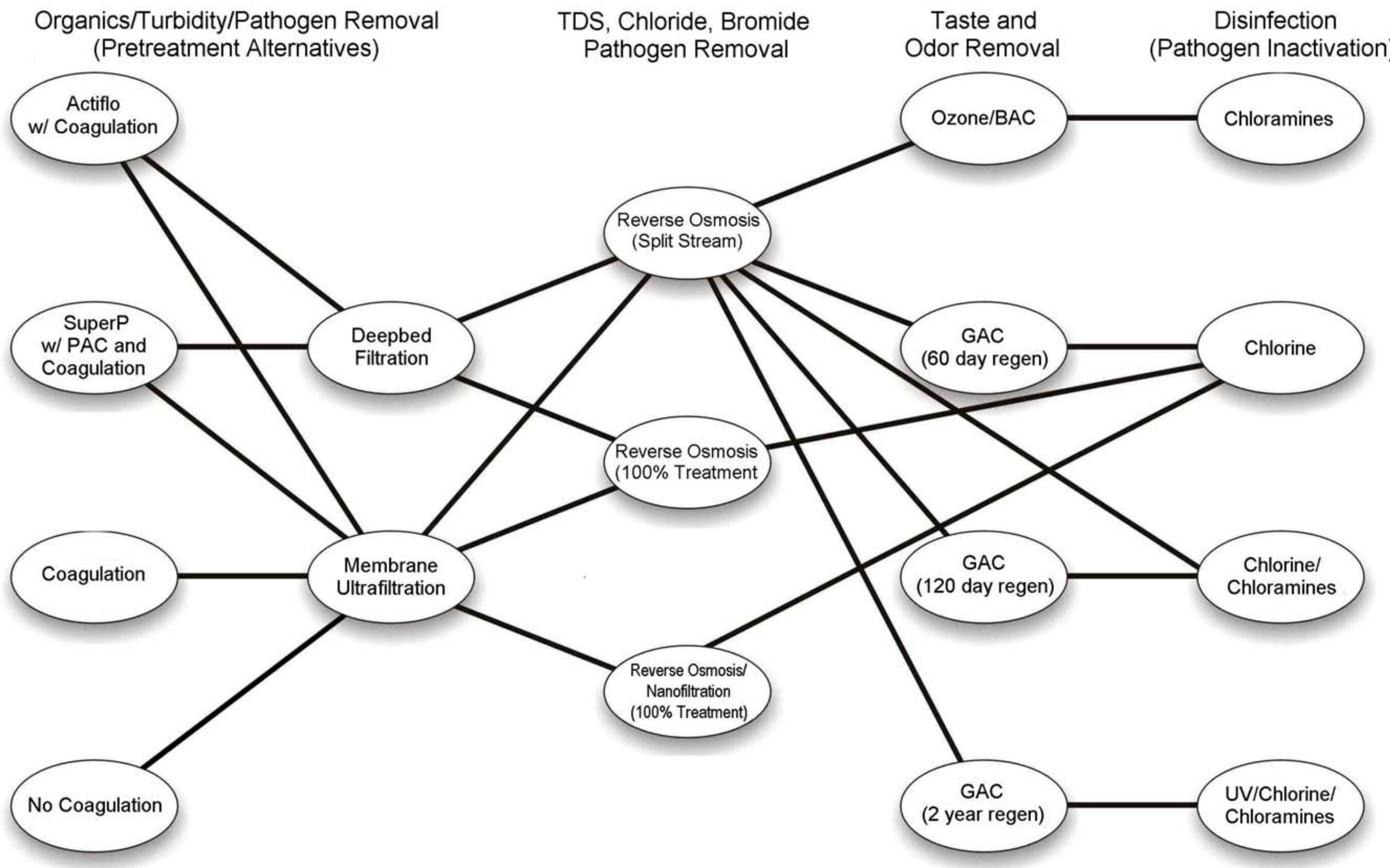
## DEVELOP TREATMENT ALTERNATIVE COST ESTIMATES

As illustrated in Figure 1, following development of specific treatment systems, treatment alternative costs were developed for the 17 alternatives. Costs are based on actual unit costs for specific unit processes as well as costs from current construction bids.

Construction costs are in dollars per gallon ($/gal) and O&M costs are in dollars per 1000 gallons ($/1000 gal) and are based on a 20 mgd plant. Costs developed for this evaluation only included comparative treatment costs of unit processes and do not include such costs as roads, raw water pumping, or engineering costs which would be common to all plant designs. In addition, labor costs have not been included in the cost estimates.

Table 7 summarizes these comparative construction and O&M costs for the 17 alternatives.

**Figure 3. Potential Treatment Process Trains**



## Table 5. Treatment Alternatives

| Alt. No. | Alternative Description |
|---|---|
| 1 | Actiflo clarification with granular media filtration for pretreatment. Split stream RO for salt removal. Ozonation for T&O control and primary disinfection followed by BAC for AOC removal. Chloramines for residual disinfection. |
| 2 | Actiflo clarification with granular media filtration for pretreatment. Split stream RO for salt removal. GAC with 60 day regeneration for T&O and organics removal. Primary and residual disinfection by chlorine. |
| 3 | Actiflo clarification with granular media filtration for pretreatment. Split stream RO for salt removal. GAC with 120 day regeneration for T&O and partial organics removal. Primary disinfection by chlorine with residual disinfection by chloramines. |
| 4 | Actiflo clarification with granular media filtration for pretreatment. Split stream RO for salt removal. GAC with 2 year regeneration for T&O control. Primary disinfection by UV and chlorine with residual disinfection by chloramines. |
| 5 | Actiflo clarification with granular media filtration for pretreatment. 100% treatment with RO. Primary and residual disinfection by chlorine. |
| 6 | SuperP clarification and PAC (for T&O control) with granular media filtration for pretreatment. Split stream RO for salt removal. Ozonation for T&O control and primary disinfection followed by BAC for AOC removal. Chloramines for residual disinfection. |
| 7 | SuperP clarification and PAC (for T&O control) with granular media filtration for pretreatment. Split stream RO for salt removal. GAC with 60 day regeneration for T&O and organics removal. Primary and residual disinfection by chlorine. |
| 8 | SuperP clarification and PAC (for T&O control) with granular media filtration for pretreatment. Split stream RO for salt removal. GAC with 120 day regeneration for T&O and partial organics removal. Primary disinfection by chlorine with residual disinfection by chloramines. |
| 9 | SuperP clarification and PAC (for T&O control) with granular media filtration for pretreatment. Split stream RO for salt removal. GAC with 2 year regeneration for T&O control. Primary disinfection by UV and chlorine with residual disinfection by chloramines. |
| 10 | SuperP clarification and PAC (for T&O control) with granular media filtration for pretreatment. Split stream RO for salt removal. Primary disinfection by UV and chlorine with residual disinfection by chloramines. |
| 11 | Actiflo clarification with membrane ultrafiltration for pretreatment. Split stream RO for salt removal. Ozonation for T&O control and primary disinfection followed by BAC for AOC removal. Chloramines for residual disinfection. |
| 12 | Actiflo clarification with membrane ultrafiltration for pretreatment. Split stream RO for salt removal. GAC with 120 day regeneration for T&O and partial organics removal. Primary disinfection by chlorine with residual disinfection by chloramines. |
| 13 | SuperP clarification and PAC (for T&O control) with granular media filtration for pretreatment. Split stream RO for salt removal. Primary disinfection by chlorine with residual disinfection by chloramines. |
| 14 | Ultrafiltration with in-tank coagulation for pretreatment. Split stream RO for salt removal. Ozonation for T&O control and primary disinfection followed by BAC for AOC removal. Chloramines for residual disinfection. |
| 15 | Ultrafiltration (without coagulation) for pretreatment. Split stream RO for salt removal. Ozonation for T&O control and primary disinfection followed by BAC for AOC removal. Chloramines for residual disinfection. |
| 16 | Ultrafiltration (without coagulation) for pretreatment. 100% treatment with RO. Primary and residual disinfection by chlorine. |
| 17 | Ultrafiltration (without coagulation) for pretreatment. 100% treatment with RO and NF. Primary and residual disinfection by chlorine. |

## Table 6. Acronym List of Screened Processes

| Acronym | Description |
|---|---|
| AC/F | Actiflo w/ Filtration |
| AC/UF | Actiflo w/ Ultrafiltration |
| SP/PAC/F | SuperP w/ PAC w/Filtration |
| SP/PAC/UF | SuperP w/ PAC w/Ultrafiltration |
| UF | Ultrafiltration |
| C/UF | Coagulation w/ Ultrafiltration |
| RO (SS) | Partial Treatment by RO |
| RO (FS) | Full Treatment by RO |
| RO/NF(FS) | Full Treatment by RO and NF |
| $O_3$ | Ozone |
| $Cl_2$ | Chlorine |
| $Cl_2NH_3$ | Chlorine and Ammonia |
| UV | Ultraviolet Disinfection |
| BAC | Biologically Active Carbon |
| GAC (60d) | GAC with a 60 day regen. (GAC for TOC and T&O removal) |
| GAC (120d) | GAC with a 120 day regen. (GAC for T&O and some TOC removal) |
| GAC (2yr) | GAC with a 2 yr. regen. (GAC for T&O removal) |

## Table 7. Cost Comparison for the Developed Alternatives

| | | Construction | | O&M | |
|---|---|---|---|---|---|
| Alt No. | Alternative | $ Total (Million) | $/gal | $ Total/yr. (Million) | $/1000 gal |
| 1 | AC/F, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | $34.21 | $1.71 | $6.21 | $0.85 |
| 2 | AC/F, RO(SS), GAC (60d), $Cl_2$ | $28.42 | $1.42 | $8.33 | $1.14 |
| 3 | AC/F, RO(SS), GAC (120d), $Cl_2$, $Cl_2NH_3$ | $28.52 | $1.43 | $6.87 | $0.94 |
| 4 | AC/F, RO(SS), GAC (2yr), UV, $Cl_2$, $Cl_2NH_3$ | $31.52 | $1.58 | $5.63 | $0.77 |
| 5 | AC/F, RO(FS), $Cl_2$ | $29.30 | $1.47 | $6.90 | $0.95 |
| 6 | SP/PAC/F, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | $34.21 | $1.71 | $6.57 | $0.90 |
| 7 | SP/PAC/F, RO(SS), GAC (60), $Cl_2$ | $28.42 | $1.42 | $8.70 | $1.19 |
| 8 | SP/PAC/F, RO(SS), GAC (120), $Cl_2$, $Cl_2NH_3$ | $28.52 | $1.43 | $7.24 | $0.99 |
| 9 | SP/PAC/F, RO(SS), GAC (2yr), UV, $Cl_2$, $Cl_2NH_3$ | $31.52 | $1.58 | $6.00 | $0.82 |
| 10 | SP/PAC/F, RO(SS), UV, $Cl_2$, $Cl_2NH_3$ | $25.52 | $1.28 | $5.34 | $0.73 |
| 11 | AC/UF, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | $52.21 | $2.61 | $7.45 | $1.02 |
| 12 | AC/UF, RO(SS), GAC (120), $Cl_2$, $Cl_2NH_3$ | $46.52 | $2.33 | $8.12 | $1.11 |
| 13 | SP/PAC/UF, RO(SS), $Cl_2$, $Cl_2NH_3$ | $40.52 | $2.03 | $6.47 | $0.89 |
| 14 | C/UF, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | $49.41 | $2.47 | $6.72 | $0.92 |
| 15 | UF, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | $49.11 | $2.46 | $5.99 | $0.82 |
| 16 | UF, RO(FS), $Cl_2$ | $44.20 | $2.21 | $6.68 | $0.92 |
| 17 | UF, RO/NF(FS), $Cl_2$ | $44.20 | $2.21 | $5.22 | $0.72 |

Note: Total construction and O&M costs are based on a 20-mgd treatment plant.

# DECISION MODEL RESULTS

As Figure 1 illustrates, the next step in the evaluation process was to score the selected 17 treatment processes against the evaluation criteria and to use this scoring to conduct the multi-attribute analysis of alternatives and benefits with the stakeholders.

The alternatives were scored using the weighted criteria/sub-criteria developed by the stakeholders. Table 8 summarizes the preliminary scoring of the 17 treatment processes with respect to the sub-criteria. The ability of each alternative to satisfy the given sub-criteria were ranked on a score of 1 to 5 (1 being the worst and 5 being the best).

The alternatives and the ranked criteria and sub-criteria weighting were entered into the decision modeling software "Criterium Plus," which was used as a tool to sort and weight the selection criteria for each alternative and determine the relative benefit for those processes. The calculated relative benefit is a unitless parameter that is the result of summing the weighted scores for each criteria.

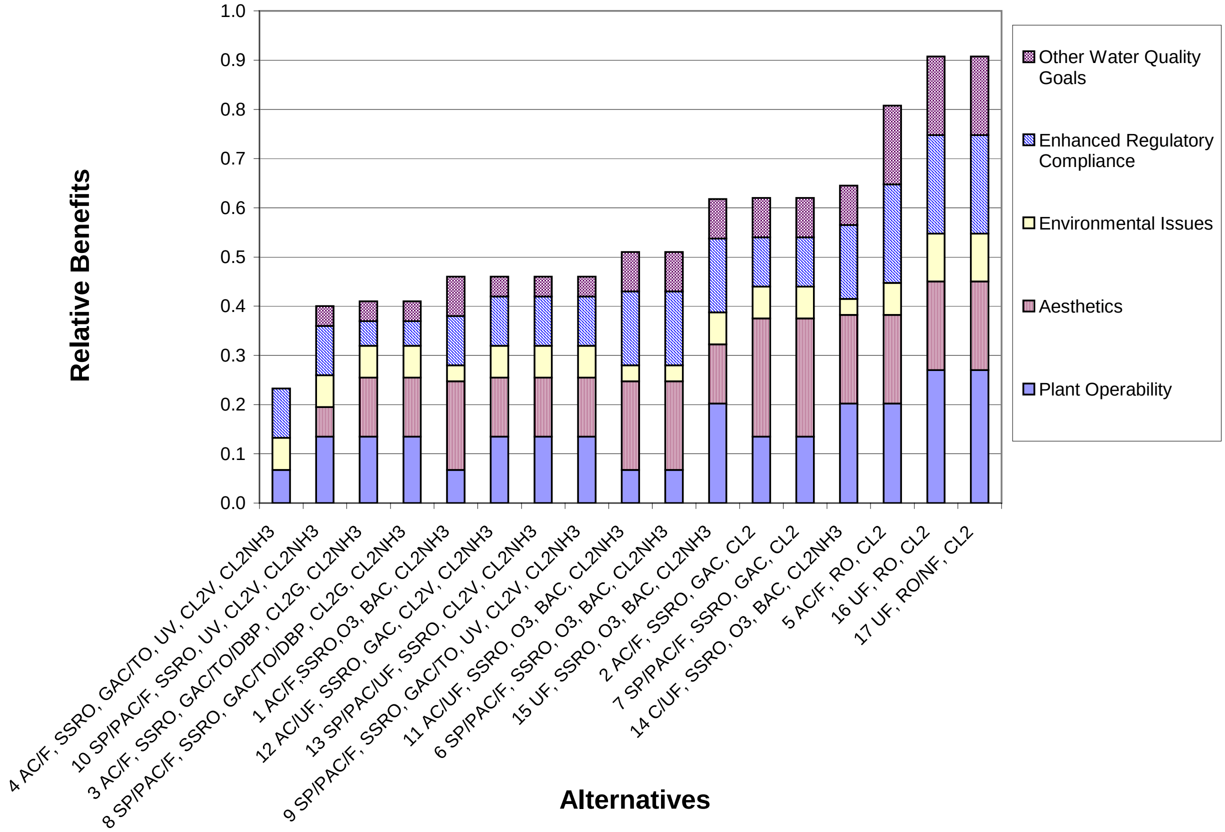
Criterium Plus uses a Simple Multiattribute Utility Technique (SMART). Before comparison of the contributions of criteria with differing scale, the decision model provides a method that allows you to handle the model scales on an equal footing. This is achieved by a process called normalization, where all scales are converted to a common internal scale that takes a value between 0 and 1. SMART permits definition of a scoring scale that uses a value function that is rescaled within the model to a standard scale of 0 to 1. A value function allows you to explicitly define how each value on your scale is transformed to the common model scale. Criterium Plus provides three value functions in determining the ratings for the attributes: a linear function, an exponential function, and a piecewise linear function. The relative benefit of each alternative can then be compared to the cost required for development of the alternative, and an informed cost-benefit comparison can be made to select the best alternative.

Figure 4 illustrates the relative benefit for each of the 17 alternatives based on the model output. As expected, Figure 4 illustrates that the greatest benefit is achieved by processes which utilize full stream treatment by RO and/or NF membranes.

### Table 8. Criteria and Sub-criteria Ranking

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Criteria** | AC/F, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | AC/F, RO(SS), GAC (60d), $Cl_2$ | AC/F, RO(SS), GAC (120d), $Cl_2$, $Cl_2NH_3$ | AC/F, RO(SS), GAC (2yr), UV, $Cl_2$, $Cl_2NH_3$ | AC/F, RO(FS), $Cl_2$ | SP/PAC/F, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | SP/PAC/F, RO(SS), GAC (60), $Cl_2$ | SP/PAC/F, RO(SS), GAC (120), $Cl_2$, $Cl_2NH_3$ | SP/PAC/F, RO(SS), GAC (2yr), UV, $Cl_2$, $Cl_2NH_3$ | SP/PAC/F, RO(SS), UV, $Cl_2$, $Cl_2NH_3$ | AC/UF, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | AC/UF, RO(SS), GAC (120), $Cl_2$, $Cl_2NH_3$ | SP/PAC/UF, RO(SS), $Cl_2$, $Cl_2NH_3$ | C/UF, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | UF, RO(SS), $O_3$, BAC, $Cl_2NH_3$ | UF, RO(FS), $Cl_2$ | UF, RO/NF(FS), $Cl_2$ |
| **DBPs** | | | | | | | | | | | | | | | | | |
| THMs | 4.0 | 4.0 | 2.0 | 1.0 | 5.0 | 4.5 | 4.5 | 2.0 | 1.5 | 1.5 | 4.0 | 3.0 | 3.5 | 4.0 | 3.5 | 5.0 | 5.0 |
| HAAs | 4.0 | 4.0 | 2.0 | 1.0 | 5.0 | 4.5 | 4.5 | 2.0 | 1.5 | 1.5 | 4.0 | 3.0 | 3.5 | 4.0 | 3.5 | 5.0 | 5.0 |
| Bromate | 1.0 | 5.0 | 5.0 | 5.0 | 5.0 | 1.0 | 5.0 | 5.0 | 5.0 | 5.0 | 1.0 | 5.0 | 5.0 | 1.0 | 1.0 | 5.0 | 5.0 |
| Chlorite | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| **Pathogens** | | | | | | | | | | | | | | | | | |
| Giardia | 3.5 | 2.0 | 1.5 | 4.5 | 5.0 | 3.5 | 1.5 | 1.0 | 4.5 | 4.5 | 3.5 | 4.0 | 3.0 | 4.0 | 4.0 | 5.0 | 5.0 |
| Crypto | 3.5 | 2.0 | 1.5 | 4.5 | 5.0 | 3.5 | 1.5 | 1.0 | 4.5 | 4.5 | 3.5 | 4.0 | 3.0 | 4.0 | 4.0 | 5.0 | 5.0 |
| Virus | 4.0 | 4.0 | 1.0 | 1.5 | 5.0 | 4.0 | 4.0 | 1.5 | 2.0 | 1.5 | 4.0 | 3.0 | 3.0 | 4.0 | 4.0 | 5.0 | 5.0 |
| **Inorganics** | | | | | | | | | | | | | | | | | |
| TDS | 3.0 | 1.0 | 1.0 | 1.0 | 5.0 | 3.0 | 1.0 | 1.0 | 1.0 | 1.0 | 3.0 | 1.0 | 1.0 | 3.0 | 3.0 | 5.0 | 5.0 |
| Chloride | 3.0 | 1.0 | 1.0 | 1.0 | 5.0 | 3.0 | 1.0 | 1.0 | 1.0 | 1.0 | 3.0 | 1.0 | 1.0 | 3.0 | 3.0 | 5.0 | 4.5 |
| Corrosion Control | 3.0 | 5.0 | 5.0 | 5.0 | 3.0 | 4.0 | 5.0 | 5.0 | 5.0 | 5.0 | 4.0 | 5.0 | 5.0 | 4.0 | 4.0 | 3.0 | 3.0 |
| **Organics** | | | | | | | | | | | | | | | | | |
| TOC | 2.5 | 4.0 | 2.0 | 1.0 | 5.0 | 3.5 | 4.5 | 3.0 | 1.5 | 1.5 | 3.0 | 2.5 | 2.0 | 3.5 | 2.5 | 5.0 | 5.0 |
| SOCs/VOCs | 2.0 | 5.0 | 2.0 | 1.0 | 4.0 | 3.5 | 5.0 | 3.5 | 3.0 | 3.0 | 2.0 | 3.0 | 3.0 | 2.0 | 2.0 | 4.0 | 3.5 |
| **Aesthetics** | | | | | | | | | | | | | | | | | |
| Taste and Odor | 4.0 | 5.0 | 3.0 | 1.0 | 4.0 | 4.5 | 5.0 | 3.5 | 3.0 | 2.0 | 4.0 | 3.0 | 2.0 | 4.0 | 4.0 | 4.0 | 4.0 |
| Color | 3.0 | 4.0 | 2.0 | 1.0 | 5.0 | 3.5 | 4.0 | 2.5 | 2.0 | 2.0 | 3.5 | 3.0 | 3.5 | 3.0 | 1.0 | 5.0 | 5.0 |
| **Other WQ Goals** | | | | | | | | | | | | | | | | | |
| Algal Toxins | 5.0 | 5.0 | 2.0 | 1.0 | 5.0 | 5.0 | 5.0 | 2.5 | 2.0 | 2.0 | 5.0 | 2.5 | 3.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Chlorides | 3.0 | 1.0 | 1.0 | 1.0 | 5.0 | 3.0 | 1.0 | 1.0 | 1.0 | 1.0 | 3.0 | 1.0 | 1.0 | 3.0 | 3.0 | 5.0 | 4.5 |
| TOC | 2.5 | 4.0 | 2.0 | 1.0 | 5.0 | 3.5 | 4.5 | 3.0 | 1.5 | 1.5 | 3.0 | 2.5 | 2.0 | 3.5 | 2.5 | 5.0 | 5.0 |
| Regrowth | 1.0 | 5.0 | 3.0 | 3.0 | 5.0 | 1.0 | 5.0 | 3.0 | 3.0 | 3.0 | 1.0 | 3.0 | 3.0 | 1.0 | 1.0 | 5.0 | 5.0 |
| Sodium | 3.0 | 1.0 | 1.0 | 1.0 | 5.0 | 3.0 | 1.0 | 1.0 | 1.0 | 1.0 | 3.0 | 1.0 | 1.0 | 3.0 | 3.0 | 5.0 | 4.5 |
| **Environmental** | | | | | | | | | | | | | | | | | |
| Residuals-Solids | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 1.0 | 1.0 | 3.0 | 2.0 | 5.0 | 5.0 | 5.0 |
| Traffic | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 4.0 | 4.0 | 4.0 |
| Plant Odors | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Sustainable | 3.0 | 5.0 | 5.0 | 5.0 | 1.0 | 3.0 | 5.0 | 5.0 | 5.0 | 5.0 | 3.0 | 5.0 | 5.0 | 2.0 | 2.5 | 1.5 | 1.5 |
| Environmental Hazards | 1.0 | 3.0 | 3.0 | 3.0 | 5.0 | 1.0 | 3.0 | 3.0 | 3.0 | 3.0 | 1.0 | 3.0 | 3.0 | 1.0 | 2.0 | 5.0 | 5.0 |
| Residuals-Liquid | 3.0 | 5.0 | 5.0 | 5.0 | 1.0 | 3.0 | 5.0 | 5.0 | 5.0 | 5.0 | 3.0 | 5.0 | 5.0 | 3.0 | 3.0 | 1.0 | 1.0 |
| Foot Print | 4.0 | 4.0 | 4.0 | 4.0 | 4.5 | 1.0 | 1.0 | 1.0 | 1.0 | 2.0 | 4.0 | 4.0 | 2.0 | 4.0 | 4.0 | 5.0 | 5.0 |
| Navigational Impairment | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Noise | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| **Plant Operability** | | | | | | | | | | | | | | | | | |
| Automation | 1.0 | 3.0 | 3.0 | 3.0 | 4.0 | 1.0 | 3.0 | 3.0 | 3.0 | 3.0 | 1.0 | 3.0 | 3.0 | 4.0 | 4.0 | 5.0 | 5.0 |
| Maintenance | 1.0 | 2.0 | 2.0 | 2.0 | 2.5 | 2.0 | 3.0 | 3.0 | 3.0 | 3.0 | 1.0 | 2.0 | 3.0 | 3.0 | 3.0 | 5.0 | 5.0 |
| Operating Complexity | 1.0 | 3.0 | 3.0 | 3.0 | 4.0 | 1.0 | 3.0 | 3.0 | 3.0 | 3.0 | 1.5 | 3.5 | 3.5 | 2.0 | 2.5 | 5.0 | 5.0 |
| Flex. to treat Deg. of WQ | 3.0 | 4.0 | 3.0 | 1.0 | 5.0 | 3.0 | 4.0 | 3.0 | 2.0 | 1.5 | 3.5 | 3.0 | 3.0 | 3.5 | 3.0 | 5.0 | 5.0 |
| Interruptible operations | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 3.0 | 3.0 | 1.0 | 5.0 | 5.0 | 5.0 | 5.0 |

## Figure 4. Relative Benefits Chart for Alternatives



# PROCESS CONFIGURATION SELECTION

## COST AND BENEFITS EVALUATION

As Figure 1 illustrates, the next step in the evaluation process was to conduct a cost benefit analysis for selection of the preferred treatment alternatives. Using the costs estimates developed for each alternative and the relative benefits from the model, the alternatives were ranked with respect to relative benefit and plotted with comparative costs.

Figure 5 illustrates the 17 alternatives, their relative benefit scores from the model and present worth costs. Present worth costs were determined by adding the capital costs to the present worth of 20 years of O&M. These costs were included in the figure as well.

Costs are based on a 20 mgd capacity treatment plant and include comparative treatment costs of unit processes. Costs do not include roads, raw water pumping, labor, or engineering costs which would be common to all plant designs.

Using Figure 5, the processes that had a lower relative benefit for a higher cost were eliminated. For example, in Figure 5, Alternative 13 and Alternative 9 had approximately the same relative benefit; however, because Alternative 13 had a higher cost for the same benefit, it was eliminated or screened.

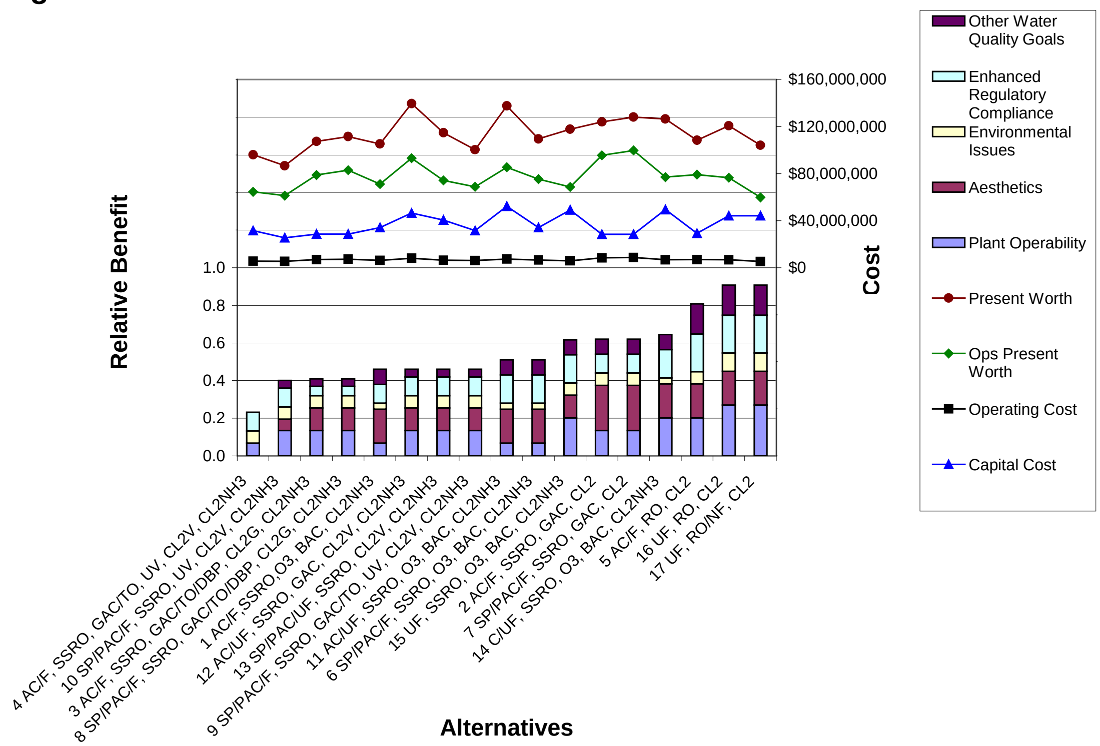
Figure 6 illustrates the results of the screened cost-benefit analysis. The processes that were <u>eliminated or screened</u> based on this evaluation are shaded. The following five alternatives were found to have the greatest benefit with respect to the criteria weighting and an appropriate ratio of increased costs for increased benefits:

- Alternative 10--SP/PAC/F, RO(SS), UV, $Cl_2$, $Cl_2NH_3$
- Alternative 1--AC/F, RO(SS), $O_3$, BAC, $Cl_2NH_3$
- Alternative 9-- AC/UF, RO(SS), $O_3$, BAC, $Cl_2NH_3$
- Alternative 5-- AC/F, RO(FS), $Cl_2$
- Alternative 17-- UF, RO/NF(FS), $Cl_2$

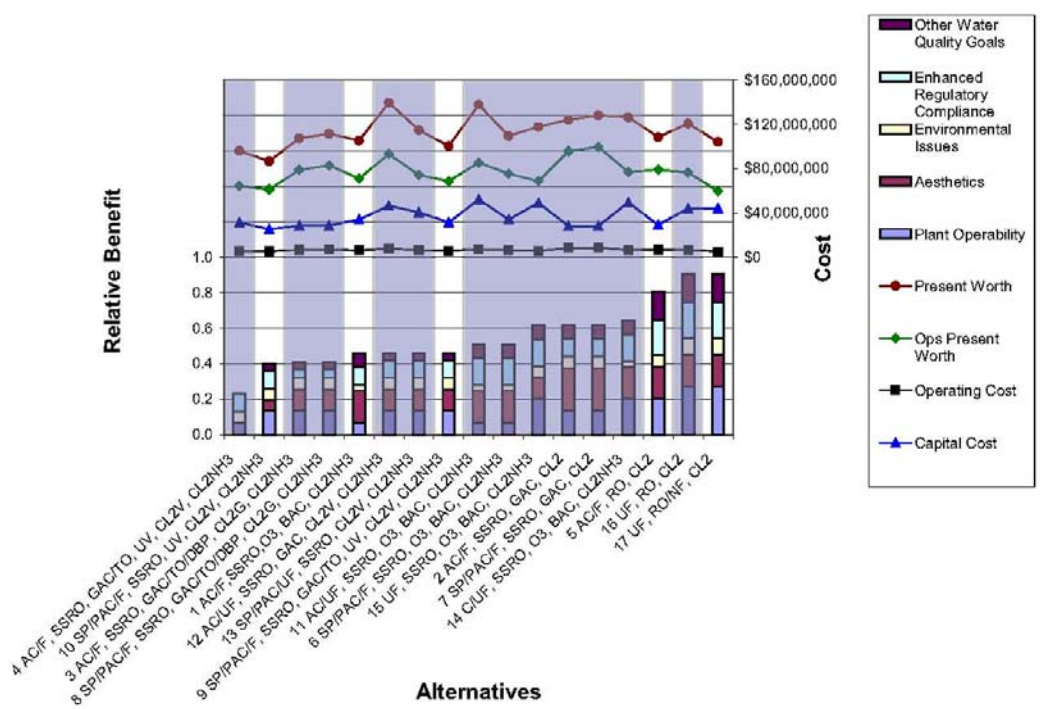
## SENSITIVITY ANALYSIS

To further evaluate the integrity of these process selections, a sensitivity analysis was conducted to see if there would be a change in the decision if there were a major shift of the criteria weighting. This was done since this project would be implemented a number of years after this study, and a different set of stakeholders may have a different weighting for this criteria.

## Figure 5. Unscreened Cost-Benefit Chart




## Figure 6. Screened Cost-Benefit Chart



**Sensitivity Analysis 1**

During sensitivity analysis 1 (SA1), criteria weights were changed for Plant Operability, Aesthetics, and Enhanced Regulatory Compliance to cause the criteria emphasis to shift process decision emphasis from that of operations to being based more on water quality. Figure 7 illustrates the criteria weighting used in this sensitivity analysis. The relative weight of Plant Operability was reduced to 50 and Aesthetics and Enhanced Regulatory Compliance were both increased to 100.

Figure 8 illustrates the cost benefit results of SA1. With the new set of criteria weightings, the alternatives were re-ranked and again compared to cost. Under this new set of criteria the alternatives had a different ranking than in Figure 5. However, the same alternatives were chosen as previously illustrated in Figure 6, the original evaluation. This illustrates that the processes selected by the stakeholders using this cost benefit evaluation will satisfy multiple sets of criteria weighting and preferences.

**Sensitivity Analysis 2**

For sensitivity analysis 2 (SA2), criteria weights were the same as those used in SA1, except other water quality goals was increased to 100. Figure 9 illustrates the criteria weights for SA2. All of the water quality criteria were ranked highest, and Plant Operability and Environmental Issues were ranked as secondary.

Figure 10 illustrates the cost benefit results of SA2. Using the new set of criteria, the alternatives were re-ranked and again compared to cost. Under this new set of criteria the alternatives had no difference in ranking than during SA1. Therefore, the alternatives remain the same for these varying criteria weights.

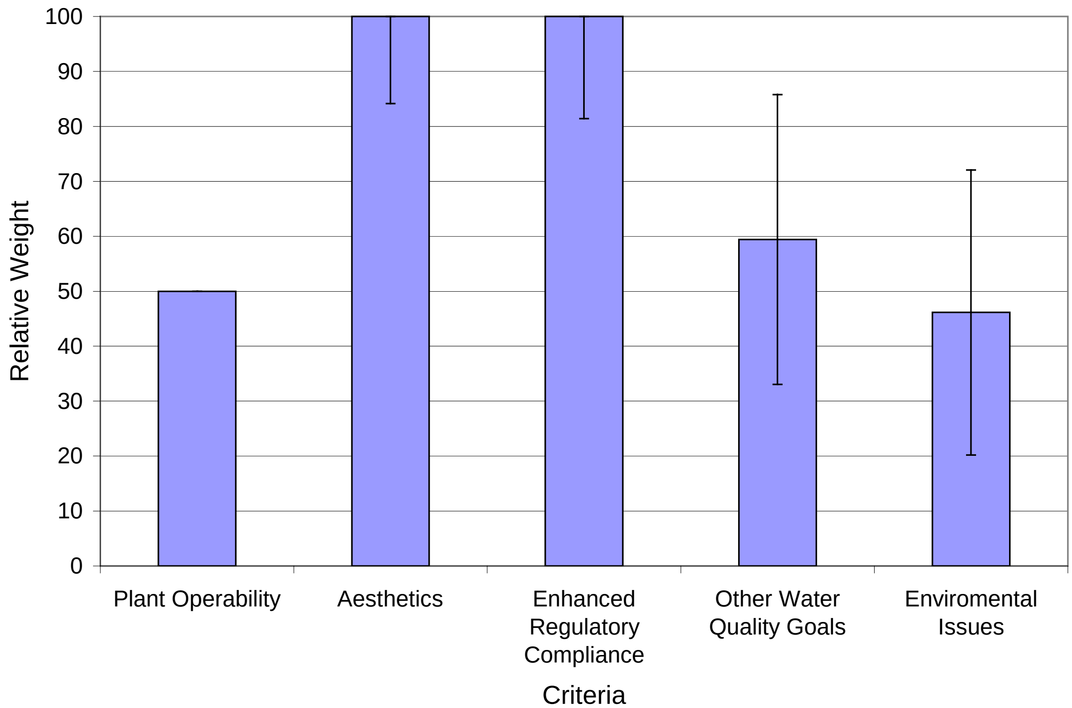
# PREFERRED TREATMENT ALTERNATIVE

As Figure 1 illustrates, the final step in the evaluation process is to select the preferred treatment alternatives.

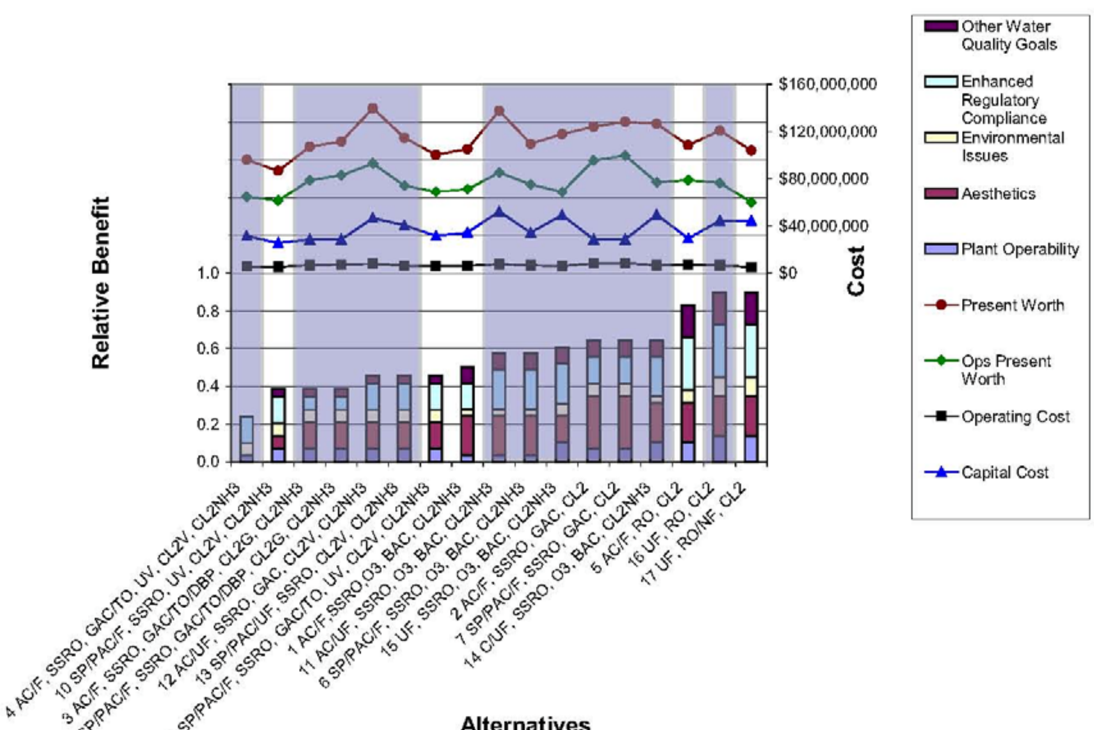
Based on the cost benefit model and the two sensitivity analyses, five process combinations were selected by the stakeholders for pilot testing:

- Alternative 10--SP/PAC/F, RO(SS), UV, $Cl_2$, $Cl_2NH_3$
- Alternative 1--AC/F, RO(SS), $O_3$, BAC, $Cl_2NH_3$
- Alternative 9-- AC/UF, RO(SS), $O_3$, BAC, $Cl_2NH_3$
- Alternative 5-- AC/F, RO(FS), $Cl_2$
- Alternative 17-- UF, RO/NF(FS), $Cl_2$

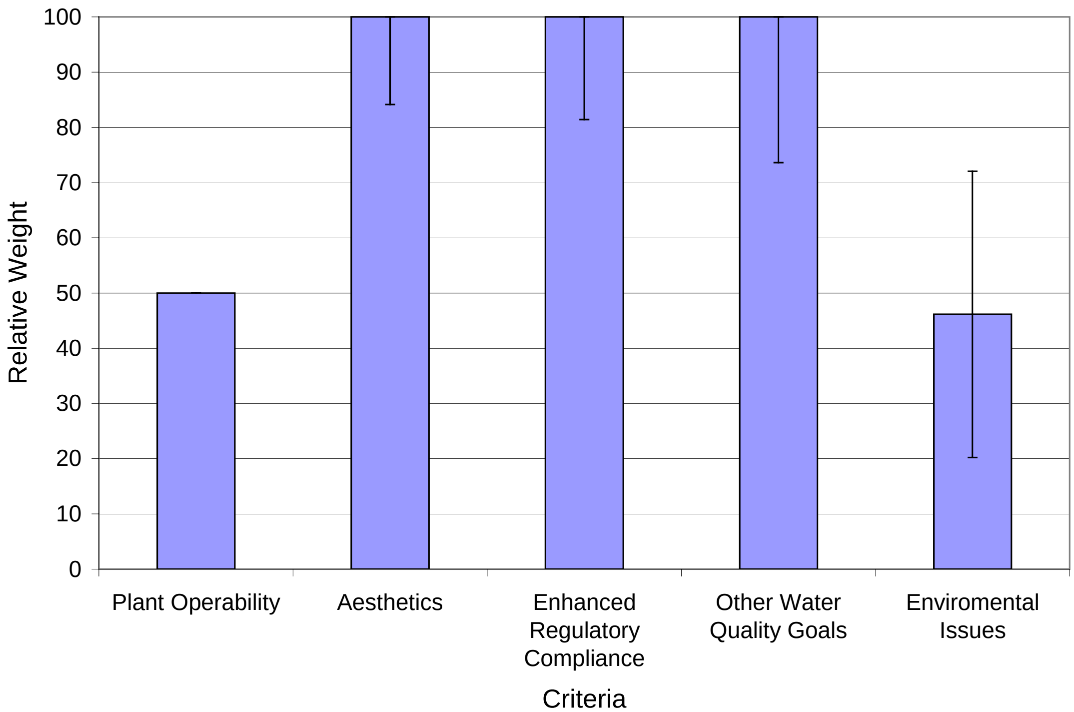
## Figure 7. Sensitivity Analysis 1 Criteria Weighting Bar Chart



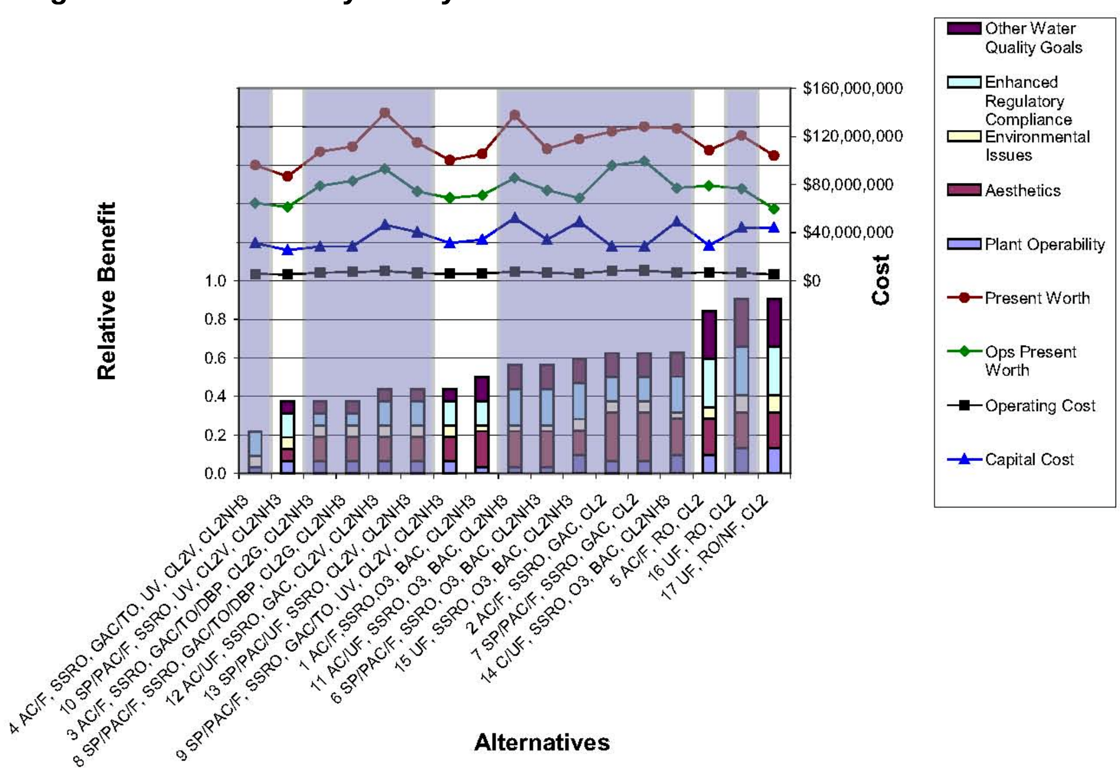

## Figure 8. Sensitivity Analysis 1 Cost-Benefit Chart



## Figure 9. Sensitivity Analysis 2 Criteria Weighting Bar Chart




## Figure 10. Sensitivity Analysis 2 Cost-Benefit Chart



Based on these five process combinations, the following three treatment process combinations were selected for pilot testing:

1. SuperP clarification with granular media filtration for pretreatment followed by reverse osmosis membranes for salt removal.
2. Actiflo clarification with granular media filtration for pretreatment followed by reverse osmosis membranes for salt removal.
3. Ultrafiltration for pretreatment followed by reverse osmosis membranes for salt removal.

These three treatment process alternatives were selected to include two alternatives with average relative benefit and average cost and one alternative with the highest relative benefit and highest cost. By evaluating these three alternatives in the pilot testing, the stakeholders will have a choice between a range of benefit and costs to be used when making the decision for potential implementation.

# Appendix B
# Technical Memorandum
# Interim Pilot Report Phase 1A
# Pilot Protocol Phases 1B & 2

# East Central Florida Water Supply Initiative
# Surface Water Treatability and Demineralization Study

**Technical Memorandum**
**Interim Pilot Report Phase 1A**
**Pilot Protocol Phases 1B & 2**

**by**

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**April 2002**
**161983.A3.PM**

# CONTENTS

# FIGURES

## TABLES



## APPENDICES

# INTRODUCTION

The pilot-testing program began in September 2001. The testing program consists of single element pretreatment testing (Phase 1A & 1B) and high recovery membrane testing (Phase 2). The Phase 1A testing was completed in December 2001. This technical memorandum will summarize the results of the Phase 1A testing and provide conclusions based on the data collected. In addition, based on the Phase 1A results, this technical memorandum will discuss the protocol and testing to be completed in Phase 1B and Phase 2.

## GOALS AND OBJECTIVES

The basis and goals of the subsequent testing, based on the Phase 1A results, is to maximize the number of alternatives available for recommendation. The Phase 1A testing indicated that all of the 3 pretreatments for the low-pressure reverse osmosis membranes performed well. This data suggests that there may be more than one suitable alternative available to treat this surface water prior to membrane desalting.

The evaluation of these pretreatments in this subsequent testing will also be based on relative benefits of each treatment as well as costs data developed from the pilot testing.

The evaluation of the reverse osmosis membranes will continue with both single element and high recovery testing. Control of biological fouling will also be evaluated with chloramines and the only current NSF approved biocide/dispersent. The final goal of the membrane testing is to maximize the flux rates to identify the most cost-effective range in which to operate these membranes.

The stakeholders developed the water quality goals earlier in the study. These goals are summarized in Technical Memoranda C.2 and C.3. The water quality goal of the membrane testing is to meet the current regulations, especially as they relate to inorganic/salt levels for this brackish water. The stakeholders then requested that the team provide data and costs for the percentage of membrane treatment required to meet these regulations (such as TDS and chloride) as well as the data and costs for 100% membrane treatment. In this manner, each stakeholder could then evaluate the cost-benefit of different levels of water quality that can be achieved with the membranes.

# PHASE 1A PRETREATMENT EVALUATION

Phase 1A testing has been completed.

Phase 1A testing consisted of the initial pretreatment evaluation, which began in September 2001 and ended in December 2001. The purpose of Phase 1A testing was to simultaneously assess the pretreatment technologies with respect to:

- the effectiveness of each technology to provide potable water after filtration;
- the effectiveness of each technology to sufficiently pretreat the water for further treatment and salt removal with membranes.

The three pretreatment processes tested during Phase 1A included:

- Actiflo ballasted sand clarifier followed by dual media filtration
- Superpulsator® (SuperP) blanket clarifier followed by dual media filtration
- Zenon microfilter

During the flat sheet testing completed last summer, the University of Central Florida (UCF) selected four membranes for testing. Each of these pretreatments were evaluated by feeding the following two of the four single element membranes selected for this study:

- Osmonics SG Brackish Water Membrane
- TriSep X-20 Membrane

The effectiveness of the three pretreatments on treating water from Lake Monroe was based on operability, treated water quality, and process stability. Further, regarding the membranes, the pretreatments were evaluated with respect to feed pressure change, trans-membrane pressure change, and water quality change.

The simultaneous pretreatment testing began in September 2001, the membrane testing began November 9, 2002 and was concluded on December 20, 2002.

# PHASE 1B MEMBRANE EVALUATION

Phase 1B is scheduled to begin in April 2002.

Based on the results of the Phase 1A membrane testing, SuperP and Zenon were selected as the lead technologies for testing in Phase 1B and 2A with Actiflo and Zenon being evaluated during Phase 2B.

As with Phase 1A, the performance of the pretreatments in Phase 1B will be evaluated based on membrane performance; however, each of the membranes will also be compared to each other to assess performance and productivity. In this phase, the SuperP and Zenon will each feed the four single element membranes selected for this study which include:

- Osmonics SG Brackish Water Membrane
- Filmtec BW30 Membrane
- Trisep X-20 Membrane
- Hydronautics Low Fouling Composite (LFC) Membrane

The goal of Phase 1B is to accumulate 1000 hours of membrane run time to rank the membranes and select the lead membrane for Phase 2A and 2B testing in the high recovery pilot unit.

## PHASE 2 HIGH RECOVERY TESTING

Phase 2 is scheduled to begin in July.

Phase 2 testing will include high recovery membrane testing during different water quality seasons. Phase 2A will be conducted during the low flow conditions in Lake Monroe characterized by higher raw water salt concentrations and lower natural organic concentrations. Phase 2B will begin during this dry season and continue through the rainy season later in the year. The rainy season is expected to have lower raw water salt concentrations and higher organic levels.

Phase 2A testing will include SuperP for pretreatment followed by the high recovery membrane skid. The top ranked membrane identified in Phase 1B will be used as the lead membrane in the high recovery skid with the other three membranes tested in the low recovery skids. During this phase, 1500 hours of membrane data will be collected.

Phase 2B will include Actiflo for pretreatment followed by the high recovery membrane skid. Similar to Phase 2A, during this phase, a new set of the four membranes will be tested for 1500 hours in the high recovery unit. This phase may also evaluate Actiflo followed by the Zenon pilot unit as a filter for membrane pretreatment.

## ADDITIONAL SAMPLING AND TESTING

Additional regulatory sampling will be conducted on the raw and finished water. This sampling will include all pertinent existing regulations that utilities must comply with such as pesticides and volatile organic compounds (VOCs) among others to be discussed later.

A disinfection evaluation will be conducted during Phase 2. This evaluation will include the use of ozone, free chlorine, chloramines, and UV. DBP formation potentials will be evaluated using RO permeate and different blends of pretreated water and RO permeate to characterize the blends, doses, and their respective DBP formation potentials.

Microbiological challenge testing will be conducted by Dr. Joan Rose. The testing will characterize the water quality of Lake Monroe for both fecal and natural microbial contaminants that are of concern in drinking water. An evaluation of the treatment processes for reducing the levels of these contaminants during water treatment will also be conducted.

## AWWARF ALGAL TOXIN TREATABILITY STUDY

In cooperation with this pilot study, a tailored collaboration between the American Water Works Association Research Foundation (AWWARF), CH2M HILL, the City of Cocoa, the City of Melbourne, and the St. Johns River Water Management District has been developed to assess the treatability of algal toxins using oxidation, adsorption, and membrane technologies. This research will develop chemical and engineering data and criteria necessary to assess algal toxin treatment for multiple raw water qualities and locations including Sanford, Melbourne, and Cocoa.

Algal toxin treatability will be evaluated by CH2M HILL with the assistance of Dr. Joan Rose and Dr. Jim Taylor. Specifically, occurrence of algal toxins in Lake Monroe, Lake Washington, and Taylor Creek Reservoir will be assessed by Dr. Joan Rose. Dr. James Taylor of UCF will assess the membrane removal of algal toxins using the membrane pilot equipment at the site.
CH2M HILL will assess the oxidation and adsorption of algal toxins with ozone and granular activated carbon (GAC), respectively.

# PHASE 1A PRETREATMENT EVALUATION RESULTS AND CONCLUSIONS

This section summarizes the results of the pilot testing for Phase 1A. As mentioned earlier, the purpose of the Phase 1A testing was to assess the treatability of water from the St. John's River as well as to evaluate the three pretreatment processes simultaneously as they each fed two single element membrane units. The three pretreatment processes tested included:

- Actiflo
- SuperP
- Zenon

Each of these pretreatments fed two of the four single element membranes selected for this study:

- Osmonics SG Brackish Water Membrane
- TriSep X-20 Membrane

The purpose of Phase 1A testing was to assess the pretreatment technologies with respect to:

- the effectiveness of each technology to provide potable water after filtration;
- the effectiveness of each technology to sufficiently pretreat the water for further treatment and salt removal with membranes.

## RAW WATER QUALITY

Raw water samples were taken daily at the site to characterize the raw water quality during the study. Table 1 summarizes average, maximum, and minimum levels for pH, turbidity, UV254, apparent color, and alkalinity for Phase 1A testing. Table 1 also summarizes the standard deviation (StDev) and coefficient of variance (CV) for each parameter in order to illustrate the variability in water quality. The coefficient of variance is calculated by dividing the standard deviation by the average and quantifies the magnitude the standard deviation varies from the average.

During Phase 1A, the average turbidity of the raw water was 7.5 NTU with a maximum turbidity of 58.6 NTU which occurred during a heavy rain event.

**Table 1. Raw Water Quality Summary – Field Analyses**

| | pH | Turbidity (NTU) | $UV_{254}$ ($cm^{-1}$) | Color (App) (pcu) | Alkalinity (mg/L) |
|---|---|---|---|---|---|
| Average | 7.1 | 7.5 | 1.448 | 429 | 51 |
| Max | 9.2 | 58.6 | 1.715 | >520 | 90 |
| Min | 6.3 | 1.5 | 0.746 | 245 | 37 |
| StDev | 0.7 | 8.9 | 0.215 | 70 | 11 |
| CV | 0.10 | 1.19 | 0.15 | 0.16 | 0.23 |

Apparent color and UV254 were monitored as surrogates for natural organic levels. The average raw water apparent color was 429 pcu during Phase 1A with a maximum of greater than 520 pcu which occurred several times due to rain and wind events.

Figure 1 illustrates the apparent color and $UV_{254}$ levels measured during Phase 1A testing. As expected, the higher organic levels occurred during the heavy rains at the beginning of the pilot study and then declined as the rainy season ended.

**Figure 1. Phase 1 Raw Water Color and $UV_{254}$**

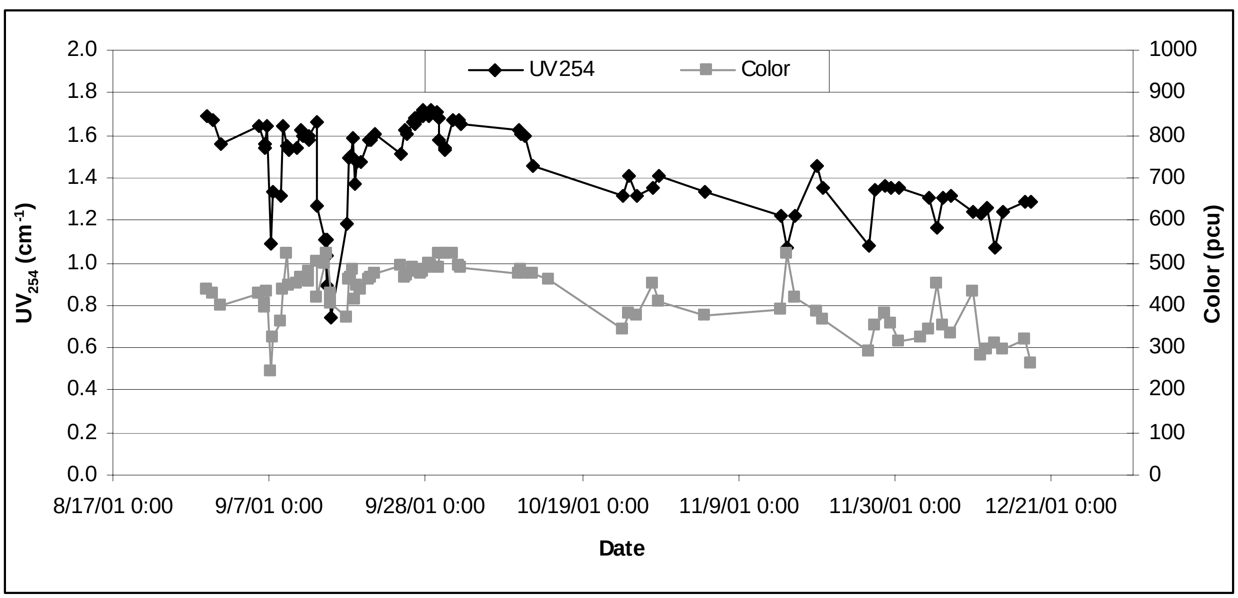


Table 2 summarizes several general water quality parameters monitored in the laboratory by UCF including non-purgable dissolved organic carbon (NPDOC), total suspended solids (TSS), total dissolved solids (TDS) concentrations, and conductivity.

As Table 2 illustrates, average NPDOC levels averaged 32.9 mg/L for the duration of the study. The maximum NPDOC during Phase 1A was 47.1 mg/L compared to a minimum NPDOC of 22.9 mg/L, 51% lower than the maximum NPDOC concentration. This illustrates the broad range of NPDOC levels between the rainy and dry season.

The maximum TDS during treatment was 988 mg/L compared to a minimum TDS concentration of 294 mg/L, less than a third of the maximum TDS during Phase 1A. As would be expected, the minimum TDS occurred during the rainy season when fresh water run off was at a maximum. As the rainy season ended, the TDS begin to increase.

**Table 2. Raw Water Quality Summary; Laboratory Analyses**

| | NPDOC (mg/L) | TSS (mg/L) | TDS (mg/L) | Conductivity (mmhos/cm) |
|---|---|---|---|---|
| Average | 32.9 | 49 | 631 | 673.4 |
| Max | 47.1 | 120 | 988 | 920.4 |
| Min | 22.9 | 16 | 294 | 437.9 |
| StDev | 5.2 | 48 | 214 | 184.7 |
| CV | 0.16 | 0.98 | 0.34 | 0.27 |

Table 3 summarizes an additional nine raw water inorganic parameters. These include bromide (Br), calcium (Ca), chloride (Cl), total iron (Fe), magnesium (Mg), sodium (Na), silica ($SiO_2$), strontium (Sr), and sulfate ($SO_4$).

During Phase 1A, average bromide levels were 0.4 mg/L, with a maximum of 0.9 mg/L. This is significant when considering the use of ozone for disinfection due to the bromate formation potential of this water and the importance membranes will have in reducing these bromate levels.

Average chloride levels were 144.7 mg/L during treatment with a maximum of 199.8 mg/L and a minimum of 87.8 mg/L.

**Table 3. Raw Water Inorganic Summary**

| | Br (mg/L) | Ca (mg/L) | Cl (mg/L) | Fe (mg/L) | Mg (mg/L) | Na (mg/L) | $SiO_2$ (mg/L) | Sr (mg/L) | $SO_4$ (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| Average | 0.4 | 30.2 | 144.7 | 1.0 | 10.3 | 53.7 | 9.7 | 0.5 | 32.2 |
| Max | 0.9 | 41.6 | 199.8 | 4.9 | 16.7 | 110.8 | 10.0 | 0.6 | 71.0 |
| Min | 0.1 | 18.4 | 87.8 | 0.4 | 6.9 | 18.4 | 9.5 | 0.3 | 20.5 |
| StDev | 0.31 | 5.9 | 37.2 | 1.13 | 2.9 | 31.0 | 0.30 | 0.10 | 14.1 |

# PRETREATMENT PERFORMANCE

To evaluate pretreatment performance, the three pretreatment processes were evaluated based on the following:

- the effectiveness of each technology to provide potable water after filtration;
- the effectiveness of each technology to sufficiently pretreat the water for further treatment and salt removal with membranes.

The operating parameters of the pretreatment processes were determined by the pretreatment manufacturers and CH2M HILL.

## Operational Summary

For the duration of the study, all pretreatments utilized ferric sulfate coagulant ($Fe_2(SO_4)_3$) for coagulation. Average coagulant dosages for Actiflo, SuperP, and Zenon were 380, 360, and 400 mg/L (ferric sulfate as 50% product), respectively. Coagulation pHs for Actiflo, SuperP, and Zenon were 4.3, 4.6, and 5.7, respectively. Coagulant dosages between pretreatment systems were similar to maximize NPDOC removal in the pretreatment systems.

Coagulation pHs were 4.3 to 4.6 for Actiflo and SuperP, with pH adjustment after coagulation to a pH of 6.5 to maximize iron removal in the filters. Because Zenon is a one-step micro-filtration system it was operated at a pH of 5.7. This was the pH which maximized organic removal while minimizing filtered iron concentration.

To aid in clarification, a cationic polymer was used by SuperP and Actiflo; however, no polymer was necessary for treatment with Zenon. Powdered activated carbon (PAC) was also added to the SuperP sludge blanket for taste and odor removal as well as additional TOC removal.

Several particulate and organic parameters were measured daily including turbidity, particle counts, silt density index, total iron, $UV_{254}$ and color in order to evaluate treatment on site. In addition, weekly water samples were collected and analyzed by the UCF laboratory in order to measure additional water quality parameters.

**Clarified Water Quality**

The Actiflo and SuperP clarification comparisons are summarized in Table 4a, Table 4b, and Table 5. Since Zenon is a membrane filter, not a clarifier, its performance will be compared to the Actiflo and SuperP filters later in this section. These tables summarize the average, maximum, minimum, standard deviation, and coefficient of variance.

Tables 4a and 4b summarize the organic surrogate data collected on the clarifiers for $UV_{254}$ and color, respectively. As Table 4.a illustrates average clarified UV254 was 0.106 $cm^{-1}$ for Actiflo compared to 0.123 $cm^{-1}$ for SuperP. As expected, both processes achieved good organic removal.

Table 4.b illustrates the small difference in average clarified color for SuperP and Actiflo. As with $UV_{254,}$ both processes were able to achieve low color levels.

The clarified turbidity is summarized in Table 5. Actiflo achieved an average clarified turbidity of 0.62 NTU compared to 0.57 NTU for SuperP during Phase 1A. Both processes achieved very low average turbidity which were well below 1 NTU. The CV for both process were 0.61 and 0.47 for Actiflo and Super-P, respectively. These low CV values indicate a very stable process operation.

**Actiflo and SuperP Filtered Water Quality and Zenon Micro-filtered Water Quality**

Filtered water quality samples for the three pretreatment systems were taken daily for pH, turbidity, UV254, and color with NPDOC samples being taken weekly.

**Table 4.a. Clarified Water $UV_{254}$ (Ultraviolet Absorbance at 254 nm, $cm^{-1}$)**

| Process | Average | Maximum | Minimum | StDev | CV |
|---|---|---|---|---|---|
| Actiflo | 0.106 | 0.163 | 0.069 | 0.019 | 0.18 |
| SuperP | 0.123 | 0.760 | 0.050 | 0.082 | 0.67 |

**Table 4.b. Clarified Water Color (pcu)**

| Process | Average | Maximum | Minimum | StDev | CV |
|---|---|---|---|---|---|
| Actiflo | 15 | 42 | 6 | 8 | 0.53 |
| SuperP | 17 | 61 | 7 | 10 | 0.59 |

**Table 5. Clarified Water Turbidity (NTU)**

| Process | Average | Maximum | Minimum | StDev | CV |
|---|---|---|---|---|---|
| Actiflo | 0.62 | 1.73 | 0.24 | 0.38 | 0.61 |
| SuperP | 0.57 | 1.6 | 0.27 | 0.98 | 0.47 |

Table 6 summarizes the filtered water quality samples for the duration of Phase 1A. All pretreatments were able to achieve an average turbidity lower than 0.1 NTU during Phase 1A.

As Table 6 also summarizes the SuperP, Actiflo, and Zenon NPDOC levels. All three processes achieved much higher than the 50% NPDOC removal required by the regulations. Actiflo had an average NPDOC level of 4.7 mg/L. SuperP had an average NPDOC level of 5.2 mg/L without PAC addition and 2.8 mg/L with PAC addition. These data show that SuperP with PAC addition can achieve much higher removals of NPDOC than can be achieved with coagulation alone. Further, Actiflo and SuperP achieved average filtered colors of 4 pcu and 5 pcu, respectively.

The average Zenon micro-filtered NPDOC was 8.1 mg/L with an average color of 21 pcu.

**Table 6. Average Filtered Water Quality for Study Duration**

| Process | pH | Turbidity (NTU) | NPDOC (mg/L) | $UV_{254}$ ($cm^{-1}$) | $Color_{App}$ (pcu) | Total $Cl_2$ (mg/L) |
|---|---|---|---|---|---|---|
| Actiflo | 6.4 | 0.07 | 4.7 | 0.094 | 4 | 6.95 |
| SuperP | 6.2 | 0.10 | 5.2/2.8* | 0.090 | 5 | 3.17 |
| Zenon | 6.4 | 0.08 | 8.1 | 0.225 | 21 | 5.93 |

*Indicates with/without PAC addition, respectively

The difference in the Zenon organic levels is attributed to the higher coagulation pH required for that process. Actiflo and SuperP coagulation occurred at pHs of 4.3 and 4.9 where optimum removal of organics occur. The pH of the clarified water was then increased to 6.5 for filtration. At this pH, soluble (dissolved) iron becomes insoluble (solid) and can be removed during the filtration step. Since Zenon is a one step process, the coagulation in the Zenon system occurred at a pH of 5.7. to control iron passage through the micro-filter. The pH of the Zenon water increases to approximately 6.4 by the end of the process due to air stripping of carbon dioxide. The coagulation pH of 5.7 is the pH at which soluble iron can be minimized and NPDOC removal can be maximized. At this high pH coagulation is not as efficient for the Zenon process, however, it does meet the regulatory requirements for NPDOC removal. In addition, using Zenon as a one step process is a constraint for testing in this Phase as a pretreatment, which requires the subsequent higher coagulation pH values as mentioned above. In later Phases, Zenon will be tested after clarification as filter. This will allow the organics to be removed in the clarification process and further test its ability as a filter, and as an absolute barrier for particles and turbidity.

### SuperP and Actiflo Filterability

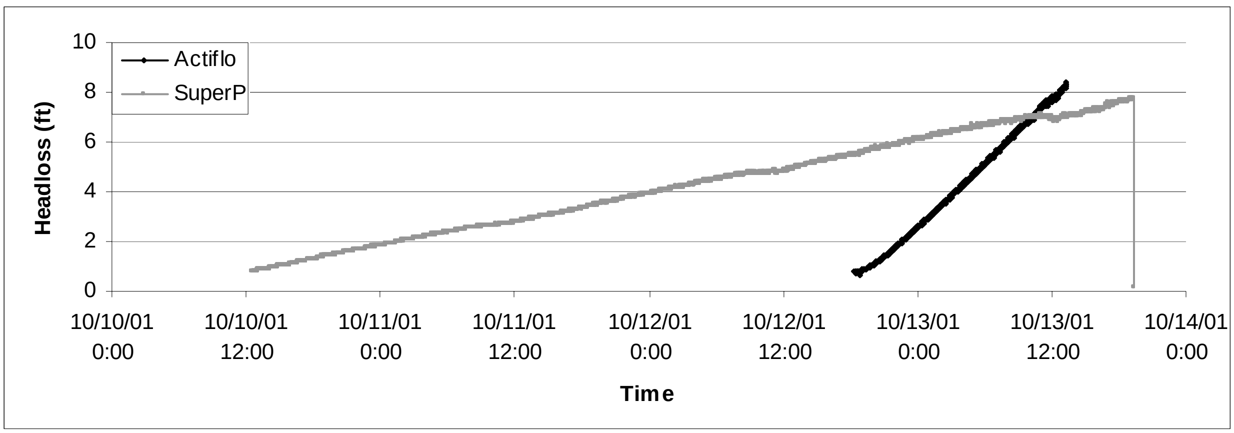
The SuperP and Actiflo units were each followed by a dual media filter.

The filterability of Super and Actiflo were evaluated based on headloss, turbidity, particle counts, unit filter run volume (UFRV). Continuous data for headloss, particle counts, and turbidity were collected in the CH2M HILL trailer using the 4" pilot scale filters and a PLC data logger.

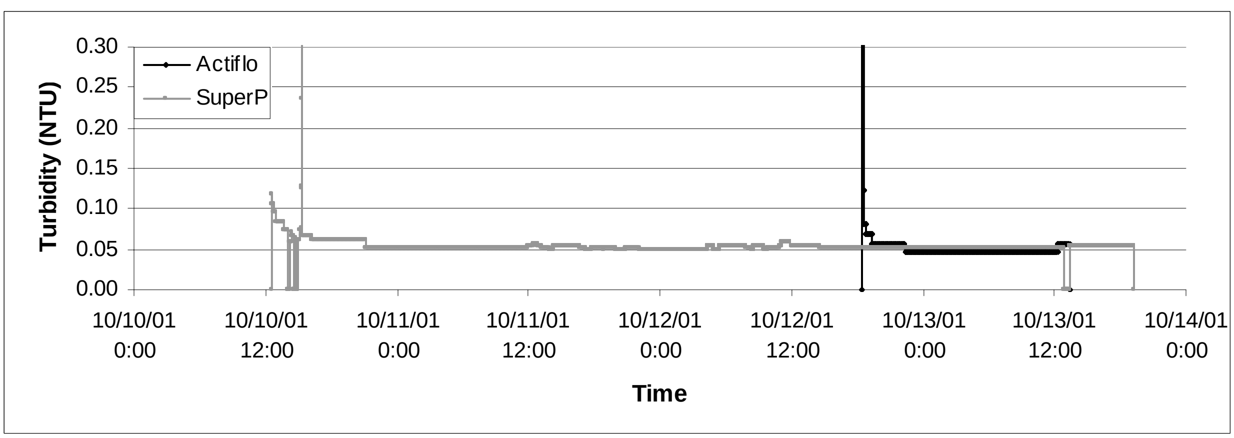
Pretreatment optimization was conducted during September and October. The goal of pretreatment optimization was to evaluate the ability of the pretreatments to achieve potable water standards without using membranes. During pretreatment optimization, chloramination of the raw water, for biological fouling control for the membranes, had not yet began.

Figure 2 (Filter Run 1) is a comparison of headloss, turbidity, and particle counts for Actiflo and SuperP during a filter run in October. Figure 2 illustrates that Actiflo and SuperP were unable to consistently produce a filtered water which achieved the minimum filtered total particle goal of less than 30 to 50 counts/mL for the duration of the filter run. Further, Actiflo was unable to meet the UFRV minimum level goal of 7,200 gal/ft$^2$ due to high headloss. Both pretreatments were, however, able to achieve the turbidity goal of <0.1 NTU with each having average turbidities of 0.053 NTU.

**Figure 2. Filter Run 1 (without chloramines)**

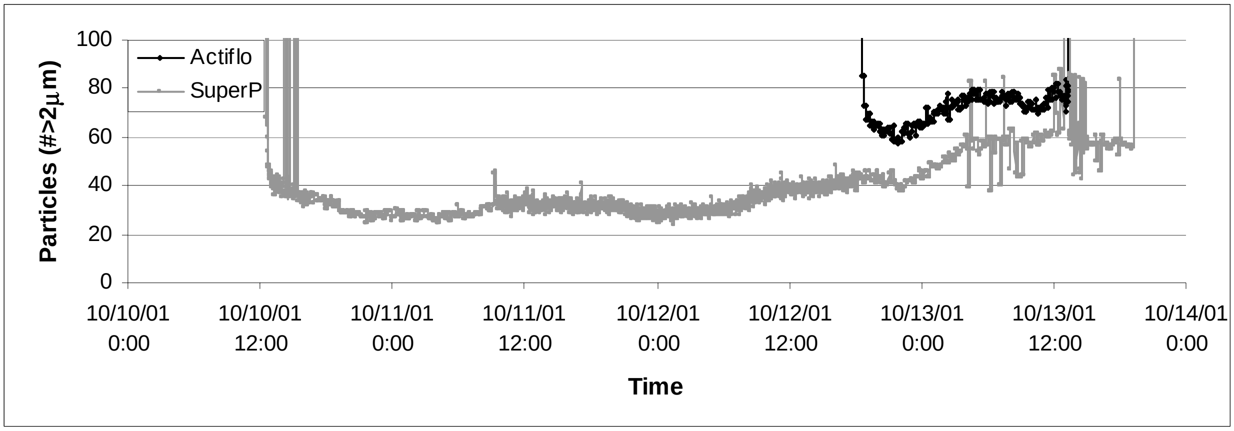



**Filter Run 1 Actiflo and SuperP Filter Headloss**




**Filter Run 1 Actiflo and SuperP Filtered Turbidity**

**Figure 2 (Continued).**




**Filter Run 1 Actiflo and SuperP Filtered Particle Counts**

| Parameter | Actiflo | SuperP |
|---|---|---|
| Filter Run Duration | 18.9 hrs | 78.7 hrs |
| Unit Filter Run Volume | 4,548 gal/ft$^2$ | 18,888 gal/ft$^2$ |
| Total Headloss | 7.59 ft | 6.94 ft |
| Rate of Headloss | 4.81 in/hr | 1.06 in/hr |
| Online Turbidity$_{Avg}$ | 0.053 NTU | 0.053 NTU |
| Online Particle counts$_{Avg}$ | 72.6 #/ml | 41.6 #/ml |

**Filter Run 1 Actiflo and SuperP Filtration Parameters Summary**

Figure 3 (Filter Run 2) illustrates the effect of chloramines on filtration performance. Figure 3 summarizes Filter Run 2, during which chloramine addition began during the first several hours of operation. The chloramines were added to control/prevent microbiological fouling of the reverse osmosis membranes.

The Actiflo and SuperP filtered particle counts in Figure 3 illustrates the sharp drop in total particles once chloramine dosing to the raw water began. The rapid decrease in particles for the Actiflo process occurred approximately 30 minutes after chloramine dosing began. This 30 minutes is approximately the detention time through Actiflo and the dual media filter. The decrease in particles for the SuperP process occurred approximately 60 minutes after chloramine dosing began which is approximately the detention time through SuperP and the dual media filter. Chloramine feed was lost during this filter run which resulted in a higher rate of headloss and total particles as Figure 3 illustrates.

During this run, SuperP and Actiflo were able to achieve the minimum level for particle counts of 30 counts/mL, as well as the goal for UFRV of 12,000 gal/ft$^2$. These data suggest that particle levels and headloss were high without preoxidation with chloramines. This may be due to the high levels of organics that may have prevented complete particle destabilization with the coagulant alone. The addition of chloramines to the raw water, however, may have provided particle conditioning , which significantly improved filterability.

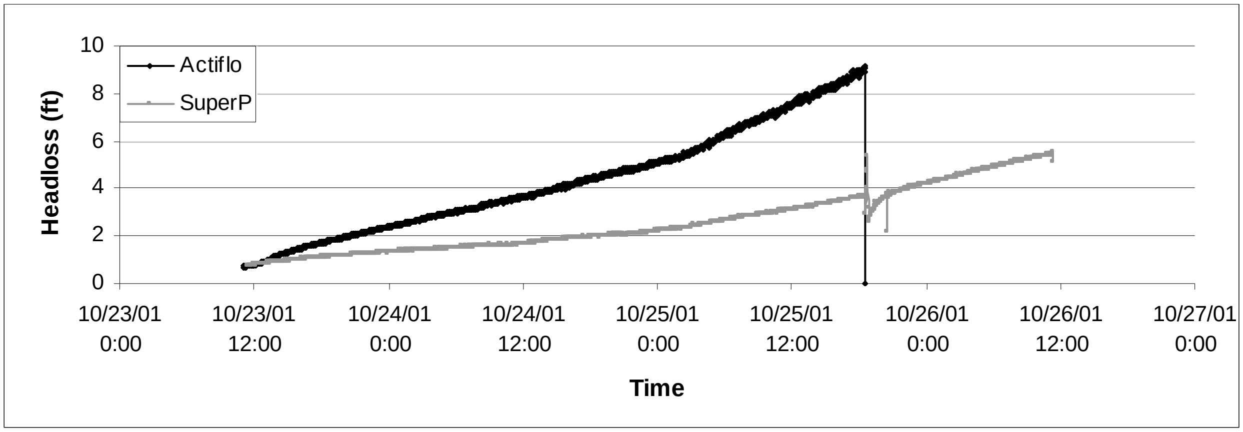
Figure 4 (Filter Run 3) summarizes a filter run that occurred during membrane treatment. During this run both pretreatments were able to meet and exceed all goals for turbidity, particle counts, and UFRV. As the Actiflo and SuperP Filtration Parameters Summary in Figure 4 illustrates, both pretreatments had nearly equal particle levels and equal turbidity levels. SuperP had a slightly lower rate of headloss, resulting in a longer run duration, and subsequently a higher UFRV. This run is typical of the filtered water quality that was provided to the membranes during the Phase 1A testing.

**Zenon Filterability**

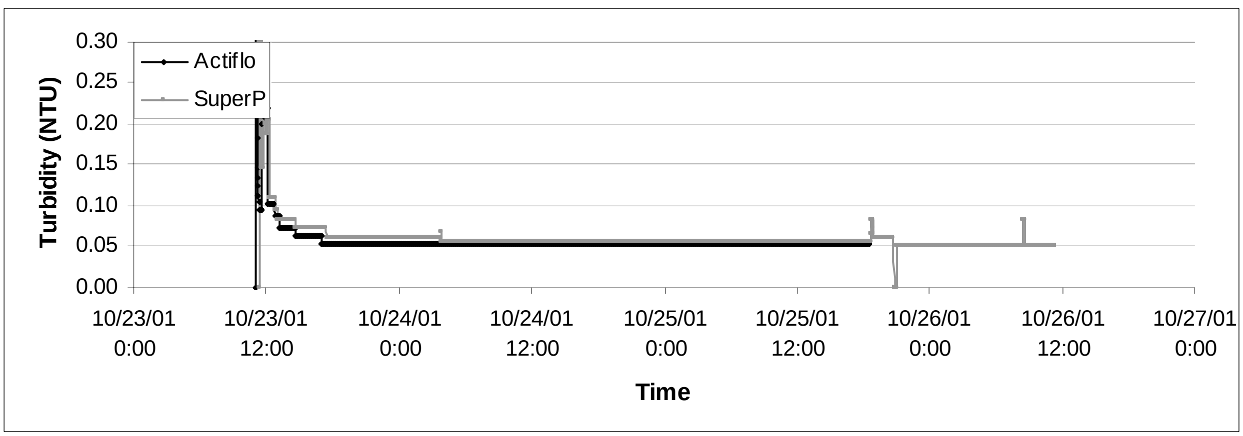
During Phase 1A, the Zenon pilot unit was operated at a flux of 20 gfd (gal/ft$^2$/day) and a recovery of 90%. Online turbidity and particle count data was collected every 15 minutes during reverse osmosis testing. The data is summarized in Figure 5. As Figure 5 illustrates, the Zenon unit was able to achieve an average turbidity of less than 0.046 NTU and average particle counts of 2.2 counts/ml for the duration of membrane treatment. This illustrates the higher level of treatment that can be achieved using membrane technology which is an absolute barrier.

Although the Actiflo and SuperP filters had relatively low levels of turbidity and particles, as expected, the Zenon micro-filtration membrane was clearly able to achieve much lower levels than the conventional media filtration.

## Figure 3. Filter Run 2 (chloramines started during run)

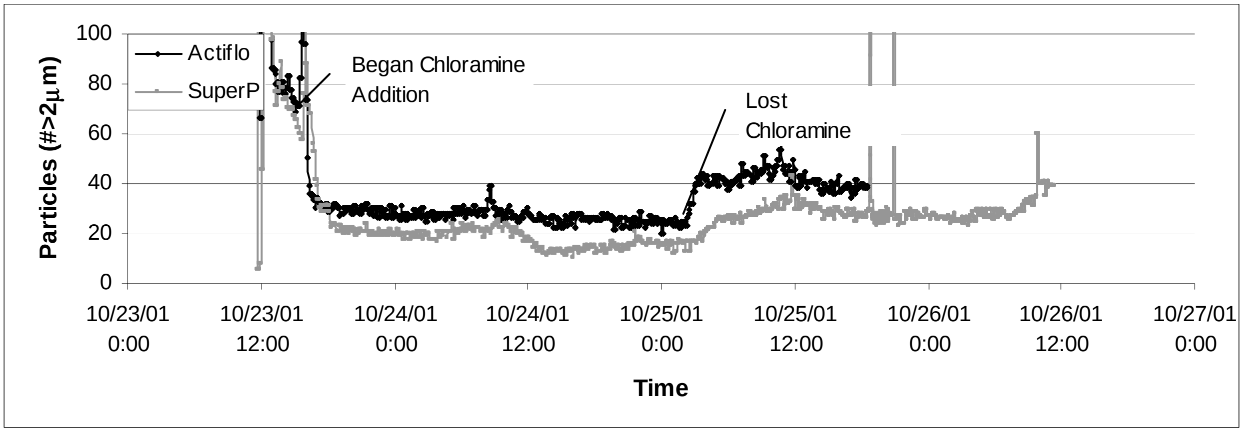



**Filter Run 2 Actiflo and SuperP Filter Headloss**




**Filter Run 2 Actiflo and SuperP Filtered Turbidity**

**Figure 3 (Continued).**

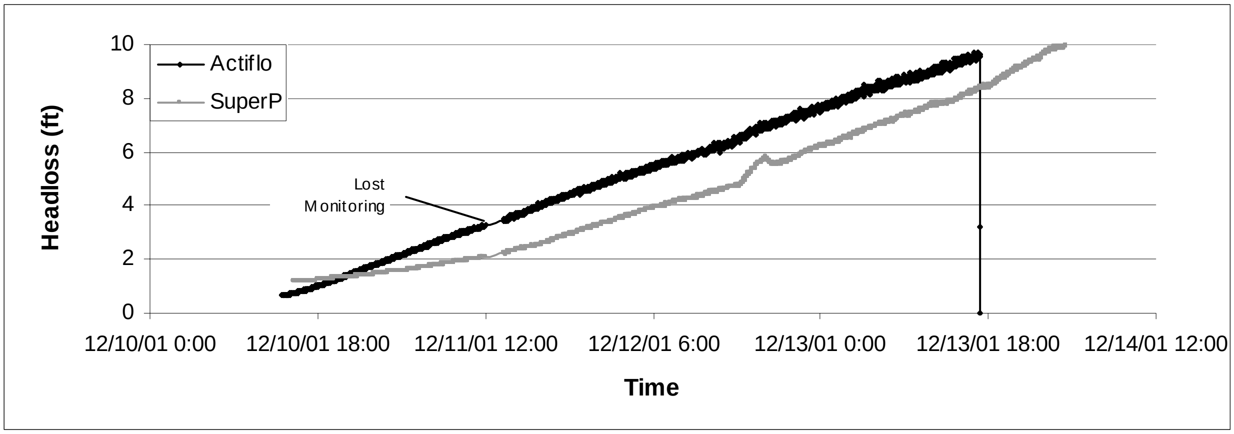



**Filter Run 2 Actiflo and SuperP Filtered Particle Counts**

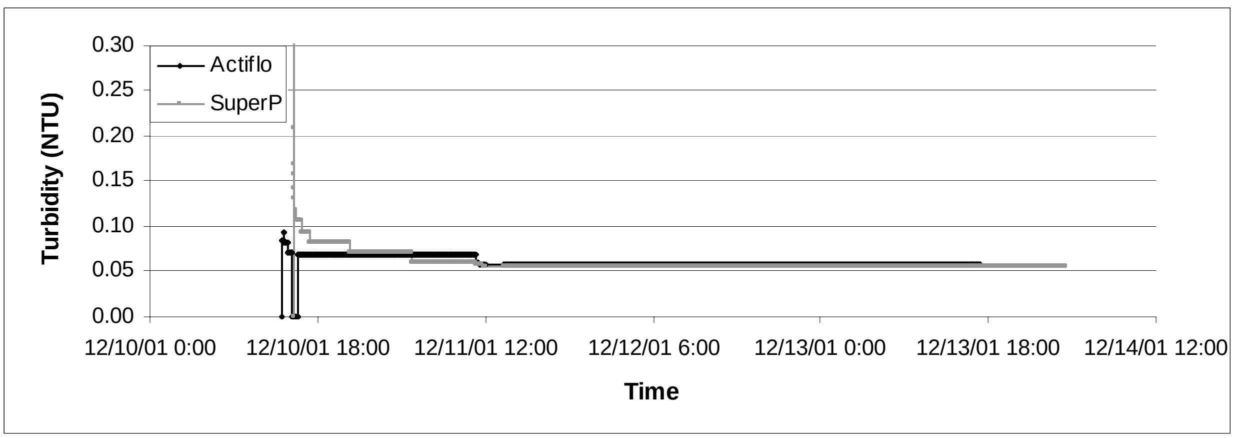
| Parameter | Actiflo | SuperP |
|---|---|---|
| Filter Run Duration | 55.5 hrs | 71.9 hrs |
| Unit Filter Run Volume | 13,308 gal/ft$^2$ | 17,256 gal/ft$^2$ |
| Total Headloss | 8.42 ft | 4.74 ft |
| Rate of Headloss | 1.82 in/hr | 0.79 in/hr |
| Online Turbidity$_{Avg}$ | 0.058 NTU | 0.059 NTU |
| Online Particle counts$_{Avg}$ | 39.0 #/ml | 28.4 #/ml |

**Filter Run 2 Actiflo and SuperP Filtration Parameters Summary**

## Figure 4. Filter Run 3 (raw water chloramination)

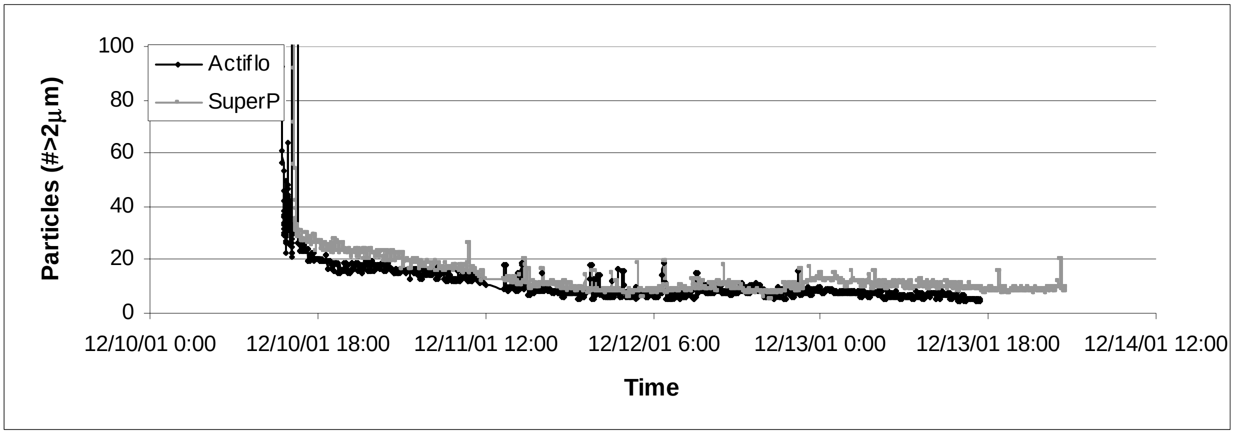



**Filter Run 3 Actiflo and SuperP Filter Headloss**




**Filter Run 3 Actiflo and SuperP Filtered Turbidity**

## Figure 4 (Continued).

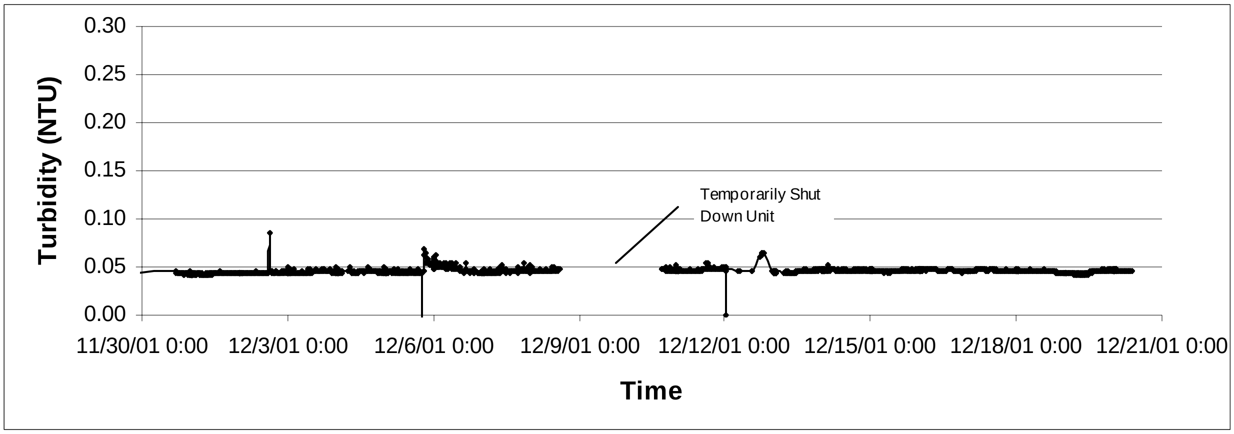



**Filter Run 3 Actiflo and SuperP filtered Particle Counts**

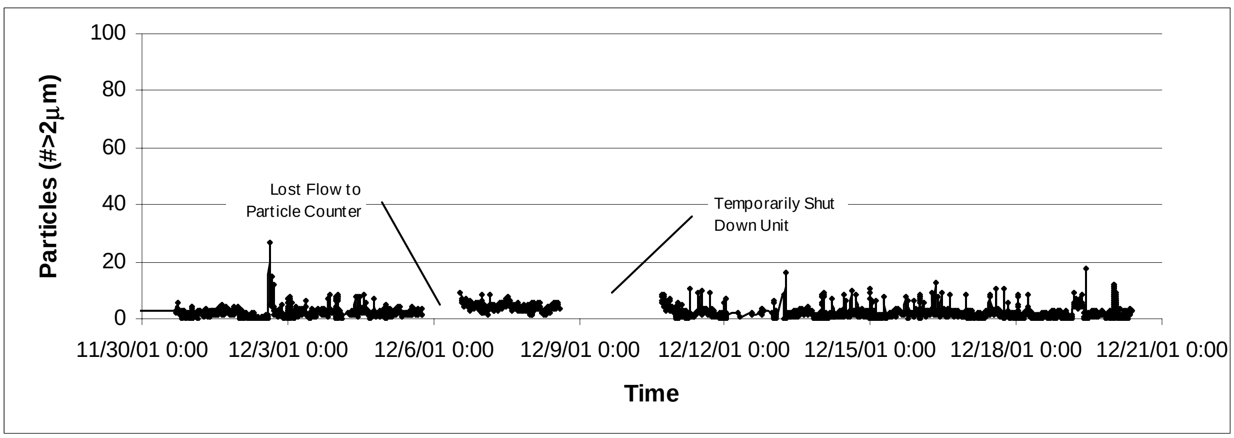
| Parameter | Actiflo | SuperP |
|---|---|---|
| Filter Run Duration | 74.9 hrs | 89.6 hrs |
| Unit Filter Run Volume | 17,972 gal/ft$^2$ | 21,504 gal/ft$^2$ |
| Total Headloss | 8.97 ft | 8.8 ft |
| Rate of Headloss | 1.44 in/hr | 1.27 in/hr |
| Online Turbidity$_{Avg}$ | 0.061 NTU | 0.061 NTU |
| Online Particle counts$_{Avg}$ | 11.9 #/ml | 13.3 #/ml |

**Filter Run 3 Actiflo and SuperP Filtration Parameters Summary**

## Figure 5. Zenon Turbidity and Particle Counts




**Zenon Online Turbidity**




**Zenon Online Particle Counts**

# REVERSE OSMOSIS MEMBRANE PERFORMANCE

Reverse osmosis membrane testing was conducted from early November 2001 to mid-December 2001. The Actiflo and SuperP membranes were put into operation on November 9, 2001 and stopped December 20, 2001. The total run time for the Actiflo and SuperP membranes was 904 hours. The Zenon pretreatment system was placed online November 30, 2001 and operated until December 21, 2001 for a total of 505 hours run time. The Zenon system had less run time since a membrane element was damaged during shipping. This problem took some time to identify and correct.

During operation the membrane system flows and pressures were monitored two to three times each day. To maintain constant flux, adjustments in flow to the membrane systems were made as necessary. Daily grab samples were taken from the membrane and analyzed for chlorine, turbidity, and conductivity. Weekly water quality samples were taken for analysis in the UCF water quality laboratory. Samples were evaluated for inorganic parameters and NPDOC among others.

### Pretreatment Water Quality

This section summarizes the pretreatment water quality during membrane treatment. Clarified water quality, filtered water quality, silt density index (SDI), and total chlorine levels are summarized for the three systems.

Table 7 summarizes the clarified water quality during membrane treatment. The data in Table 7 illustrate that both Actiflo and SuperP were able to produce high quality clarified water before filtration.

**Table 7. Average Clarified Water Quality Summary During Membrane Treatment**

| Process | pH | Turbidity (NTU) | $UV_{254}$ ($cm^{-1}$) | $Color_{App}$ (pcu) | Particles (#/mL>2µm) | Total Iron (mg/L) |
|---|---|---|---|---|---|---|
| Actiflo | 4.5 | 0.78 | 0.115 | 16 | 906 | 0.651 |
| SuperP | 4.9 | 0.56 | 0.094 | 13 | 774 | 0.362 |

Note: During membrane treatment, the clarified water was still treated through the dual media filters before going to the R.O. membranes. This table summarizes the clarified water quality after this interim step.

Several days prior to membrane treatment beginning, addition of PAC at a dose of 20 mg/L to the SuperP process began. The purpose for the PAC addition was to evaluate the effect of additional organic removal on organic fouling of the membranes. The PAC with the SuperP was able to achieve 35% lower NPDOC than Actiflo with coagulation only.

The addition of PAC to the SuperP resulted in lower color and $UV_{254}$ levels compared to Actiflo; further, the PAC may have allowed for a more stable sludge blanket, resulting in a lower clarified turbidity. Total iron levels were lower due to a higher coagulation pH for the SuperP.

Table 8 summarizes the feed water quality from the three pretreatments; the feed water was the finished, filtered water from the pretreatments. As Table 8 illustrates, NPDOC levels were lowest for the SuperP process due to the addition of PAC. NPDOC levels for SuperP were 2.8 mg/L, 35% lower than the NPDOC of 4.3 mg/L for Actiflo, and 62% lower than the NPDOC of 7.3 mg/L for Zenon.

**Table 8. Membrane Feed (filtered*) Water Quality Summary**

| Process | pH | Turbidity (NTU) | NPDOC (mg/L) | $UV_{254}$ ($cm^{-1}$) | $Color_{App}$ (pcu) | Total $Cl_2$ (mg/L) |
|---|---|---|---|---|---|---|
| Actiflo | 6.6 | 0.07 | 4.3 | 0.103 | 4 | 6.95 |
| SuperP | 6.6 | 0.07 | 2.8 | 0.070 | 3 | 3.32 |
| Zenon | 6.3 | 0.06 | 7.3 | 0.183 | 10 | 5.57 |

Note: * Membrane feed water represents filtered water from Actiflo and SuperP and the micro-filtered water from Zenon.

Table 9 summarizes the pretreatment total chlorine concentrations for membrane treatment. Average total chlorine levels ranged from 3.3 mg/L as $Cl_2$ for the SuperP up to 6.9 mg/L as $Cl_2$ for the Actiflo system. Total chlorine concentrations for the SuperP were significantly lower due to chloramine adsorption by the PAC.

**Table 9. Membrane Feed Total Chlorine Summary (mg/L as $Cl_2$)**

| Process | Average | Maximum | Minimum | StDev | CV |
|---|---|---|---|---|---|
| Actiflo | 6.9 | 11.9 | 1.1 | 2.5 | 0.37 |
| SuperP | 3.3 | 6.8 | 0.1 | 1.5 | 0.46 |
| Zenon | 5.6 | 10.3 | 2.5 | 2.0 | 0.36 |

Table 10 summarizes the SDI measurements for the pretreatment systems. The SDI measurement is a membrane fouling index used to quantify the particle fouling nature of a water. As expected, the Zenon system achieved the lowest average SDI of 3.2. This is due to the low particle/turbidity levels by the Zenon microfilter discussed previously. All pretreatment systems achieved an average SDI less than 4.0. Lower SDI levels suggest that less fouling will occur on the membranes. All three pretreatments achieved SDI's lower than the recommended maximum SDI's from the membrane manufacturers.

**Table 10. Membrane Feed SDI Summary**

| Process | Average | Maximum | Minimum | StDev | CV |
|---|---|---|---|---|---|
| Actiflo | 3.7 | 5.5 | 2.0 | 0.94 | 0.26 |
| SuperP | 3.3 | 5.6 | 2.2 | 0.78 | 0.24 |
| Zenon | 3.2 | 3.7 | 2.4 | 0.45 | 0.14 |

## Membrane Productivity

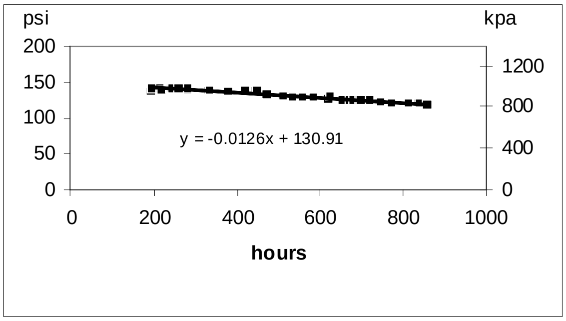
During membrane treatment, membrane flux was kept constant at 12 gfd (gallons/ft$^2$/day) and recovery was kept constant at 70%. Flows to the Osmonics SG and TriSep X-20 were as follows:

| Membrane Element | Feed Flow (gpm) | Recycle Flow (gpm) | Permeate Flow (gpm) | Concentration Flow (gpm) |
|---|---|---|---|---|
| TriSep X-20 | 0.96 | 4.23 | 0.68 | 0.29 |
| Osmonics SG | 1.07 | 4.70 | 0.75 | 0.32 |

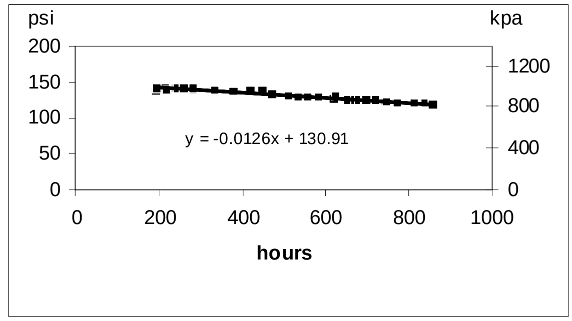
Required feed pressures for these parameters are illustrated in Figure 6. For membrane treatment, feed pressures ranged from 95 psi up to 140 psi. Under the given flow parameters, these feed pressures are typical for low pressure reverse osmosis treatment.

The water mass transfer coefficient (MTC) is an indicator of membrane productivity and is often used to determine the rate and extent of membrane fouling. In Figure 7, the MTC for each system is summarized. The MTC for each system is plotted vs. run time to illustrate the MTC trend for Phase 1A. The graphs in Figure 7 suggest little to no decline in MTC suggesting little to no fouling during this phase of the study.

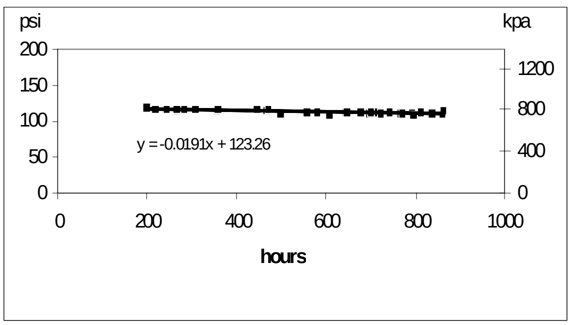
## Figure 6. Membrane Feed Pressure vs. Run Time



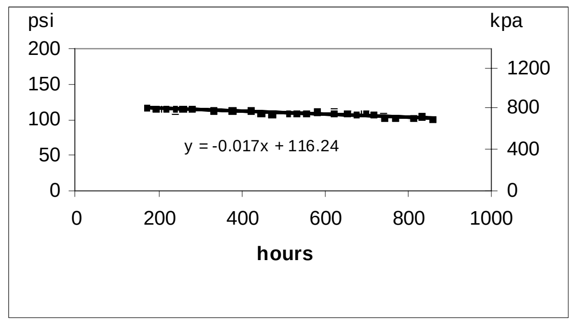

**Actiflo X-20**



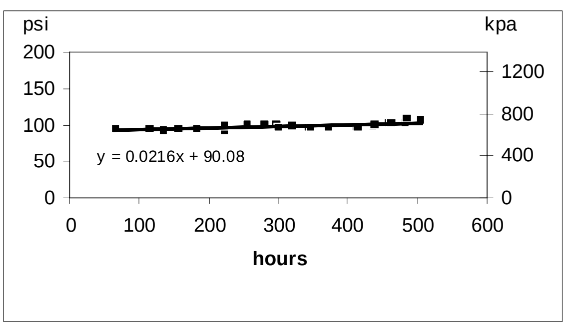

**Actiflo SG**



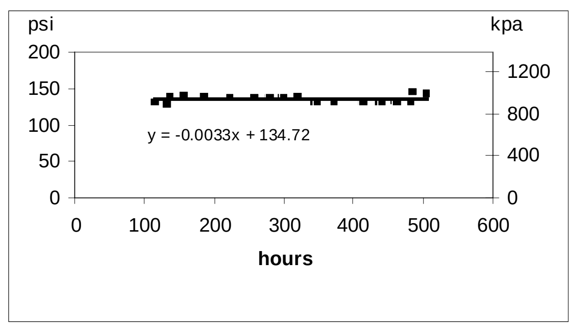

**SuperP X-20**




**SuperP SG**

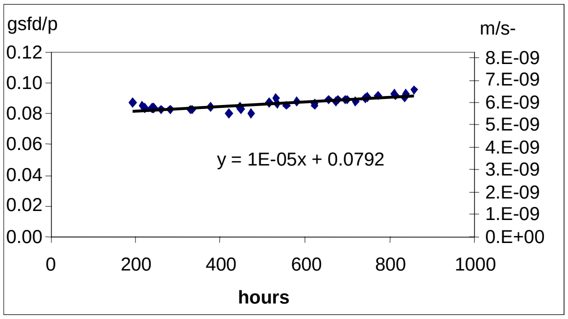



**Zenon X-20**

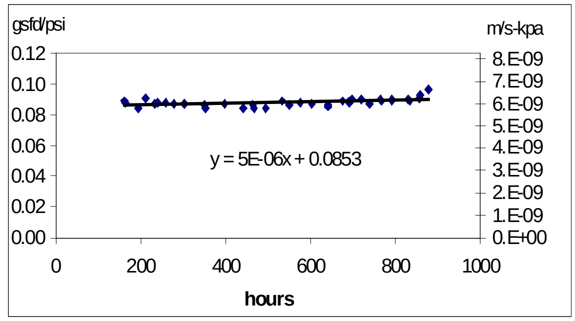



**Zenon SG**

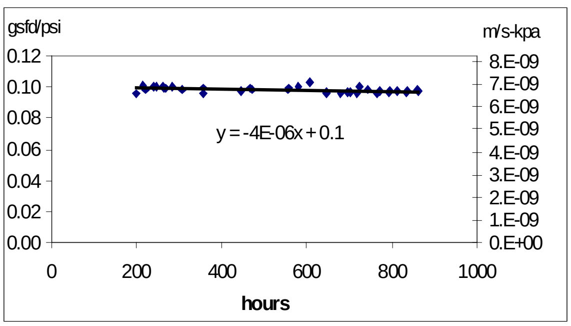
## Figure 7. Water Mass Transfer Coefficient vs. Run Time



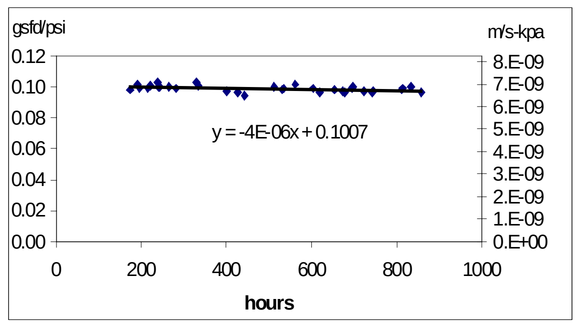

**Actiflo X-20**



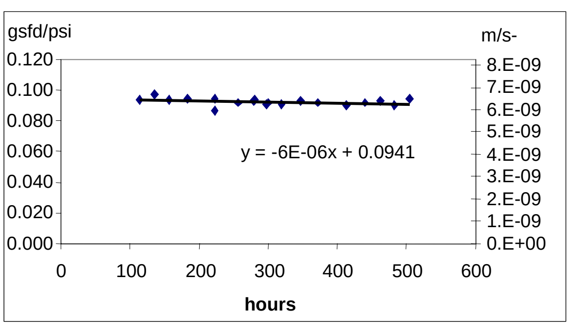

**Actiflo SG**



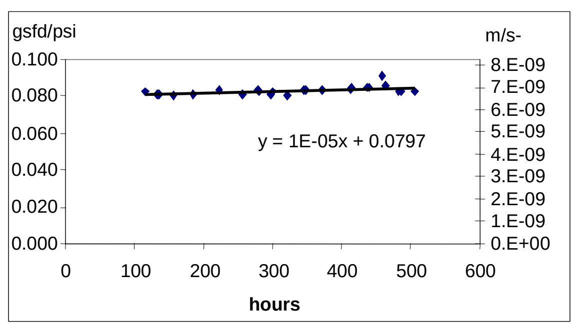

**SuperP X-20**




**SuperP SG**




**Zenon X-20**




**Zenon SG**

## Membrane Water Quality

At the pilot plant, membrane water quality was monitored using conductivity as an indicator of salt passage. Figure 8 summarizes the conductivity rejection of each membrane system for the duration of Phase 1A. As Figure 8 illustrates, conductivity removal for all membrane systems was greater than 95% for Phase 1A. Further, removal by the TriSep X-20 membranes was higher than the Osmonics SG membranes in all three pretreatment systems.

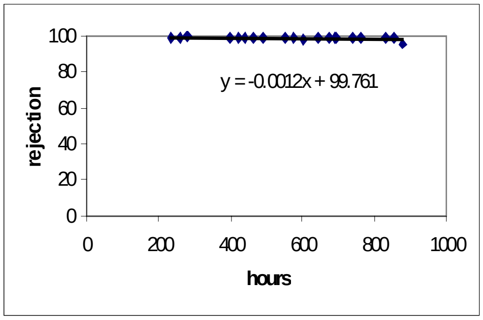
Figure 9 summarizes the NPDOC removal for the membrane systems. NPDOC removal was approximately 95% for all systems. NPDOC removal by the SuperP membranes was not as high as the Zenon and Actiflo membranes; however, the SuperP had the lowest influent NPDOC concentration due to the addition of PAC discussed earlier. Figure 9 also illustrates the slightly lower NPDOC removal by the Osmonics SG membranes compared to the TriSep X-20 membranes.

Table 11.a and Table 11.b summarize the water quality data analyzed at the UCF laboratory. Feed water quality and permeate water quality for both membranes is summarized for each pretreatment system.

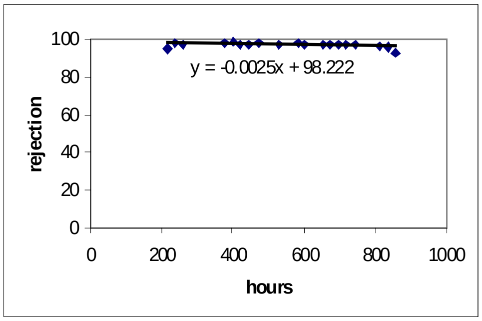
Table 11.a summarizes general water quality parameters such as turbidity, pH, and particle counts, as well as organic parameters such as $UV_{254}$, NPDOC, and color. As expected, average NPDOC levels in the permeate ranged from 0.2 to 0.4 mg/L and color levels were 0 to 1 pcu for the membrane systems.

Table 11.b summarizes the inorganic parameters including TDS, Ca, Mg, Cl and Br among others. The average TDS levels of the membrane feed ranged from 440 mg/L up 578 mg/L. The average TDS of the membrane permeate ranged from 8 to 50 mg/L. This represents a TDS removal of from 89% to 97%. TDS levels for the TriSep X-20 membranes were lower than the Osmonics SG membranes in all three systems. Calcium and magnesium levels were below 1 mg/L, respectively, for all three membrane systems. Bromide levels were below detection levels on all of the membranes. Chloride levels were below 20 mg/L for all membrane systems and were again slightly lower for the X-20 membranes than the SG membranes.

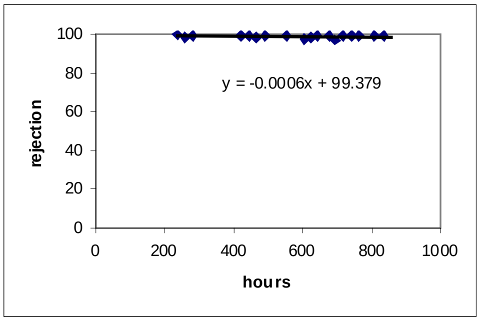
## Figure 8. Conductivity Rejection vs. Run Time



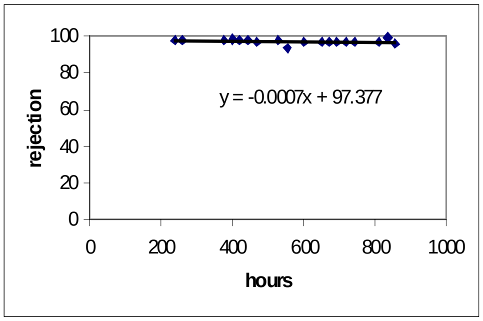

**Actiflo X-20**



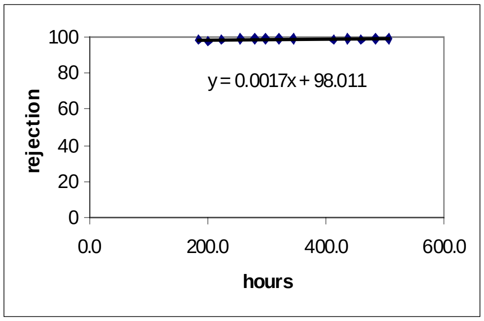

**Actiflo SG**



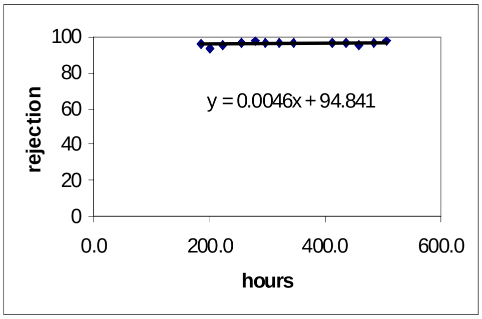

**SuperP X-20**




**SuperP SG**

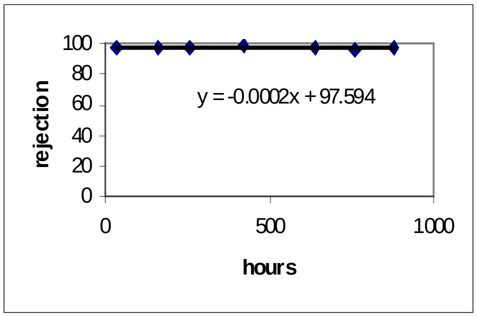



**Zenon X-20**

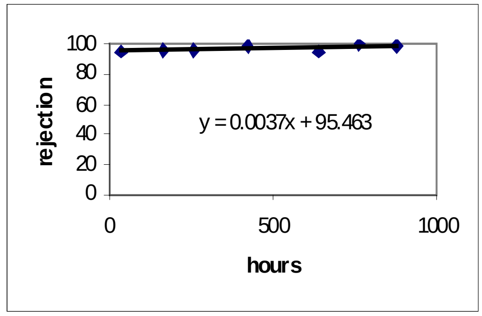



**Zenon SG**

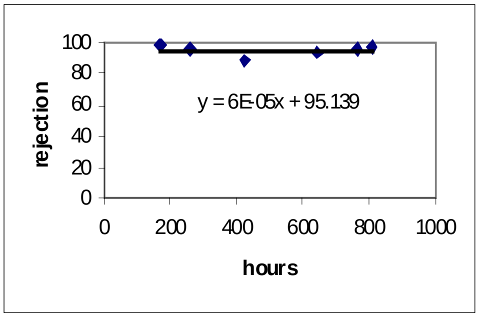
## Figure 9. NPDOC Rejection vs. Run Time



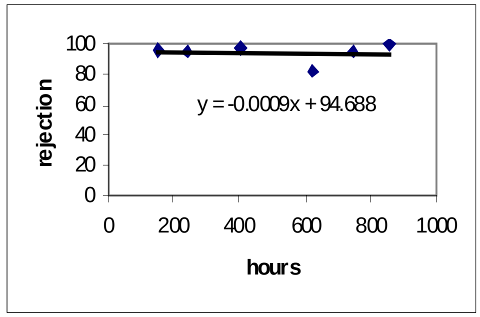

Actiflo X-20



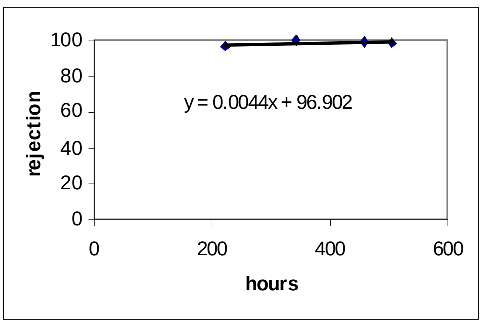

Actiflo SG



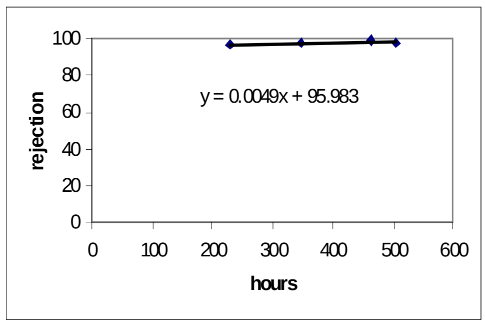

SuperP X-20




SuperP SG




Zenon X-20




Zenon SG

**Table 11.a. Membrane Feed and Permeate General Water Quality Parameters**

| System | Source | pH | Turb. (NTU) | Part. (#/mL) | NPDOC (mg/L) | UV-254 (cm-) | Color (CPU) |
|---|---|---|---|---|---|---|---|
| Actiflo | Feed | 6.81 | 0.115 | 217 | 4.4 | 0.105 | 4 |
| | SG | 6.04 | 0.053 | 37 | 0.3 | 0.023 | 0 |
| | X20 | 5.98 | 0.05 | 54 | 0.3 | 0.024 | 0 |
| SuperP | Feed | 6.77 | 0.083 | 162 | 3.6 | 0.066 | 2 |
| | SG | 5.98 | 0.053 | 41 | 0.3 | 0.013 | 1 |
| | X20 | 5.93 | 0.058 | 40 | 0.3 | 0.01 | 0 |
| Zenon | Feed | 6.21 | 0.1 | NSD | 7.3 | 0.183 | 10 |
| | SG | 5.92 | 0.066 | NSD | 0.4 | 0.019 | 0 |
| | X20 | 6.05 | 0.075 | NSD | 0.2 | 0.024 | 0 |

**Table 11.b. Membrane Feed and Permeate Inorganic Parameters**

| System | Source | TDS (mg/L) | Cond. (Ms/m) | Ca (mg/L) | Mg (mg/L) | Na (mg/L) | Cl (mg/L) | Br (mg/L) | $SO_4$ (mg/L) | Fe (mg/L) | Sr (mg/L) | Si (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actiflo | Feed | 440 | 80.8 | 35.8 | 11.1 | 111 | 127 | 0.3 | 136 | 54 | 0.7 | 10.7 |
| | SG | 50 | 6.05 | 0.4 | 0.1 | 8.5 | 16.6 | 0 | 3.7 | 37.1 | 0 | 0.2 |
| | X20 | 8 | 1.93 | 0.5 | 0 | 1.3 | 6.1 | 0 | 2.5 | 34.7 | 0 | 0 |
| SuperP | Feed | 578 | 88.9 | 36.9 | 11.3 | 132 | 123 | 0.3 | 148 | NSD | 0.7 | 11.4 |
| | SG | 47 | 6.87 | 0.3 | 0 | 9.6 | 17.4 | 0 | 2.8 | 38.2 | 0 | 0.3 |
| | X20 | 19 | 2.86 | 0.5 | 0 | 1.6 | 5.6 | 0 | 2.6 | 34 | 0 | 0 |
| Zenon | Feed | 540 | 82.4 | 39.6 | 11.2 | 96.7 | 146 | 0.3 | 127 | 46 | 0.8 | 8.8 |
| | SG | 19 | 2.94 | 0.4 | 0 | 3.2 | 9.1 | 0 | 2.7 | 36 | 0.2 | 3.5 |
| | X20 | 11 | 1.79 | 0.8 | 0 | 1.6 | 6.9 | 0 | 3.4 | 31 | 0 | 2.9 |

### Effect of Chloramination on Membrane Water Quality

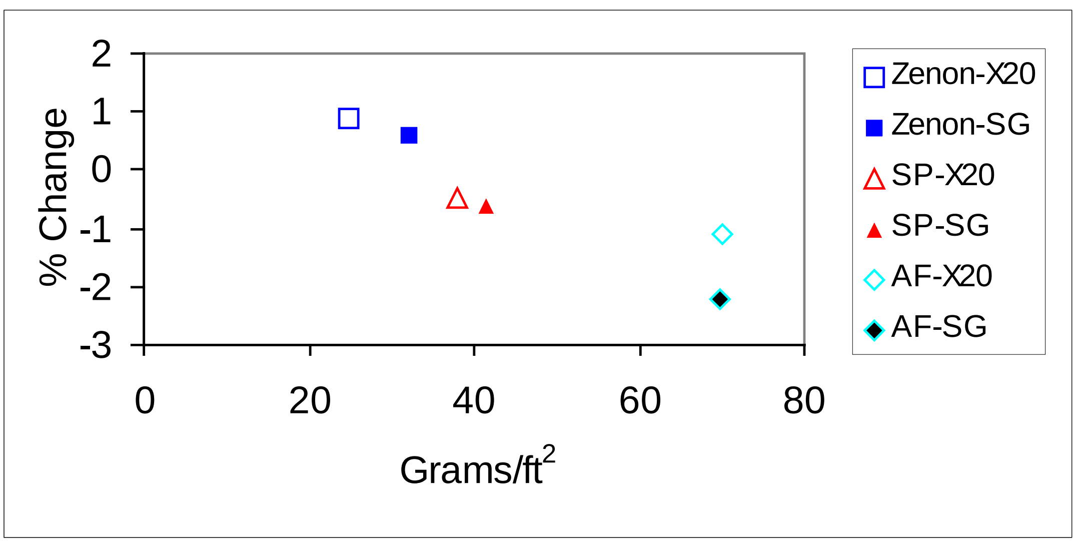
During Phase 1A, a change in membrane permeate water quality was observed. After approximately 400 hours of operation, slight increases in salt levels in the membrane permeates were observed. It is possible that the monochloramine residual may have caused membrane surface degradation, which subsequently allowed higher rates of salt passage through the membrane.

A membrane feed chloramine concentration of 4 to 6 mg/L as $Cl_2$ was recommended for Phase 1A. This range was recommended based on published data on similar surface water integrated membrane system studies in Florida. This range was found necessary to successfully control biological fouling on the membrane surface.

During Phase 1A, actual average chloramine levels on the membranes ranged from 3 to 7 mg/L as $Cl_2$ depending on the pretreatment detention time. Figure 10 and Figure 11 compare the total mass loading of chlorine to the membrane with percent change TDS passage and NPDOC passage, respectively.

As Figure 10 illustrates, the higher chloramine loading on the SuperP and Actiflo membranes caused an increase in TDS passage. This suggests that these levels of chloramines may have degraded the membranes. The Zenon membranes, with lower chloramine loading, did not show an increase in TDS passage, but rather a decrease; however, the Zenon membranes had less hours of operation than the Actiflo and SuperP membranes, therefore less chloramine loading. Further, Figure 10 illustrates that the SG membranes were more sensitive to chlorine loading compared to the X-20 membranes. This data suggests that for this water, the recommended chloramine dosages may affect membrane performance and that certain membranes may be more resistant to chloramine degradation than others.

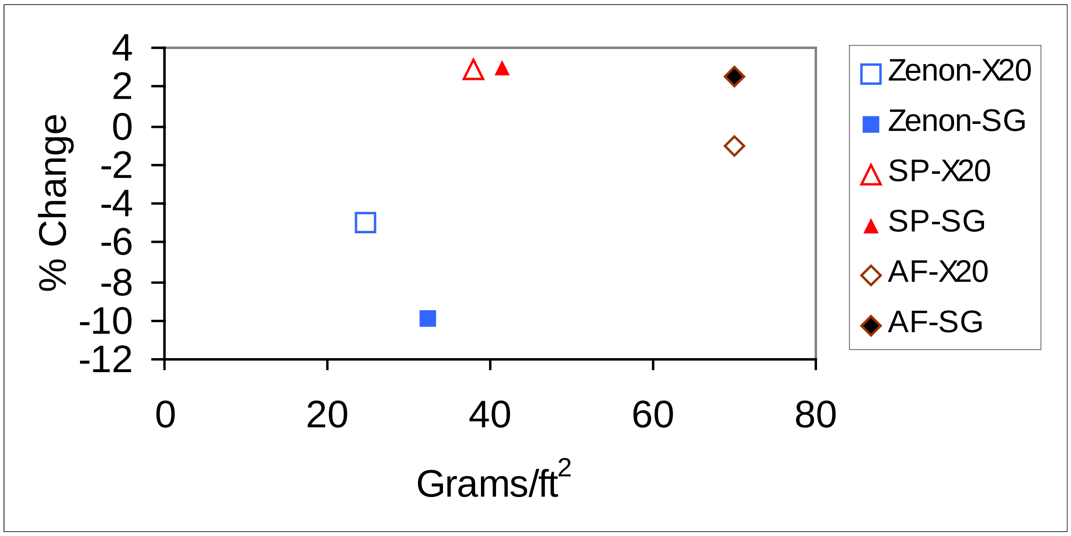
**Figure 10. Change in TDS Rejection vs. Monochloramine Loading**



Based on this data, lower levels of chloramines will be evaluated during Phase 1B and 2 to assess the effect on the membrane performance and biological fouling.

Figure 11 illustrates monochloramine loading to the membranes compared to the change in NPDOC rejection. Figure 11 suggests no clear trend in chlorine loading compared to change in NPDOC removal suggesting that unlike the salts, the organic rejection was not affected by the chloramine residual.

**Figure 11. Change in NPDOC Rejection vs. Monochloramine Loading**




### Membrane Concentrate Water Quality

In addition to feed water quality and permeate water quality, membrane concentrate water quality was analyzed for both membranes on each pretreatment system. Table 12 summarizes concentrate water quality for Phase 1A testing. Table 12 summarizes NPDOC, TDS, and TSS as well as several inorganic parameters including Na, Cl, SO4, Ca, and Mg.

As Table 12 illustrates concentrate NPDOC ranged from 11.3 mg/L for the SuperP X-20 membrane, to 21.9 mg/L for the Zenon X-20 membrane. The NPDOC concentrations were lowest for SuperP due to the lower feed NPDOC concentrations and highest for Zenon due to the higher feed NPDOC concentrations as summarized previously.

The concentrate data further illustrate the significantly higher TDS concentrations as compared to feed concentrations. Average concentrate TDS values ranged from 1203.5 mg/L for the SuperP SG to 1849.0 mg/L for the Zenon X-20. As expected, these values are approximately three to four times higher than the feed concentrations.

**Table 12. Phase 1A Concentrate Characterization**

| Membrane | NPDOC (mg/L) | TDS (mg/L) | TSS (mg/L) | Na (mg/L) | C l (mg/L) | $S0_4$ (mg/L) | Ca (mg/L) | Mg (mg/L) |
|---|---|---|---|---|---|---|---|---|
| Actiflo SG | 13.5 | 1463.6 | 139.1 | 333.4 | 401.0 | 459.7 | 91.3 | 29.4 |
| Actiflo X-20 | 13.6 | 1549.4 | 138.9 | 297.4 | 434.6 | 474.5 | 98.0 | 30.7 |
| SuperP SG | 11.5 | 1203.5 | 133.0 | 375.4 | 426.4 | 583.2 | 97.9 | 29.8 |
| SuperP X-20 | 11.3 | 1278.9 | 136.3 | 385.4 | 450.3 | 575.2 | 84.6 | 29.9 |
| Zenon SG | 21.4 | 1669.8 | 177.5 | 314.5 | 524.6 | 443.1 | 110.2 | 34.5 |
| Zenon X-20 | 21.9 | 1849.0 | 140.0 | 321.2 | 541.7 | 450.4 | 106.0 | 34.4 |

# CONCLUSIONS

The goal of Phase 1A was to simultaneously test each of the three (3) pretreatments for their ability to produce potable water without membrane treatment during the rainy season; and to also test their ability to feed low pressure R.O. membranes during the dry season with higher raw water salt concentrations.

All three pretreatments were able to produce potable water quality without membranes; Actiflo followed by dual media filtration, SuperP followed by dual media filtration, and Zenon micro-filtration. The organic removal by each pretreatment exceed regulatory requirements, the filtered turbidity from each process was significantly below the potential future standard of 0.1 NTU, and each process demonstrated a stable operation throughout this phase.

With respect to membranes in Phase 1A, all three pretreatments were able to provide water to the low pressure R.O. membranes without any measurable fouling. The pretreated water was supplied reliably to the membranes and allowed for continuous operation of the membranes with little down-time.

Both of the membranes tested performed well. Each membrane demonstrated over 95% salt rejection and 95% organic rejection.

As anticipated, the chloramine addition (4 to 6 mg/L) prevented biological fouling of the membranes; however, chloramine loading at this level may have degraded the membrane surface. This degradation was evident considering the increased salt passage through the membranes and with higher salt passages correlating to higher chloramine loading.

Based on these results, the protocol and testing plan for Phases 1B, 2A, and 2B have been developed and will be discussed in the following sections.

Since all three pretreatments performed well, the remaining phases of testing will include SuperP, Zenon, and Actiflo providing water to the low recovery and high recovery membranes at different times. This will allow for additional data to be collected on the three processes since they all have exhibited good performance. The membrane testing will be expanded from 2 membranes to 4 membranes. With the pretreatments evaluated in Phase 1A, these subsequent phases will focus more on membrane performance and design data.

An important element of the subsequent phases of testing will be the continued evaluation of chloramine addition. Due to the potential degradation of the membranes during Phase 1A, significantly lower chloramine levels will be added to control biological fouling. Chloramine addition will be lowered to 1-2 mg/L. At these lower chloramine dosages, the fouling of the membranes will be closely monitored using all three pretreatment processes. The goal of the subsequent phases of testing is to better quantify the level of chloramine addition required to control biological fouling without degrading the membrane surface.

# PHASE 1B, 2A, & 2B OPERATIONAL PROTOCOL

Based on the Phase 1A results, the SuperP process will be the primary process for testing during Phase 1B and Phase 2A. However, because the Actiflo process performed comparably to the SuperP process, the Actiflo process will also be evaluated during Phase 2B to collect additional design and operational data. In the multi attribute cost-benefit decision model for this project, Zenon had a higher relative benefit than SuperP and Actiflo, but at a much higher cost. Therefore, Zenon will be tested throughout the remainder of the study as a higher cost/higher relative benefit alternative.

During the remaining phases, each pretreatment will be tested using the four different single elements selected by the University of Central Florida. The purpose of Phase 1B is to select the best performing reverse osmosis membrane for treating water from the St. Johns River. Phase 2A and 2B seasonal verification testing will be conducted with the high recovery membrane system using the membrane selected during Phase 1B.

## PHASE 1B

During Phase 1B, SuperP and Zenon will be evaluated for 1,000 hours of membrane testing. The two pretreatments will each feed the four single element membranes selected for this study which include:

- Osmonics SG Brackish Water Membrane
- Filmtec BW30FR Membrane
- Trisep X-20 Membrane
- Hydronautics Low Fouling Composite (LFC) Membrane

As with Phase 1A, the performance of the two pretreatments will be evaluated based on the feed pressure changes and cleaning frequency of the membranes over 1,000 hours of testing. In addition, the pretreatments will further be evaluated regarding, cost, operability, and process stability.

### Goals

Zenon optimization will be conducted early in the study. This will ensure adequate time is available to optimize the system.

Reoptimization of the coagulant dosage and coagulation pH is necessary due to the change in raw water quality. Further, a flux optimization will be conducted to achieve the highest productivity allowable by the Zenon system.

Optimization of the SuperP will again be necessary due to the raw water quality change. The unit will be optimized to determine the appropriate coagulation pH, coagulation dosage, and polymer dosage for filtration and membrane treatment.

For SuperP, polymer minimization will be a goal of treatment. The cationic polymer required for treatment with the SuperP could cause membrane fouling. For membrane treatment, the cationic (positively charged) polymer cannot carry through treatment and come into contact with the negatively charged membrane surface. This interaction may lead to immediate and irreversible fouling of the membranes.

Filtration testing with SuperP water will be investigated using multiple media configurations, prefiltration chloramine dosages, filtration pHs, and different filter loading rates. Maximizing filter bed performance while maintaining adequate particles, turbidity, and headloss will be the goal of filtration testing.

Management of the pretreatment sludge and membrane concentrate will also be evaluated during the remainder of the study. For the pretreatments, sludge production rates, sludge solids concentrations, and sludge quality will be evaluated and compared. Further, membrane concentrate water quality will be further evaluated.

Single element testing will be conducted for 1000 hours to collect membrane design data with respect to cleaning frequency, membrane fouling, and membrane water quality. Data from the 1000 hours of testing will be used to determine the rankings of the 4 membranes. The top-ranked membrane will be used in the high recovery for Phase 2 long term testing.

Due to the monochloramine degradation experienced during Phase 1A, a goal of treatment will be reducing the chloramine dosage to prevent membrane degradation while controlling biological fouling.

## Approach

Phase 1B testing will be conducted from March 2002 to mid-June 2002. Phase 1B will include testing the Zenon system, the SuperP with dual media filtration, and the single element membranes.

### Task 1—Zenon Setup, Optimization and Operation

Prior to Phase 1B operations, the Zenon unit was optimized for coagulation pH, coagulant dose, and flux. This process was conducted by UCF under the direction of CH2M HILL and Zenon. Optimization was conducted in order to reach the optimum operating point to be used for the Phase 1B membrane testing. The following operational conditions will be used during Phase 1B:

- Coagulation pH of 5.6 based on a maximum soluble iron concentration of 0.05 mg/L
- Coagulation dosage of 300 mg/L (ferric sulfate as product) based on $UV_{254}$ removal
- Flux of 25 gfd based on a cleaning interval of four to six weeks
- Recovery of 90%

Coagulant dose may be modified in Phase 1B during the expected seasonal decline in organic concentrations.

Chemical usage will be monitored for Zenon for ferric sulfate and caustic soda.

Appendix A.1 contains the Zenon sampling log sheets for operation. Further, process log sheets for Zenon are contained in Appendix A.2. The listed parameters will be collected daily.

### Task 2—SuperP Setup and Optimization

Clarification Optimization for Media Filtration Testing
During Phase 1B, the optimization testing will be conducted with the SuperP clarifier prior to filtration optimization. The Phase 1A coagulation pH of 4.6 and PAC dose of 20 mg/L will be used during the optimization. The optimum coagulant dosage will be determined by monitoring $UV_{254}$ removal.

Chemical usage will be monitored for SuperP for polymer, ferric sulfate, and caustic soda. Dosages will be verified by conducting titrations with ferric sulfate and caustic soda every two weeks.

A polymer minimization study will be conducted during the optimization process to determine the minimum polymer dose required to still achieve a cohesive sludge blanket.

Blowdown frequency will be evaluated to determine the recovery percentage which can be achieved by the SuperP process.

Appendix A.3 contains the SuperP grab sampling log tables to be used for clarifier operation. The listed parameters will be collected daily.

Filtration Optimization and Operation for Membrane Testing
Before feeding the single element membranes, the filterability of the SuperP clarified water will be evaluated. The filterability of the clarified water will be evaluated based on the following filtration guidelines for the study:

| Parameter | Ultimate Performance Goal | Acceptable Performance Levels |
|---|---|---|
| Turbidity | < 0.1 ntu | 0.3 ntu |
| Particles | < 20/ml | 30/ml |
| Filter Loading | 4 gpm/ft$^2$ | 4 gpm/ft$^2$ |
| Filter Run Time | 50 hrs | 30 hrs |
| Unit Filter Run Volume | 12,000 gal/ft$^2$ | 7,200 gal/ft$^2$ |
| Silt Density Index | < 3.0 | 5.0 |

The above guidelines summarize the target range for each of the filtration parameters. These target ranges had to be met in Phase 1A to demonstrate that each of the processes can produce portable water quality from the filters without membrane treatment. This was necessary since during the rainy seasons, the raw water is fresh and does not need membrane treatment for TDS removal. As the salt levels increase in the dry season requiring membrane treatment, the ionic strength of the water will increase. High levels of ionic strength can interfere with coagulation. If the filtered water particles exceed the range specified above, it will not be a fatal flaw since these particles will be removed by the membranes.

Chemical usage will be monitored for the following unit processes: coagulant for SuperP, caustic soda for filtration, and ammonia and chloramine usage for filtration. Dosages will be verified by conducting titrations of the clarified water to the required pH using caustic soda, chlorine, and ammonia.

Appendix A.4 contains the SuperP grab sampling log tables for filtered water quality. The listed parameters will be collected daily.

**Task 3—SuperP Filtration Testing**

Pilot Scale Filter Optimization Study
Using the pilot filters in the CH2M HILL pilot trailer, a filterability study will be conducted which will evaluate the following parameters:

- Filter loading rates
- Filtration pHs
- Pre-filtration chloramine dosages

SuperP was able to achieve low rates of headloss with low levels of filtered turbidity and particles during Phase 1A. The filter loading rate of 4 gpm/$ft^2$ was used in Phase 1A with 42-in of anthracite.

Higher filter loading rates will be evaluated in Phase 1B. A filter loading rate of 4 gpm/$ft^2$ was used for the duration of Phase 1A. Filter loading rates of 6 gpm/$ft^2$, 8 gpm/$ft^2$, and 10 gpm/$ft^2$ will be tested in parallel to the baseline filter loading rate of 4 gpm/$ft^2$ for comparisons of particle counts, turbidity, and headloss.

To evaluate the optimum filtration pH for iron minimization and pH optimization experiments will be conducted at pH's of 6.0, 6.5, 7.0 and 7.5.

During Phase 1A, chloramines were found to have a positive effect on filter run duration based on particle removal and headloss rates. The effect of chloramine dosage on filtration will be evaluated at dosages of 0.0 mg/L as $Cl_2$, 1.0 mg/L as $Cl_2$, and 2.0 mg/L as $Cl_2$. Optimum chloramine dosages will be based on filter run duration with respect to headloss, particle counts, and turbidity.

Filtration data will be collected and input into the filtration log in Appendix A.4.

**Task 4—Sludge Production Characterization**

Sludge production rates will be monitored every other week during treatment. Sludge production rates will be based on percent recovery for each process as well as the solids percentage of samples.

Samples of the SuperP blow-downs will be taken every other week and analyzed for solids concentration and supernate water quality. Lab analyses will be conducted on the sludge by UCF once during this phase to determine the metals content of the sludge.

Samples of the concentrate from the Zenon unit will be taken every other week and analyzed for solids concentration and supernate water quality. Lab analyses will be conducted on the sludge once during this phase to determine the metals content of the sludge by UCF.

**Task 5—Single Element Membrane Testing**

Once pretreatment optimization is completed, reverse osmosis membrane testing will begin. For Phase 1B, single element testing will be conducted for 1000 hours of membrane run time.

The two pretreatments will each feed the four single element membranes selected for this study which include:

- Osmonics SG Brackish Water Membrane
- Filmtec BW30FR Membrane
- Trisep X-20 Membrane
- Hydronautics Low Fouling Composite (LFC) Membrane

Cartridge filter replacement will be monitored for each of the pretreatment to determine the replacement frequency for the pretreatment processes. Cartridge filters will be replaced based on manufacturers recommendations of differential pressure.

Appendix A.5 and A.6 contain the four membrane log sheets for SuperP and Zenon. Each pretreatment has a membrane log sheet for each membrane element being tested. The log sheets will be completed once per day with flow and pressure measurements being taken two to three more times throughout the day.

Adjustments to the membranes to maintain the required flux and recovery will be made by CH2M HILL as necessary.

Membrane performance will be evaluated based on productivity, feed pressure increase, and cleaning frequency.

**Task 6—Membrane Ranking**

The membranes will be ranked by comparing performance data between the four single element membranes for each pretreatment system during Phase 1B.

Once the membranes have been ranked based on performance, the top ranked membrane will be selected to be tested in the high recovery unit during Phase 2.

Membrane selection must be made several weeks in advance of Phase 2A due to the long lead times encountered in ordering reverse osmosis membrane elements.  Therefore, the analysis of the membrane data will begin after 600 hours of operation.

## Equipment Configuration

**Raw Water**

Raw water supply to the pretreatments will be dosed with chloramines at a 3:1 ratio of chlorine to ammonia and at a dosage that will achieve a total chlorine concentration of 0.5 to 1.0 mg/L as $Cl_2$ with a maximum concentration of 2.0 mg/L as $Cl_2$.

**Zenon**

The Zenon pilot unit will be operated at a coagulation pH of 5.6, a coagulant dosage of 300 mg/L ferric sulfate (as product), a flux of 25 gfd, and a recovery of 90%.

During reverse osmosis membrane treatment, a caustic soda chemical feed pump will need to be installed on the permeate stream of the Zenon unit to increase pH to 7.0 prior to reaching the break tank.  Adjustment of pH after filtration is necessary on the Zenon unit because under these operational parameters, the permeate pH is approximately 6.0.

**SuperP/Media Filtration**

SuperP will be operated at a coagulant pH of 4.6 and a PAC dosage of 20 mg/L.  The optimum coagulant dosage will be determined during the clarifier testing mentioned previously. Based on natural organic matter concentrations in the raw water, coagulant dosages may be reduced or increased during Phase 1B.

Due to the variable water quality of Lake Monroe, alkalinity concentrations are expected to vary. Depending on raw water alkalinity levels and coagulant dosages, pH adjustment may need to be performed using sulfuric acid rather than caustic soda. Therefore, an additional feed system may be used for feeding sulfuric acid on the SuperP pilot unit.

Because the SuperP utilizes PAC, adsorption of chloramines in the sludge blanket will decrease chloramine concentrations to below the required 0.5 mg/L as $Cl_2$ for the membranes. Therefore, a booster chloramine dosing system will be installed on the SuperP clarified water to increase the chloramine concentration to 0.5 to 1.0 mg/L as $Cl_2$ with a maximum concentration of 2.0 mg/L as $Cl_2$.

The pressure filter in the pilot building which supplies filtered water to the membranes will be operated at a filter loading rate of 4 gpm/ft$^2$, a pH of 6.5 to 7.0, and will be backwashed every 36 hours.

**Single Element Membranes**

As with Phase 1A, all single element membranes will be operated at a constant flux of 12 gfd and a constant recovery of 70%. Based on the given flux and recovery and the membrane element surface areas, system flows will be as follows:

| Membrane Element | Element Area ($ft^3$) | Flux (gfd) | System Recovery (%) | Feed Flow (gpm) | Permeate Flow (gpm) | Concentrate Flow (gpm) | Recycle Flow (gpm) |
|---|---|---|---|---|---|---|---|
| TriSep X-20 | 81 | 12 | 70 | 0.96 | 0.68 | 0.289 | 4.23 |
| Osmonics SG | 90 | 12 | 70 | 1.07 | 0.75 | 0.321 | 4.70 |
| Hydranautics LFC-1 | 85 | 12 | 70 | 1.01 | 0.71 | 0.304 | 4.44 |
| FilmTec BW 30FR | 82 | 12 | 70 | 0.98 | 0.68 | 0.293 | 4.28 |

In order to further evaluate membrane degradation due to chloramines observed during Phase 1A, as mentioned earlier, the raw water chloramine dosage will be reduced to a total chlorine concentration of 0.5 to 1.0 mg/L as $Cl_2$ prior to membrane treatment with a maximum concentration of 2.0 mg/L as $Cl_2$.

Further, a finished/filtered water pH of 7.0 will be maintained to help prevent chloramine compounds from disassociating to free chlorine at the membrane surface.

To prevent scaling/inorganic fouling, the feed stream will be dosed with 2.7 mg/L Hypersperse MDC 700 antiscalant.

**Anticipated Results and Deliverables**

From the data collected, figures and tables will be developed to illustrate pretreatment and membrane performance.

Raw water quality parameters will be graphed relative to time and summarized in tables showing averages, maximums, minimums, standard deviations, and coefficients of variances.

To summarize SuperP and Zenon filtration runs, filtration graphs will be prepared with water quality summary tables that include average particles and turbidity. Summaries for SuperP will include run duration and UFRV. Figures illustrating membrane pressures for Zenon will also be included. Time trend graphs and summary tables will also be prepared for grab samples data and UCF lab data.

For the SuperP filtration optimization, filter performance data between the different filtration loading rates will be included on the same graph. Trends in turbidity, particle counts, and UFRV can be compared between the different conditions.

For membrane ranking, time trend graphs will be prepared illustrating pressure, mass transfer coefficient, salt passage, and organic passage. Selection of the lead element for Phase 2 will be done using these data.

**Schedule**

Phase 1B testing will be conducted from April 2002 until June 2002. The following table contains the schedule of tasks to be completed during Phase 1B:

| Description | Start | Finish |
|---|---|---|
| Task 1 - Zenon Setup, Operation, and Optimization | 04/01/2002 | 06/11/2002 |
| Task 2 – SuperP Setup and Optimization | 04/15/2002 | 04/01/2002 |
| Task 3 – SuperP Filtration Testing | 05/01/2002 | 06/11/2002 |

| Description | Start | Finish |
|---|---|---|
| Task 4 – Sludge Production Testing | 05/22/2002 | 06/11/2002 |
| Task 5 – Single Element Membrane Testing | 05/22/2002 | 06/11/2002 |
| Task 6 – Lead Element Membrane Selection | | 05/21/2002 |

It is anticipated that all Phase 1B testing will be completed by June 11, 2002. Due to the long lead time for membrane ordering and production, membrane selection will need to be completed by May 21, 2002.

# PHASE 2A

During Phase 2A, testing with the high recovery unit will be conducted using the SuperP clarifier followed by media filtration. The top ranked membrane from Phase 1B will be used in the high recovery unit. The other three membranes will be evaluated in parallel with the top ranked membrane using low recovery units.

**Goals**

The Zenon unit will continue operation the same as in Phase 1B. This will allow additional run time on the 4 single elements to further assess membrane productivity and performance. It is anticipated that the total membrane run time will exceed 2000 hours.

Optimization of the SuperP may again be necessary depending on raw water quality. The unit will be optimized to determine the appropriate coagulation pH, coagulation dosage, and polymer dosage for treatment.

Filtration testing with the SuperP will be investigated using GAC in place of anthracite. The GAC will be tested without chloramines and will be evaluated in parallel with anthracite. Prefiltration chloramine dosages, filtration pHs, and different filter loading rates will be evaluated. Maximizing filter bed performance while maintaining adequate particles, turbidity, and headloss will be the goal of filtration testing.

Further chemical dosage information will be collected to determine expected maximum and minimum required dosages for treatment.

Pretreatment sludge and membrane concentrate will again be monitored.

Membrane testing during Phase 2A will consist of 1500 hours of run time using the high recovery unit. Membrane design data with respect to cleaning frequency, membrane fouling, and membrane water quality will be collected on the high recovery unit

Non-fouling resistant reverse osmosis membranes are often less expensive and require lower feed pressures when compared to fouling resistant membranes. All of the 4 membranes selected in this study are non-fouling composite membranes. During Phase 2A using one of the single element skids, a non-fouling resistant membrane element will be evaluated to again investigate if a low fouling membrane can perform adequately for this water. Performance data will be compared to the other membrane elements.

## Approach

### Task 1—SuperP/Media Filtration Operation

Unless reoptimization of coagulant dosage or coagulation pH is necessary, the SuperP pilot unit will be operated under the same coagulation pH, and blow-down schedule as that used during Phase 1B.

Adjustment of the clarified water pH to 6.5 to 7.0 following filtration will still be conducted.

Sludge production will again be monitored every other week during treatment with respect to recovery percentage, solids concentration and supernate water quality. Lab analyses will be conducted on the sludge once during this phase to characterize the sludge.

Appendix A.3 contains the SuperP grab sampling log tables to be used for clarifier operation. The listed parameters will be collected daily.

Appendix A.4 contains the SuperP grab sampling log tables for filtered water quality. The listed parameters will be collected daily.

**Task 2—Zenon Microfilter Operation**

Unless reoptimization of coagulant dosage or flux is necessary, the Zenon pilot unit will be operated under the same flux, coagulation pH, and recovery as that used during Phase 1B.

Appendix A.1 contains the Zenon sampling log sheets for operation. Further, process log sheets developed by Zenon are contained in Appendix A.2. The listed parameters will be collected daily.

**Task 3—SuperP/Media Filtration Study**

A filtration study similar to Phase 1B will be conducted during Phase 2A. However, instead of using anthracite/sand filters, GAC/sand filters will be used.

Pilot Scale Filter Optimization Study
Using the pilot filters in the CH2M HILL pilot trailer, a comprehensive filterability study will be conducted which will evaluate the following parameters:

- Media types
- Filter loading rates
- Filtration pHs
- Pre-filtration chloramine dosages
- Different media configurations will be investigated to characterize the performance of GAC with respect to particle counts, turbidity, and headloss. Further, UV254, color, and NPDOC removal will be evaluated.

Higher filter loading rates will be evaluated. Filter loading rates of 6 gpm/ft$^2$, 8 gpm/ft$^2$ and 10 gpm/ft$^2$ will be evaluated based on particle counts, turbidity, and headloss.

To evaluate the optimum filtration pH for iron minimization and pH optimization experiments will be conducted at pH's of 6.0, 6.5, 7.0 and 7.5.

The effect of chloramine dosage on filtration will be evaluated at dosages of 0.0 mg/L as $Cl_2$, 1.0 mg/L as $Cl_2$, and 2.0 mg/L as $Cl_2$. Optimum chloramine dosages will be based on filter run duration with respect to headloss, particle counts, and turbidity.

**Task 4—Single Element Membrane Testing**

The single element testing during Phase 1B with the Zenon pretreatment will continue during Phase 2A to collect 1500 hours of additional data. This will result in a total of 2500 hours run time for the single element membranes. This additional run time will result in further insight into membrane performance over time. More information on membrane fouling, cleaning intervals, feed pressure changes, and productivity will be collected.

During Phase 2A, the single element membranes will continue to be operated under the same conditions as Phase 1B:

- Flux of 12 gfd
- Recovery of 70%
- 2.7 mg/L dosage of Hypersperse MDC 700 antiscalant
- 0.5 to 1.0 mg/L as $Cl_2$ chloramine concentration in feed water
- pH of 6.5 to 7.0

During testing, the 5μm cartridge filter on the membrane skid will be replaced based on the manufacturer recommended maximum differential pressure.

The membrane data sheets utilized in Phase 1B (Appendix A.5 and A.6) will continue to be used for Phase 2A membrane testing.

**Task 5—High Recovery Membrane Testing**

Using the top ranked membrane selected during Phase 1B, 1500 hours of high recovery testing data will be collected.

During Phase 2A, the high recovery membrane system will be operated under the same testing conditions for this study:

- Flux of 12 gfd
- Recovery of 70%
- 2.7 mg/L dosage of Hypersperse MDC 700 antiscalant
- 0.5 to 1.0 mg/L as $Cl_2$ chloramine concentration in feed water
- pH of 6.5 to 7.0

Replacement of the 5μm cartridge filters on the membrane skid will be evaluated and replaced per manufacturer requirements.

### Task 6—Evaluation of Non-Fouling Resistant Membrane

Non-fouling resistant membranes require less feed pressure than the fouling resistant membranes currently being evaluated. Therefore, a non-fouling resistant membrane will be evaluated during Phase 2A to evaluate this option. This membrane is being evaluated since it is considered as a low-energy membrane and will be compared to the higher pressure low-fouling membrane.

During Phase 2A, the membrane will be operated under the same conditions as the other single element membranes. The membrane conditions are as follows:

- Flux of 12 gfd
- Recovery of 70%
- 2.7 mg/L dosage of Hypersperse MDC 700 antiscalant
- 0.5 to 1.0 mg/L as $Cl_2$ chloramine concentration in feed water
- pH of 6.5 to 7.0

During testing, the 5µm cartridge filter on the membrane skid will be replaced based on manufacturer requirements.

## Equipment Configuration

### Raw Water

Raw water supply to the pretreatments will be dosed with chloramines at a 3:1 ratio of chlorine to ammonia and at a dosage that will achieve a Zenon permeate total chlorine concentration of 0.5 to 1.0 mg/L as $Cl_2$ with a maximum concentration of 2.0 mg/L as $Cl_2$.

### Zenon

The Zenon pilot unit will be operated at a coagulation pH of 5.6, a coagulant dosage of 300 mg/L ferric sulfate (as product), a flux of 25 gfd, and a recovery of 90%.

Membrane treatment will require a caustic soda chemical feed pump on the permeate stream of the Zenon unit to increase pH to 7.0 prior to reaching the break tank. Adjustment of pH after filtration is necessary on the Zenon unit because under the given dosing parameters, the permeate pH is approximately 6.0.

**SuperP/Media Filtration**

SuperP will be operated at a coagulation pH of 4.6 and a PAC dosage of 20 mg/L. The optimum coagulant dosage will be determined during the clarifier optimization mentioned previously. Based on natural organic matter concentrations in the raw water, coagulant dosages may be reduced or increased during Phase 2A.

Due to the variable water quality of Lake Monroe, alkalinity concentrations are expected to vary. Depending on raw water alkalinity levels and coagulant dosages, pH adjustment may need to be performed using sulfuric acid rather than caustic soda. Therefore, an additional feed system may be used for feeding sulfuric acid on the SuperP pilot unit.

Because the SuperP utilizes PAC, adsorption of chloramines in the sludge blanket will decrease chloramine concentrations to below the required 0.5 mg/L as $Cl_2$ for the membranes. Therefore, a booster chloramine dosing system will be installed on the SuperP clarified water to increase the chloramine concentration to 0.5 to 1.0 mg/L as $Cl_2$ with a maximum concentration of 2.0 mg/L as $Cl_2$.

The pressure filter in the pilot building which supplies the filtered water to the membranes will be operated at a filter loading rate of 4 gpm/ft$^2$, a pH of 6.5 to 7.0, and will be backwashed every 36 hours.

**Single Element Membranes**

As with Phase 1A and 1B all single element membranes will be operated at a constant flux of 12 gfd and a constant recovery of 70%. Based on the given flux and recovery restraints and the membrane element surface areas, system flows will be as listed as follows:

| Membrane Element | Element Area (ft$^3$) | Flux (gfd) | System Recovery (%) | Feed Flow (gpm) | Permeate Flow (gpm) | Concentrate Flow (gpm) | Recycle Flow (gpm) |
|---|---|---|---|---|---|---|---|
| TriSep X-20 | 81 | 12 | 70 | 0.96 | 0.68 | 0.289 | 4.23 |
| Osmonics SG | 90 | 12 | 70 | 1.07 | 0.75 | 0.321 | 4.70 |
| Hydranautics LFC-1 | 85 | 12 | 70 | 1.01 | 0.71 | 0.304 | 4.44 |
| FilmTec BW 30FR | 82 | 12 | 70 | 0.98 | 0.68 | 0.293 | 4.28 |

The raw water chloramine dosage will be 0.5 to 1.0 mg/L as $Cl_2$ prior to membrane treatment with a maximum concentration of 2.0 mg/L as $Cl_2$. Further, a finished/filtered water pH of 6.5 to 7.0 will be maintained to help prevent chloramine compounds from disassociating to free chlorine at the membrane surface.

To prevent scaling/inorganic fouling, the feed stream will be dosed with 2.7 mg/L Hypersperse MDC 700 antiscalant.

**High Recovery Membrane System**

The SuperP and dual media filter will be used to supply pretreated water to the high recovery membrane system. A pressure booster pump will be used after the SuperP break tank to supply the high recovery membrane system.

The high recovery membrane system will be evaluated in a 2-2-1-1 membrane array setup. The system will be operated at a flux of 12 gfd and a recovery of 70%. Raw water chloramine dosage will be of 0.5 to 1.0 mg/L as $Cl_2$ with a maximum concentration of 2.0 mg/L as $Cl_2$. Filtered water from the SuperP dual media filter will be at a pH of 6.5 to 7.0.

To prevent scaling/inorganic fouling, the feed stream will be dosed with 2.7 mg/L Hypersperse MDC 700 antiscalant.

## Anticipated Results and Deliverables

From the data collected, figures and tables will be developed to illustrate pretreatment and membrane performance.

Raw water quality parameters will be graphed relative to time and summarized in tables showing averages, maximums, minimums, standard deviations, and coefficients of variances.

To summarize SuperP and Zenon filterability, particle count and turbidity figures will be prepared with summary tables that include average particles and turbidity. Summaries for SuperP will include run duration and UFRV. Figures illustrating membrane pressures for Zenon will also be included. Time trend graphs and summary tables will also be prepared for grab samples data and UCF lab data.

For the SuperP filtration testing using GAC, filtered water quality for both GAC and anthracite will be summarized on the same graph. Trends in turbidity, particle counts, and UFRV will be compared between the different types of media.

Using data from the high recovery membrane unit, figures will be prepared illustrating pressure, mass transfer coefficient, salt passage, and organic passage over time. These parameters will be evaluated for the first and second stage of the skid.

Comparisons of the non-fouling resistant membrane will be made to the fouling resistant membranes.

Additional operational data will be collected for the single element skids. Figures will be prepared illustrating pressure, mass transfer coefficient, salt passage, and organic passage.

**Schedule**

Phase 2A testing will be conducted from June 2002 until August 2002. The following table contains the schedule of tasks to be completed during Phase 2A:

| Description | Start | Finish |
|---|---|---|
| Task 1 – SuperP/Media Filtration Operation | 06/11/2002 | 08/12/2002 |
| Task 2 – Zenon Microfilter Operation | 06/11/2002 | 08/12/2002 |
| Task 3 – SuperP/Media Filtration Study | 06/11/2002 | 08/12/2002 |
| Task 4 – Single Element Membrane Testing | 06/11/2002 | 08/12/2002 |
| Task 5 – High Recovery Membrane Testing | 06/11/2002 | 08/12/2002 |
| Task 6 – Evaluation of Non-Fouling Resistant Membrane | 06/11/2002 | 08/12/2002 |

Phase 2A testing will begin immediately following Phase 1B testing and will be conducted for 1500 hours of membrane run time. It is anticipated that all Phase 2A testing will be completed by August 12, 2002.

# PHASE 2B

During Phase 2B, an additional 1500 hours of membrane testing with the high recovery and low recovery membranes will be conducted using the Actiflo process. The membranes used during Phase 2A will be replaced with new elements during this phase, including the 4 membranes for the high recovery unit and the non-fouling resistant composite membrane for the single element skid.

The Zenon elements will be removed and replaced with new elements for algal toxin testing discussed in the *AWWARF Algal Toxin Treatability Study* section.

## Goals

The goal of Phase 2B is to collect 1,500 hours of high recovery membrane data using the Actiflo process for pretreatment. This will provide membrane design data for an Actiflo system as Phase 2A did for the SuperP system.

The non-fouling resistant membrane will also continue to be tested for an additional 1500 hours for further comparison to non-fouling membranes.

## Approach

### Task 1—Actiflo Setup and Optimization

The coagulation pH for this phase of testing will be the same as that used during Phase 1A. The coagulation pH will be 4.2. The optimum coagulant dosage will be determined during optimization of the Actiflo pilot unit and will remain at that coagulant dosage for the duration of Phase 2B unless a significant change in the organic concentration warrants a change in dose. The optimum coagulant dose will be determined based on UV254 removal.

A polymer minimization study will be conducted during the optimization process to determine the minimum polymer dose required to still achieve a clarified water quality that allows the filtered water quality goals described below to be met.

Sludge production will be monitored every other week during treatment for recovery percentage, solids concentration and supernate water quality. Lab analyses will be conducted on the sludge once during this phase to determine the metals content of the sludge.

### Task 2—Actiflo/Media Filtration Testing

Filtration Optimization and Operation for Membrane Testing
Before feeding the single element membranes, the filterability of the Actiflo clarified water will be evaluated. The filterability of

the clarified water will again be evaluated based on the following filtration guidelines for the study:

| Parameter | Ultimate Performance Goal | Acceptable Performance Levels |
|---|---|---|
| Turbidity | < 0.1 ntu | 0.3 ntu |
| Particles | < 20/ml | 30/ml |
| Filter Loading | 4 gpm/ft$^2$ | 4 gpm/ft$^2$ |
| Filter Run Time | 50 hrs | 30 hrs |
| Unit Filter Run Volume | 12,000 gal/ft$^2$ | 7,200 gal/ft$^2$ |

The above guidelines summarize the target range for each of the filtration parameters. These target ranges had to be met in Phase 1A to demonstrate that each of the processes can produce water quality from the filters without membrane treatment. This was necessary because during the rainy seasons, the raw water is fresh and does not need membrane treatment. As the salt levels increase in the dry season, requiring membrane treatment, the ionic strength of the water will increase. High levels of ionic strength can interfere with coagulation. If the filtered water particles exceed the range specified above, it will not be a fatal flaw since the particles will be removed by the membranes.

After the initial filterability study, the pressure filters which supply the membranes will be operated at a filter loading rate of 4 gpm/ft$^2$, a pH of 7.0, and will be backwashed every 36 hours.

Pilot Scale Filter Optimization Study
Using the pilot filters in the CH2M HILL pilot trailer, a filterability study will be conducted on the Actiflo filters which will evaluate the following parameters:

- Filter loading rates
- Filtration pHs
- Pre-filtration chloramine dosages

Higher filter loading rates will be evaluated in Phase 2B. A filter loading rate of 4 gpm/ft$^2$ and 42-in of anthracite was used for Phase 1A. Filter loading rates of 6 gpm/ft$^2$, 8 gpm/ft$^2$ , and 10 gpm/ft$^2$ will be tested in parallel to the baseline filter loading rate of 4 gpm/ft$^2$ for comparisons of particle counts, turbidity, and headloss.

To evaluate the optimum filtration pH for iron minimization, experiments will be conducted at pH's of 6.0, 6.5, 7.0 and 7.5.

During Phase 1A, chloramines were found to have a positive effect on filter run duration based on particle removal and headloss rates. Actiflo was unable to achieve low rates of headloss and particles during Phase 1A when chloramines were not dosed to the raw water. Because chloramine concentrations will be substantially lower than those used during Phase 1A, the effect of chloramine concentration on filter performance must be evaluated using Actiflo pretreated water to determine if Actiflo can produce a filterable water under the lower chloramine concentrations. Therefore, the effect of chloramine dosage on filtration will be evaluated at dosages of 0.0 mg/L as $Cl_2$, 1.0 mg/L as $Cl_2$, 2.0 mg/L as $Cl_2$, 3.0 mg/L as $Cl_2$, and 4.0 mg/L as $Cl_2$. Optimum chloramine dosages will be based on filter run duration with respect to headloss, particle counts, and turbidity.

**Task 3—Actiflo/Zenon Microfiltration Testing**

During Phase 2B, testing may be conducted using the Actiflo clarifier followed by the Zenon pilot unit. Water will be treated by the Actiflo pilot unit with filtration being performed by the Zenon pilot unit.

pH Optimization

In order to determine the optimum pH for filtration with the Zenon unit, a pH optimization will be conducted to determine the optimum coagulation pH for minimizing soluble iron, turbidity, and particle counts.

The pH optimization will be conducted at the optimum coagulant dosage to be determined during clarification optimization. The flux will be held constant at 20 gfd with a recovery of 90%. The following filtration pHs will be tested: 6.0, 6.5, 7.0, and 7.5.

Flux Optimization

The flux optimization will determine the highest flux which will allow a cleaning frequency from 4 to 6 weeks. Because the clarified water from Actiflo during Phase 1A was generally a high quality water with a low turbidity. It is expected that the Zenon flux can be much higher when treating water that has already been clarified.

Therefore, the following fluxes will be evaluated: 35 gfd, 40 gfd, 45 gfd, and 50 gfd. These fluxes will each be tested for approximately four (4) days each. Higher fluxes may be evaluated based on the cleaning frequencies achieved during testing.

Recovery Optimization
A recovery optimization will be conducted at a recovery of 90%, 95%, and 97%.

**Task 4—Single Element Membrane Testing**

The same elements that were tested during Phase 1B and 2A may be used during Phase 2B so that an additional 1500 hours of run data can be collected. This will result in over 4000 hours of total run time for the single element membranes. This additional run time will result in further insight into membrane performance over time. More information on membrane fouling, cleaning intervals, feed pressure changes, and productivity will be collected.

During Phase 2B, the single element membranes will continue to be operated under the same conditions as Phase 2A as follows:

- Flux of 12 gfd
- Recovery of 70%
- 2.7 mg/L dosage of Hypersperse MDC 700 antiscalant
- 0.5 to 1.0 mg/L as $Cl_2$ chloramine concentration in feed water
- pH of 6.5 to 7.0

**Task 5—High Recovery Membrane Testing**

Using the lead element selected during Phase 1B, 1500 hours of high recovery testing data will be collected using Actiflo followed by dual media filters as a pretreatment.

During Phase 2B, the high recovery membrane system will be operated under the same conditions as Phase 2A:

- Flux of 12 gfd
- Recovery of 70%
- 2.7 mg/L dosage of Hypersperse MDC 700 antiscalant
- 0.5 to 1.0 mg/L as $Cl_2$ chloramine concentration in feed water
- pH of 6.5 to 7.0

Replacement of the 5µm cartridge filters on the membrane skid will be evaluated and replaced per manufacturer specifications.

The same elements that were tested during Phase 2A may be used during Phase 2B so that an additional 1500 hours of run time can be obtained. This will result in a total of 3000 hours of total run time for the membranes. This additional run time will provide additional data on membrane performance. More information on membrane fouling, cleaning intervals, feed pressure changes, and productivity will be obtained.

### Task 6—Evaluation of Non-Fouling Resistant Membrane

During Phase 2B, the non-fouling resistant membrane will be operated as well under the same conditions as the other single element membranes. The membrane conditions are as follows:

- Flux of 12 gfd
- Recovery of 70%
- 2.7 mg/L dosage of Hypersperse MDC 700 antiscalant
- 0.5 to 1.0 mg/L as $Cl_2$ chloramine concentration in feed water
- pH of 6.5 to 7.0

During testing, the 5µm cartridge filter on the membrane skid will be replaced based on the manufacturer's recommendations.

## Equipment Configuration

### Raw Water

Raw water supply to the pretreatments will be dosed with chloramines at a 3:1 ratio of chlorine to ammonia and at a dosage that will achieve a Actiflo filtered total chlorine concentration of 0.5 to 1.0 mg/L as $Cl_2$ with a maximum concentration of 2.0 mg/L as $Cl_2$.

### Actiflo/Media Filtration

Actiflo will be operated at a coagulation pH of 4.2. The optimum coagulant dosage will be determined during the clarifier optimization described previously. Based on natural organic matter concentrations in the raw water, coagulant dosages may be reduced or increased.

Due to the variable water quality of Lake Monroe, alkalinity concentrations are expected to vary. Depending on raw water alkalinity levels and coagulant dosages, pH adjustment may need to be performed using sulfuric acid rather than caustic soda. Therefore, an additional feed system may be used for feeding sulfuric acid on the Actiflo pilot unit.

The pressure filter in the pilot building which supplies the membranes will be operated at a filter loading rate of 4 gpm/ft$^2$, a pH of 6.5 to 7.0, and will be backwashed every 36 hours.

**Zenon**

The Zenon pilot unit may be operated as a filtration system for water clarified by Actiflo. Prior to filtration, the pH will be adjusted to a pH of 6.5. The unit will be operated at the optimum flux and recovery.

**Single Element Membranes**

All single element membranes will be operated at a constant flux of 12 gfd and a constant recovery of 70%. Based on the given flux and recovery, and the membrane element surface areas, system flows will be as listed in the following table:

| Membrane Element | Element Area ($ft^3$) | Flux (gfd) | System Recovery (%) | Feed Flow (gpm) | Permeate Flow (gpm) | Concentrate Flow (gpm) | Recycle Flow (gpm) |
|---|---|---|---|---|---|---|---|
| TriSep X-20 | 81 | 12 | 70 | 0.96 | 0.68 | 0.289 | 4.23 |
| Osmonics SG | 90 | 12 | 70 | 1.07 | 0.75 | 0.321 | 4.70 |
| Hydranautics LFC-1 | 85 | 12 | 70 | 1.01 | 0.71 | 0.304 | 4.44 |
| FilmTec BW 30FR | 82 | 12 | 70 | 0.98 | 0.68 | 0.293 | 4.28 |

The raw water chloramine dosage will be 0.5 to 1.0 mg/L as $Cl_2$ prior to membrane treatment with a maximum concentration of 2.0 mg/L as $Cl_2$. Further, a finished/filtered water pH of 6.5 to 7.0 will be maintained to help prevent chloramine compounds from reverting to free chlorine at the membrane surface.

To prevent scaling/inorganic fouling, the feed stream will be dosed with 2.7 mg/L Hypersperse MDC 700 antiscalant.

### High Recovery Membrane System

Treated water from the Actiflo/dual media filter system will be used to supply pretreated water to the high recovery membrane system. A pressure booster pump will be used after the Actiflo break tank to supply the pretreated water to the high recovery membrane system.

The high recovery membrane system will be evaluated in a 2-2-1-1 membrane array setup. The system will be operated at a flux of 12 gfd and a recovery of 70%. Raw water chloramine dosage will be of 0.5 to 1.0 mg/L as $Cl_2$ with a maximum concentration of 2.0 mg/L as $Cl_2$. Filtered water from the Actiflo/dual media filter will be at a pH of 6.5 to 7.0.

To prevent scaling/inorganic fouling, the feed stream will be dosed with 2.7 mg/L Hypersperse MDC 700 antiscalant.

## Anticipated Results and Deliverables

From the data collected, figures and tables will be developed to illustrate pretreatment and membrane performance.

Raw water quality parameters will be graphed relative to time and summarized in tables showing averages, maximums, minimums, standard deviations, and coefficients of variances.

To summarize Actiflo filterability with the media filters and the Zenon microfilter, particle count and turbidity figures will be prepared with summary tables that include average particles and turbidity. Summaries for Actiflo with media filtration will include run duration and UFRV. Figures illustrating membrane pressures for Zenon will also be included. Time trend graphs and summary tables will also be prepared for grab samples data and UCF lab data.

For the Actiflo filtration testing using GAC dual media filters, filtered water for both GAC and anthracite will be summarized on the same graph. Trends in turbidity, particle counts, and UFRV will be compared between the different types of media.

Using the data from the high recovery membrane unit, figures will be prepared illustrating pressure, mass transfer coefficient, salt passage, and organic passage over time. These parameters will be evaluated for the first and second stage of the skid.

Comparisons of non-fouling resistant membrane will be made to the fouling resistant membranes.

Additional operational data will be collected for the single element skids. Figures will be prepared illustrating pressure, mass transfer coefficient, salt passage, and organic passage.

### Schedule

Phase 2B testing will be conducted from August 2002 until November 2002. The following table contains the schedule of tasks to be completed during Phase 2B:

| Description | Start | Finish |
|---|---|---|
| Task 1 – Actiflo Setup and Optimization | 08/01/2002 | 08/22/2002 |
| Task 2 – Actiflo/Media Filtration Testing | 08/08/2002 | 11/05/2002 |
| Task 3 – Actiflo/Zenon Microfiltration Testing | 08/08/2002 | 09/01/2002 |
| Task 4 – Single Element Membrane Testing | 08/22/2002 | 11/05/2002 |
| Task 5 – High Recovery Membrane Testing | 08/22/2002 | 11/05/2002 |
| Task 6 – Evaluation of Non-Fouling Resistant Membrane | 08/22/2002 | 11/05/2002 |

Phase 2B testing will begin during the final weeks of Phase 2A testing. Testing will include Actiflo setup and optimization, filtration testing with both media filtration and Zenon microfiltration, 1500 hours of high recovery membrane evaluation. It is anticipated that all Phase 2B testing will be completed by November 5, 2002.

## PHASE 1B, 2A, & 2B SAMPLING PLAN

### Daily Samples

Samples will be collected and analyzed by UCF students or CH2M HILL staff at the site daily. Samples will be collected in order of treatment process to take into account process detention time. Therefore, raw water samples will be collected first at the site, followed by pretreated samples, then break-tank samples, and finally reverse osmosis samples--permeate and concentrate. Daily grab samples will be collected for both pretreatment processes.

## Lab Analyses

Lab samples will be collected per the sampling schedule summarized in Table 13. Sampling schedules for Phase 2A and 2B will not differ. Raw water will be sampled twice per week with at least two days between each sampling event. Samples to be collected once per week will be collected during a raw water sampling event. Further, there will be at least 6 days but not more than 8 days of separation between weekly sampling events.

Sample bottles for lab analyses will be prelabeled prior to arriving at the site and checked by CH2M HILL to ensure all sample bottles are present. Further, samples collected once per week will be collected in order by flow path, considering detention times, so reasonably accurate removals can be calculated for each unit process.

The results from sampling will be delivered to CH2M HILL within 10 days after sampling to ensure that possible issues with treatment can be corrected in a timely manner. Data needs to be transmitted both by standard mail and electronically in Excel spreadsheet format. CH2M HILL will keep a running master spreadsheet containing all of the data that will be updated every time data is transmitted by UCF. For standard mailing, data needs to be sent to the following address:

Attn: Matt Alvarez, P.E.
CH2M HILL
225 E. Robinson St.
Suite 505
Orlando, FL 32801-4321

Electronic copies in Excel spreadsheet format need to be submitted to the following email addresses:

Cjohns11@ch2m.com
Malvarez@ch2m.com

**TABLE 13. Phase 1B UCF Lab Analysis**

Duration (hours) 1000

Duration (days) 47

| | Raw Water | | SuperP | | | | Zenon | | Membrane Feed | | Low Recovery Membranes | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Clarified Water | | Filtered Water | | Filtered Water | | Break Tank | | Feed + Recycle | | Concentrate | | Permeate | | Ph. 1B | Ph. 2A | Ph. 2B | Total |
| **Analytes** | **Freq.** | **Quan.** | **Freq.** | **Quan.** | **Freq.** | **Quan.** | **Freq.** | **Quan.** | **Freq.** | **Quan.** | **Freq.** | **Quan.** | **Freq.** | **Quan.** | **Freq.** | **Quan.** | **Quan.** | **Quan.** | **Quan.** | **Quan.** |
| pH | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Alkalinity | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Conductivity | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Total Dissolved Solids | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| NPDOC | 2/wk | 13 | 1/wk | 6 | 1/wk | 6 | 1/wk | 6 | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 122 | 220 | 220 | 562 |
| UV254 | 2/wk | 13 | 1/wk | 6 | 1/wk | 6 | 1/wk | 6 | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 122 | 220 | 220 | 562 |
| Sodium | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Potassium | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Chloride | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Bromide | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Fluoride | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Calcium | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Magnesium | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Iron | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Aluminum | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Manganese | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Barium | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Strontium | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Arsenic | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Silica | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Sulfate | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Phosphate | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |
| Nitrate/Nitrite | 2/wk | 13 | | | | | | | 1/wk | 13 | 1/wk | 26 | 1/wk | 26 | 1/wk | 26 | 104 | 190 | 190 | 484 |

# ADDITIONAL TESTING AND SAMPLING

To gather additional water quality data, additional testing and sampling will be conducted during the pilot study. Testing will include two to three regulatory sampling events, disinfection testing, and raw water microbial characterization.

## REGULATORY SAMPLING

Regulatory sampling will be conducted to ensure that a surface water plant on this reach of the St. Johns River would be able to meet the existing regulatory requirements of the Environmental Protection Agency (EPA) and the Florida Department of Environmental Protection (FDEP).

### Goals

Regulatory sampling will determine if water from this reach of the St. Johns River would meet maximum contaminant levels (MCLs) for contaminants regulated by EPA and FDEP. Further, the ability of the treatment processes to remove the contaminants will be quantified.

### Approach

Regulatory sampling of raw, pretreated, and reverse osmosis membrane treated water will be conducted.

**Task 1—Raw, Pretreated, & RO Membrane Water Analysis**

Samples of raw water and treated water will be sent to the Corvallis Lab of CH2M HILL to be analyzed for contaminants regulated by EPA and FDEP.

Table 14 lists the contaminants that will be analyzed. This list of contaminants covers many existing regulations which include Phase 1 VOCs (1987), Phase II SOCs (1991), Phase II IOCs (1991), Phase V SOCs (1997), and Phase V IOCs (1992). Note that microbiological contaminants will be monitored as a part of the microbiological testing discussed later.

In addition to the contaminants listed in Table 14, contaminants regulated by the radionuclide rule will be tested as well. THM/HAA samples will be collected on the pre-chloraminated water before the membranes. Future analytes of concern will also be measured including Boron and NDMA.

# Table 14. Regulatory Sampling Contaminants List

| Inorganics | |
|---|---|
| **Contaminant** | **MCL** |
| Antimony | 0.006 mg/L |
| Arsenic | 0.05 mg/L |
| Asbestos | $7x10^6$ fibers/L |
| Barium | 2 mg/L |
| Beryllium | 0.004 mg/L |
| Cadmium | 0.005 mg/L |
| Chromium | 0.1 mg/L |
| Cyanide | 0.2 mg/L |
| Fluoride | 4.0 mg/L |
| Lead | 0.015 mg/L |
| Mercury | 0.002 mg/L |
| Nickel | 0.1 mg/L |
| Nitrate | 10 mg/L as N |
| Nitrite | 1 mg/L as N |
| Total Nitrate and Nitrite | 10 mg/L as N |
| Selenium | 0.05 mg/L |
| Sodium | 160 mg/L |
| Thallium | 0.002 mg/L |

| VOCs | |
|---|---|
| **Contaminant** | **MCL** |
| 1,1-Dichloroethylene | 0.007 mg/L |
| 1,1,1-Trichloroethane | 0.2 mg/L |
| 1,1,2-Tricholoroethane | 0.005 mg/L |
| 1,2-Dichloroethane | 0.003 mg/L |
| 1,2-Dichloropropane | 0.005 mg/L |
| 1,2,4-Trichlorobenzene | 0.07 mg/L |
| Benzene | 0.001 mg/L |
| Carbon tetrachloride | 0.003 mg/L |
| cis-1,2-Dichloroethylene | 0.07 mg/L |
| Dichloromethane | 0.005 mg/L |
| Ethylbenzene | 0.7 mg/L |
| Monochlorobenzene | 0.1 mg/L |
| 0-Dichlorobenzene | 0.6 mg/L |
| para-Dichlorobenzene | 0.075 mg/L |
| Styrene | 0.1 mg/L |
| Tetrachloroethylene | 0.003 mg/L |
| Toluene | 1 mg/L |
| trans-1,2-Dichloroethylene | 0.1 mg/L |
| Trichloroethylene | 0.003 mg/L |
| Vinyl chloride | 0.001 mg/L |
| Xylenes (total) | 10 mg/L |

| SOCs | |
|---|---|
| **Contaminant** | **MCL** |
| 2,3,7,8-TCDD (Dioxin) | $3 \times 10^{-8}$ mg/L |
| 2,4-D | 0.07 mg/L |
| 2,4,5-TP (Silvex) | 0.05 mg/L |
| Alachlor | 0.002 mg/L |
| Atrazine | 0.003 mg/L |
| Benzo(a)pyrene | 0.0002 mg/L |
| Carbofuran | 0.04 mg/L |
| Chlordane | 0.002 mg/L |
| Dalapon | 0.2 mg/L |
| Di(2-ethylhexyl)adipate | 0.4 mg/L |
| Di(2-ethylhexyl)phthalate | 0.006 mg/L |
| Dibromochloropropane (DBCP) | 0.0002 mg/L |
| Dinoseb | 0.007mg/L |
| Diquat | 0.02mg/L |
| Endothall | 0.1 mg/L |
| Endrin | 0.002 mg/L |
| Ethylene dibromide (EDB) | 0.00002 mg/L |
| Glyphosate | 0.7 mg/L |
| Heptachlor | 0.0004 mg/L |
| Heptachlor epoxide | 0.0002 mg/L |
| Hexachlorobenzene | 0.001 mg/L |
| Hexachlorocyclopentadiene | 0.05 mg/L |
| Lindane | 0.0002 mg/L |
| Methoxychlor | 0.04 mg/L |
| oxamyl (vydate) | 0.2 mg/L |
| Pentachlorophenol | 0.001 mg/L |
| Picloram | 0.5 mg/L |
| Polychlorinated byphenyl (PCB) | 0.0005 mg/L |
| Simazine | 0.004 mg/L |
| Toxaphene | 0.003 mg/L |

| Secondary Standards | |
|---|---|
| **Contaminant** | **MCL** |
| Aluminum | 0.2 mg/L |
| Chloride | 250 mg/L |
| Copper | 1 mg/L |
| Fluoride | 2.0 mg/L |
| Iron | 0.3 mg/L |
| Manganese | 0.05 mg/L |
| Silver | 0.1 mg/L |
| Sulfate | 250 mg/L |
| Zinc | 5 mg/L |
| Color | 15 pcu |
| Odor | 3 (TON) |
| pH | 6.5 - 8.5 |
| TDS | 500 mg/L |
| Foaming Agents | 0.5 mg/L |

### Anticipated Results and Deliverables

A table with the analytical results will be provided and will list concentrations for raw water, and treated water. The table will compare the concentrations to the regulatory MCL.

### Schedule

Two (2) to three (3) regulatory sampling events will be conducted during the remaining testing.

## DISINFECTION STUDY

During the remaining phases of the study, bench-top and pilot scale disinfection studies will be conducted using chlorine, chloramines, ozone, and ultraviolet (UV) disinfection.

### Goals

The disinfection study will be conducted to develop disinfectant dosage and design data. Further, disinfection by-product formation potentials will be evaluated. Design data will be developed for chlorine, chloramines, ozone, and UV.

Disinfection studies will be conducted using various blends of reverse osmosis permeate and pretreated water.

### Approach

#### Task 1—Free Chlorine Testing

Free chlorine will be evaluated as a primary and a residual disinfectant once during each of the remaining phases. THM and HAA formation potential testing will be completed at the Corvallis lab of CH2M HILL on treated water to study the THM/HAA formation potentials of various blends of RO permeate and pretreated water. These blends will be analyzed to identify the blend ratio to use free chlorine as the primary disinfectant, yet still meet primary and secondary water treatment standards.

Raw water samples will be characterized with respect to the following parameters:

- pH
- Alkalinity
- Turbidity
- NPDOC

- UV-254
- Color
- Bromide

When using chlorine as the primary disinfectant, contact times will be much lower, subsequently requiring a higher dose for the required CT. For chlorine as the primary disinfectant, the following conditions will be tested:

- Time*:* 1 min, 5 min, 10 min, 15 min, 30 min, 45 min, 60 min, and 2 hr
- pH: 8.5
- Chlorine Residual: will be based on desired CT values
- Temperature: 25° C

When free chlorine is used as the residual disinfectant, reaction dosages will be much lower and reaction times will be much higher due to the long detention time in the distribution system. For free chlorine as the residual disinfectant, the conditions will be as follows:

- Time*:* 1 min, 5 min, 10 min, 15 min, 30 min, 45 min, 60 min, 6 hr, 5 D
- pH: 8.5
- Chlorine Residual: 2.5 to 3.0 mg/L after 25 minutes
- Temperature: 25° C

THM and HAA analyses will be performed on each sample to determine THM/HAA formation potentials under the given conditions. The formation potentials will be measured at each time interval and compared to the existing and potential D/DBP Rules.

**Task 2—Raw Water Chloramine Testing**

Raw water chloramination is a concern due to the pH changes experienced during treatment. Upon dosing the chloramines to the raw water, the pH of the water changes to approximately 8.5. Under the given dose conditio\\\\\\\\\\\\\\ppns ($Cl_2$:$NH_3$ ratio of 3:1), the chloramine species will be primarily monochloramine. However, during clarification, the pH of the water is depressed to 4.5 for SuperP, 4.0 for Actiflo, and 5.6 for

Zenon. The depression of the pH, creates favorable conditions for the monochloramine to convert to dichloramine. Dichloramine is more unstable than monochloramine and will subsequently degrade much faster.

Tests will therefore be performed to determine the amount of degradation that occurs during clarification and to make recommendations regarding the point of chloramine addition.

Prior to chloramine addition, raw water samples will be characterized with respect to the following parameters:

- pH
- Alkalinity
- Turbidity
- UV-254
- Color

Raw water dosing conditions will be as follows:

- Total Chlorine Residual: 0.5 to 1.0 mg/L at the membranes after 8 hours
- Chlorine to Ammonia Ratios: 4:1
- Temperature: Ambient

Chloramine speciation tests for the SuperP pretreatment will be conducted to determine the concentration of total chlorine, monochloramine, dichloramine, and trichloramine at the following points in each process:

- Raw water at 1 min, 5 min, 10 min
- Clarified water prior to pH adjustment for filtration
- Filtered water
- Break-tank at 4 hours, 8 hours
- Membrane permeate and concentrate

Chloramine speciation tests for the Zenon pretreatment will be conducted to determine the concentration of total chlorine, monochloramine, dichloramine, and trichloramine at the following points in each process:

- Raw water at 1 min, 5 min, 10 min
- Filtered water prior to pH adjustment for break-tank storage
- Break-tank at 4 hours, 8 hours
- Membrane permeate and concentrate

If the determination is made that chloramine degradation is occurring, the point of chloramine addition for either or both processes may be moved such that the chloramines are dosed prior to filtration after pH addition for the SuperP process and dosed following pH adjustment prior to break-tank storage for the Zenon process.

**Task 3—Treated Water Chloramination**

Chloramine testing will be conducted at the Corvallis lab of CH2M HILL to evaluate the optimum chloramine ratio and dose for chloramination for residual disinfection prior to distribution. Optimum dosages will be based on chloramine decay and chloramine speciation. Also, raw water chloramine testing will be conducted at the CH2M HILL pilot trailer.

Water samples will be characterized with respect to the following parameters:

- pH
- Alkalinity
- Turbidity
- NPDOC
- UV-254
- Color

The test conditions will be as follows:

- pH: 8.5
- Total Chlorine Residual: 3.0 to 4.0 mg/L after 25 minutes
- Chlorine to Ammonia Ratios: 3:1, 4:1, 5:1
- Temperature: 25° C

THM and HAA analyses will be performed for each sample to determine THM/HAA formation potentials under the given conditions. The optimum chloramine to ammonia ratio will be selected based on chloramine degradation/stability and monochloramine concentration.

**Task 4—Pilot Scale Ozone Testing**

Ozone tests will be conducted using the pilot-scale ozone generator and contactor in the CH2M HILL pilot trailer. Water samples will be sent to the UCF lab for water quality analysis. Varying blends of RO permeate and pretreated water will be analyzed to identify the blend ratio that meets primary and secondary water treatment standards. Ozone testing will be conducted once during Phase 2A using water from SuperP/media filter and from the high recovery membrane skid. Ozone testing will be conducted twice during Phase 2B using water from the Actiflo/Zenon micro-filter pretreatment and the high recovery skid.

Water samples will be characterized with respect to the following parameters:

- pH
- Alkalinity
- Turbidity
- NPDOC
- UV-254
- Color
- Bromide

The ozone tests will be performed using water from the pretreatment process combined with water from the high recovery reverse osmosis system. Flow will be dosed with ozone, allowed to react with the water in the ozone contactor, and will flow into a reservoir with a mixing apparatus which will act as a continuously stirred tank reactor (CSTR). Ozone levels in the CSTR will be monitored and adjusted until the desired ozone level has been achieved. Once the desired level has been achieved, flow to the reservoir will stop and grab samples to measure ozone decay will be taken and then quenched with hydrogen peroxide for bromate analysis.

Bromate analyses will be performed during decay intervals to determine bromate formation potentials for different ozone residuals. From the water quality data collected, ozone demand/decay kinetics will be developed as well as bromide decay/bromate formation kinetics.

Previous studies on Florida surface water have identified that maximum bromide levels of 0.3 mg/L may not exceed the regulatory limit of 10 µg/L bromate. Bromate is the DBP formed by the reaction of ozone with bromide. Different levels of bromide will be tested to identify this target level. The following three blends of pretreated water and RO permeate will be tested for each pretreatment system:

- 100% RO permeate
- RO/Pretreated blend to achieve a bromide level of 0.15 mg/L
- RO/Pretreated blend to achieve a bromide level of 0.30 mg/L

**Task 5—Bench Scale Ozone Testing**

Verification ozone testing will be conducted at the CH2M HILL Corvallis lab using a bench top ozone testing setup. Testing will be conducted under the same treatment conditions as described for the pilot scale ozone system.

**Task 6—Ultraviolet Testing**

To determine the requirements for disinfecting a water with ultraviolet light, the transmittance of a water must be determined. During each phase, the absorbance of treated water samples will be measured at a wavelength of 254 nm.

Water samples will be characterized with respect to the following parameters:

- pH
- Alkalinity
- Turbidity
- NPDOC
- UV-254
- Color
- Bromide

Different blends of pretreated water and RO permeate will be analyzed for both pretreatment systems twice during each phase. The samples will be analyzed at five different blends as follows:

- 100% RO
- 75% RO, 25% Pretreated
- 50% RO, 50% Pretreated
- 25% RO, 75% Pretreated
- 100% Pretreated

The absorbance at 254 nm of the samples will be used to determine the transmittance of the sample. Relationships between transmittance and blend will be developed for each set of experiments. This data will be used to size the UV equipment for a full-scale plant.

### Anticipated Results and Deliverables

Disinfectant dosage data will be developed for the different blends of RO permeate and pretreated water based on DBP formation potentials for the given blends.

Disinfection demand/decay kinetics and DBP formation kinetics will be developed for each of the blends with each of the disinfectants.

Ultraviolet absorbance at 254 nm will be quantified for each of the blends to determine the feasibility of UV disinfection.

### Schedule

Disinfection testing will be conducted once during Phase 2A and once during Phase 2B. Exact testing dates will be determined later.

## MICROBIOLOGICAL CHALLENGE TESTING

Microbiological challenge testing will be conducted by Dr. Joan Rose. The testing will examine the water quality of Lake Monroe for both fecal and natural microbial contaminants that are of concern in drinking water. An evaluation of treatment processes for reducing the levels of these contaminants during water treatment will also be conducted.

### Goals

This study will be used to provide data to assess the microbial characteristics of the St. Johns River both above and below Lake Monroe to evaluate the potential areas at which a surface water plant may be sited.

Further, USF will conduct microbial challenge studies during Phase 2A and 2B long-term testing with the selected pretreatment and membranes. The pilot feed streams to the treatment units will be challenged with inactivated Cryptosporidium oocysts (or similar surrogate) to evaluate removal of pathogens.

### Approach

The microbiological testing will be completed under two tasks.

**Task 1—Raw Water Monitoring and Characterization**

Three (3) sites will be monitored at Lake Monroe to identify and characterize the microbial contaminants present in the water supply. These sites will be monitored monthly for 12 months to assess the influent raw water to the Lake Monroe watershed, the raw water at the intake of Lake Monroe, and the effluent raw water of the Lake Monroe watershed.

Fecal indicators to be monitored include the following:

- Fecal coliform bacteria
- *E. coli*
- Enterococci
- Coliphage

Fecal pathogens to be monitored include:

- Cryptosporidium
- Giardia
- Enteric viruses

Further, Cyanobacteria (blue-green algae) in the Lake will also be evaluated for cells, toxins, and Chlorophyll a.

**Task 2—Microbial Challenge Studies**

Nine (9) challenges on different locations in the process stream will be conducted during Phase 2A and 2B testing. The testing will include challenges on the clarification treatment units, the Zenon unit, and the reverse osmosis membranes.

**Anticipated Results and Deliverables**

The data will be analyzed using standard and specialized techniques to provide information on the water quality during seasonal changes in water temperature, rainfall, and flow. The data will be summarized and compared to other state-wide and national databases (Information Collection Rule) for interpreting the extent and significance of the findings.

Log removal data for the unit processes will be determined.

**Schedule**

Testing will be performed once during Phase 2A and once during Phase 2B.

# RESEARCH IN CONJUNCTION WITH PILOT STUDY

## AWWARF ALGAL TOXIN TREATABILITY STUDY

Research for the AWWARF tailored collaboration research project on the treatability of algal toxins using oxidation, adsorption, and membrane technologies will be assessed as a part of this pilot study. Algal toxin occurrence will be assessed by Dr. Joan Rose and membrane treatment of algal toxins will be assessed by Dr. Jim Taylor. Oxidation and absorption of the toxins will be assessed by CH2M HILL.

### Goals

The occurrence of algae and the subsequent toxins produced by the algae in Lake Monroe, and other surface waters, is important regarding any plant that could be constructed in this reach of the St. Johns River.

Field testing of algal toxin removal will be conducted to determine rejection of algal toxins. Oxidation and absorption of the toxins will be assessed by CH2M HILL at their Corvallis, OR laboratory.

This research will be conducted to assess the occurrence and subsequent removal of algal toxins using reverse osmosis membranes.

### Approach

**Task 1—Evaluate Occurrence in Lake Monroe**

Samples at Lake Monroe will be collected twice per month for one year and will include routine sampling and sampling of any bloom conditions. Up to 5-liter grab samples will be collected using sterile bottles and gloves, placed on ice, and shipped to the Michigan State Laboratory for analysis.

Analyses will then be conducted to characterize the algae present in the source water. Characterization under bloom conditions will be of particular interest and an attempt will be made to culture the cyanobacteria detected during blooms, to be used in bench-scale removal studies. Lake conditions will be characterized at the time of sampling to examine whether this influences the water quality at the intake.

**Task 2—Determine Removals using Membrane Treatment**

Membrane treatment experimentation will be coordinated with the pilot testing to be conducted at the plant using four of the single element membranes at the plant. The four membranes will be challenged with algal toxins provided by Dr. Joan Rose using water from Lake Monroe.

The membrane challenge studies will be conducted with bench and field experimentation. The membrane challenge studies with algal toxins will be the only part of the AWWARF study that will be done in cooperation with this pilot study. Challenge tests will be conducted with algal toxins at varying concentrations and for different operating conditions. Further, challenge studies with chlorides or another inorganic solute will be done to determine the time constant and the time to steady state for each membrane system. The field experimentation matrix will include:

- Four different membranes with varying levels of diffusion
- Two levels of flux
- Two levels of recovery, which will affect the surface charge of the membranes
- Two levels of algal toxin concentration

Variation of concentration, flux, and recovery will allow determination of the primary rejection mechanism. Variation of charge by major ion concentration will allow determination of the charge effect on diffusion or size exclusion. Specifically, each membrane will be challenged with model algal toxins for both low and high flux and recovery operating conditions. Consequently, variation of major ion concentration and compositions will determine if algal toxins compound rejection is size exclusion or diffusion controlled and affected by ion coupling or charge.

**Task 3—Determine Removals using Oxidation and Activated Carbon**

Ozone will be tested for effectiveness in oxidizing algal toxins. Ozone dose requirements will be developed. The results will be presented as toxin decay constants that relate the ozone dose to the amount of decay using first order relationships. The slope of the log of algal toxin removal vs. ozone dose results in a decay constant that can be used to design systems at various toxin concentrations.

Rapid small-scale column tests (RSSCT) will be used to define the shape of the adsorption wavefront for GAC adsorption. Four columns in series will be used, each with a 5-minutes EBCT. When placed in series, this arrangement will allow the evaluation of the following EBCTs:

- 5 minutes; 10 minutes; 5 minutes; 20 minutes

At least 10 samples of microcystins and TOC will be collected from each column during the test.

**Equipment Configurations**

Single element membrane testing will be conducted using the four single element systems currently being used for Zenon evaluation.

**Anticipated Results and Deliverables**

Raw water algal toxins will be quantified in Lake Monroe.

From the bench and field data membrane data, a model will be developed to predict membrane performance for algal toxin rejection. From the ozone testing the slope of the log of algal toxin removal vs. ozone dose results in a decay constant will be developed. This can then be used to design ozone systems to treat various toxin concentrations. The wavefront adsorption for treatment of algal toxins will also be developed to assist in the design of carbon systems for algal toxin removal.

**Schedule**

Membrane testing will be performed once during Phase 2B.

# OVERALL SCHEDULE

The schedule for all remaining testing is summarized in the following table:

| Description | Start | Finish |
|---|---|---|
| Phase 1B Testing – Lead Element Selection | 04/01/2002 | 06/11/2002 |
| Phase 2A Testing – High Recovery Testing (SuperP) | 06/11/2002 | 08/12/2002 |
| Phase 2B Testing – High Recovery Testing (Actiflo) | 08/01/2002 | 11/05/2002 |
| Regulatory Sampling | 06/11/2002 | 11/05/2002 |
| Disinfection Study | 06/11/2002 | 11/05/2002 |
| Microbiological Testing | 06/11/2002 | 11/05/2002 |
| AWWARF Algal Toxin Treatability Testing | 08/01/2002 | 11/05/2002 |

Testing will include Phase 1B, 2A and 2B pilot testing as well as regulatory sampling, a disinfection evaluation, microbial testing, and the AWWARF algal toxin treatability study.

Phase 1B, 2A, and 2B testing is anticipated to be completed by November 5, 2002. The regulatory sampling, disinfection testing, microbiological testing, and algal toxin testing will be conducted during the regular pilot testing.

# Appendix C
# Definition of Terms

# Standard Practice for Standardizing Reverse Osmosis Performance Data[1]

This standard is issued under the fixed designation D 4516; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice covers the standardization of permeate flow and salt passage data for reverse osmosis (RO) systems.

1.2 This practice is applicable to waters including brackish waters and seawaters but is not necessarily applicable to waste waters.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

D 1129 Definitions of Terms Relating to Water[2]

D 4194 Test Methods for Operating Characteristics of Reverse Osmosis Devices[3]

## 3. Terminology

3.1 For definitions of terms used in this practice, refer to Definitions D 1129.

3.2 For description of terms relating to reverse osmosis, refer to Test Method D 4194.

## 4. Summary of Practice

4.1 This practice consists of calculating the permeate flow and salt passage of RO systems at a standard set of conditions using data obtained at actual operating conditions.

## 5. Significance and Use

5.1 During the operation of an RO system, system conditions such as pressure, temperature, conversion, and feed concentration can vary, causing permeate flow and salt passage to change. To effectively evaluate system performance, it is necessary to compare permeate flow and salt passage data at the same conditions. Since data may not always be obtained at the same conditions, it is necessary to convert the RO data obtained at actual conditions to a set of selected constant conditions, thereby standardizing the data. This practice gives the procedure to standardize RO data.

5.2 This practice can be used for both spiral wound and hollow fiber systems.

5.3 This practice can be used for a single element or a multi-element system. However, if the RO system is brine staged, that is, the brine from one group of RO devices is the feed to a second group of RO devices, standardize the permeate flow and salt passage for each stage separately.

5.4 This practice is applicable for reverse osmosis systems with high rejections and with no significant leaks between the feed-brine and permeate streams.

## 6. Procedure

6.1 *Standardization of Permeate Flow:*

6.1.1 Calculate the permeate flow at standard conditions using Eq 1:

$$\boxed{Q_{ps} = \frac{\left[P_{fs} - \frac{\Delta P_{fbs}}{2} - P_{ps} - \pi_{fbs} + \pi_{ps}\right](TCF_s)}{\left[P_{fa} - \frac{\Delta P_{fba}}{2} - P_{pa} - \pi_{fba} + \pi_{pa}\right](TCF_a)}(Q_{pa})} \quad (1)$$

where:

$Q_{ps}$ = permeate flow at standard conditions,

$P_{fs}$ = feed pressure at standard conditions, kpa, Or PSI, if used for all Eq's

$\frac{\Delta P_{fbs}}{2}$ = one half device pressure drop at standard conditions, kpa,

$P_{ps}$ = permeate pressure at standard conditions, kpa,

$\pi_{fbs}$ = feed-brine osmotic pressure at standard conditions, kpa,

$\pi_{ps}$ = permeate osmotic pressure at standard conditions, kpa,

$TCF_S$ = temperature correction factor at standard conditions,

$Q_{pa}$ = permeate flow at actual conditions,

$P_{fa}$ = feed pressure at actual conditions, kpa,

$\frac{\Delta P_{fba}}{2}$ = one half device pressure drop at actual conditions, kpa,

$P_{pa}$ = permeate pressure at actual conditions, kpa,

$\pi_{fba}$ = feed-brine osmotic pressure at actual conditions, kpa,

$\pi_{pa}$ = permeate osmotic pressure at actual conditions, kpa, and

$TCF_a$ = temperature correction factor at actual conditions.

6.2 *Standardization of Salt Passage:*

6.2.1 Calculate the salt passage at standard conditions using Eq 2:

$$\boxed{\%SP_s = \frac{\left[P_{fa} - \frac{\Delta P_{fba}}{2} - P_{pa} - \pi_{fba} + \pi_{pa}\right] \times (C_{fbs})(C_{fs})}{\left[P_{fs} - \frac{\Delta P_{fbs}}{2} - P_{ps} - \pi_{fbs} + \pi_{ps}\right] \times (C_{fba})(C_{fa})} \times [\%\ SP_a]} \quad (2)$$

where:

$\%\ SP_s$ = percent salt passage at standard conditions,

$\%\ SP_a$ = percent salt passage at actual conditions,

$C_{fba}$ = feed-brine concentration at actual conditions, mg/L NaCl,

$C_{fbs}$ = feed-brine concentration at standard conditions, mg/L NaCl,

$C_{fa}$ = feed concentration at actual conditions, mg/L NaCl, and

$C_{fs}$ = feed concentration at standard conditions, mg/L NaCl.

6.3 In Eq 1, $TCF_s$ and $TCF_a$ are dependent on the type of device (spiral or hollow fiber) and on the membrane type (cellulose acetate, polyamide, composite). Obtain equations for $TCF_s$ and $TCF_a$ from the supplier of device. If unavailable use Eqs 3 and 4.

$$\boxed{\begin{aligned} TCF_s &= 1.03^{(T_s - 25)} \quad (3)\\ TCF_a &= 1.03^{(T_a - 25)} \quad (4)\end{aligned}}$$

where:

$T_s$ = temperature at standard conditions, °C, and

$T_a$ = temperature at actual conditions, °C.

6.4 In Eqs 1 and 2, $\pi_{fba}$ and $\pi_{fbs}$ are calculated from the concentration of salt (expressed as mg/L NaCl) in the feed and brine streams. See Annex A1 for the procedure to calculate the concentrations of salt in feed stream as mg/L NaCl.

6.4.1 The concentration of salt in the brine stream is calculated using Eq 5:

$$C_b = C_f/(1 - Y) \quad (5)$$

where:

$C_b$ = concentration of salt in the brine, mg/L NaCl,

$C_f$ = concentration of salt in the feed, mg/L NaCl, and

$Y$ = conversion, expressed as a decimal.

6.4.2 The feed-brine concentration for some RO devices is based on an average (Eq 6):

$$C_{fb} = (C_f + C_b)/2 \quad (6)$$

and for other RO devices, the feed-brine concentration is based on a log mean average (Eq 7):

$$\boxed{C_{fb} = C_f \ln[1/(1 - Y)]/Y} \quad (7)$$

Consult supplier of device to determine whether Eq 6 or 7 should be used. Below, use 0.2654 for KPa, or 0.0385 for PSI:

6.4.3 Calculate $\pi_{fb}$ using Eq 8:

$$\boxed{\pi_{fb} = 0.2654\ C_{fb}\ (T + 273.15)/(1000 - C_{fb}/1000)} \quad (8)$$

6.5 The value for $\Delta P_{fbs}/2$ in Eqs 1 and 2 is a selected and constant value. A realistic value can be obtained from the supplier of the RO device.

6.6 To calculate $\pi_{ps}$ and $\pi_{pa}$ in Eqs 1 and 2 use Eq 9 for brackish water and Eq 10 for seawater as follows:

$$\pi_p = 0.05\ \pi_{fb} \quad (9)$$

For 99% rejection: $$\boxed{\pi_p = 0.01\ \pi_{fb}} \quad (10)$$

6.7 To obtain the most accurate standardization, the standard conditions should be set close to the average actual conditions.

6.8 Proper calibration and reading of instrumentation is critical for accurate actual RO data.

6.9 For large differences in pressure between actual and standard conditions, the standardized salt passage can be inaccurate if ions whose passage are independent of pressure are present to a significant extent. Consult supplier of RO device to determine if modification to the salt passage equation is needed.

## 7. Use of Computers for Standardization

7.1 The calculations in this practice are adaptable to simple computer analysis.

[1] This practice is under the jurisdiction of ASTM Committee D-19 on Water and is the direct responsibility of Subcommittee D19.08 on Membranes and Ion Exchange Materials.

Current edition approved Aug. 30, 1985. Published November 1985.

[2] *Annual Book of ASTM Standards*, Vol 11.01.

[3] *Annual Book of ASTM Standards*, Vol 11.02.





## ANNEX

### (Mandatory Information)

### A.1 CALCULATION FOR CONCENTRATION OF SALT IN RO FEED STREAM AS mg/L NaCl

A1.1 First calculate the osmotic pressure of the RO feed ($\pi_f$) in kPa using Eq A1.

$$\pi_f = 8.308\ \phi (T_f + 273.15)\ \Sigma \bar{m}_i \quad (A1)$$

where:

$\phi$ = osmotic coefficient,

$T_f$ = temperature of feed stream, °C, and

$\Sigma \bar{m}_i$ = summation of molalities of all ionic and non-ionic constituents in the water.

NOTE—Estimates of osmotic coefficients for brackish and seawater of 0.93 and 0.90, respectively, can be used in Eq A1.

A.1.2 Calculate the concentration of salt in the RO feed ($C_f$) as mg/L NaCl using Eq A2:

$$C_f = 1000\ \pi_f/[0.2654\ (T_f + 273.15) + \pi_f/1000] \quad (A2)$$

# Appendix D
# FTIR Reverse Osmosis Membrane Analysis

# Attenuated Total Reflectance
# Fourier Transform Infrared Spectrometry

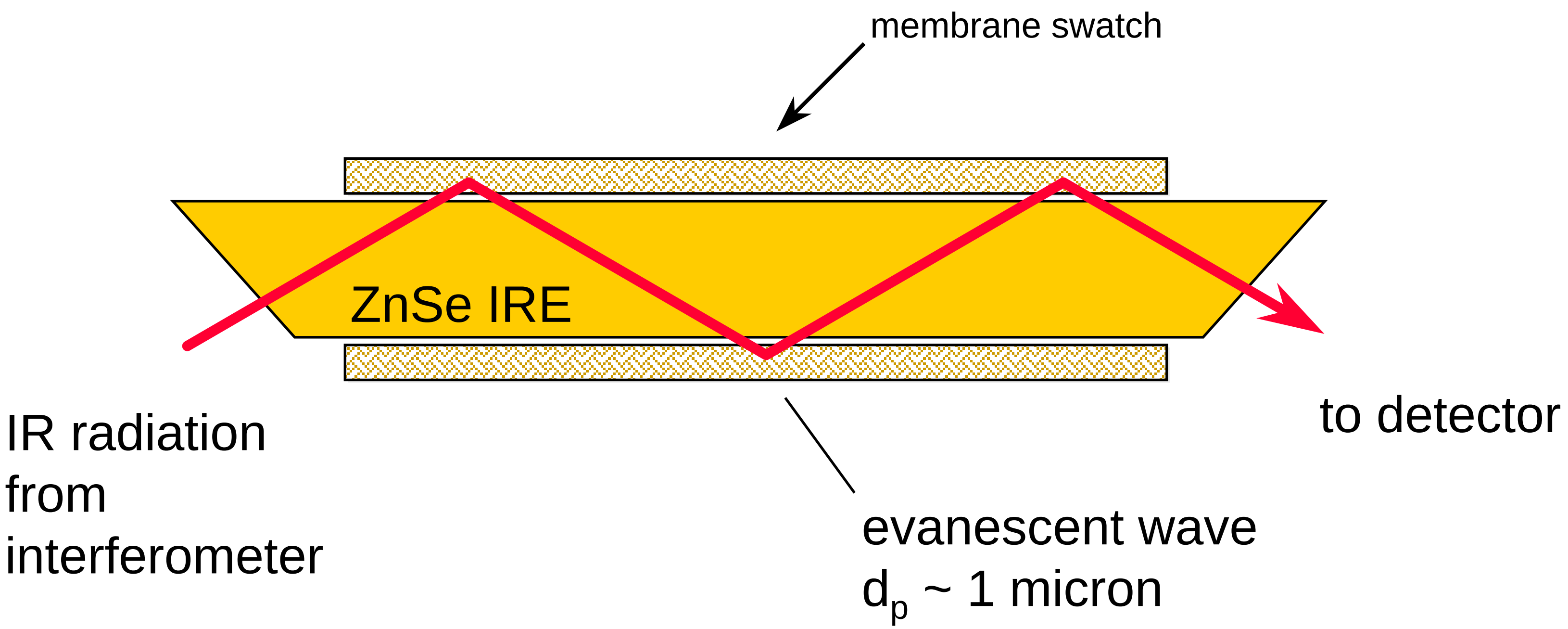
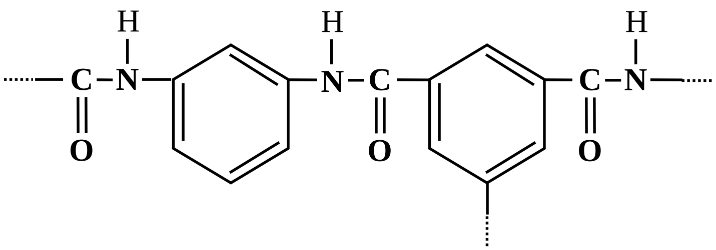


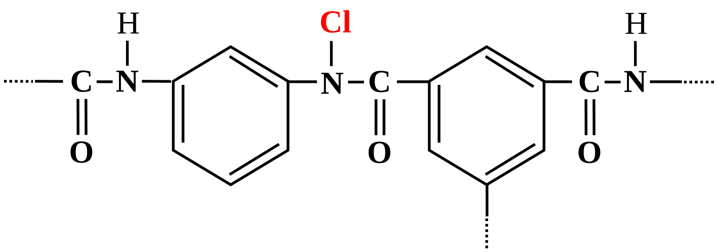

Figure 1.

**Polyamide**



**N-chlorination**

**(reversible: dechlorination with reducing agent)**



**Chlorination at the aromatic nucleus**

**(irreversible)**

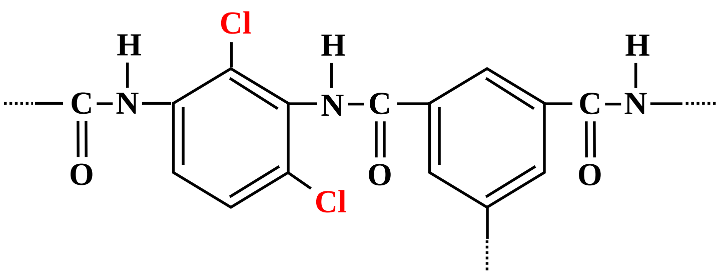


Figure 2.

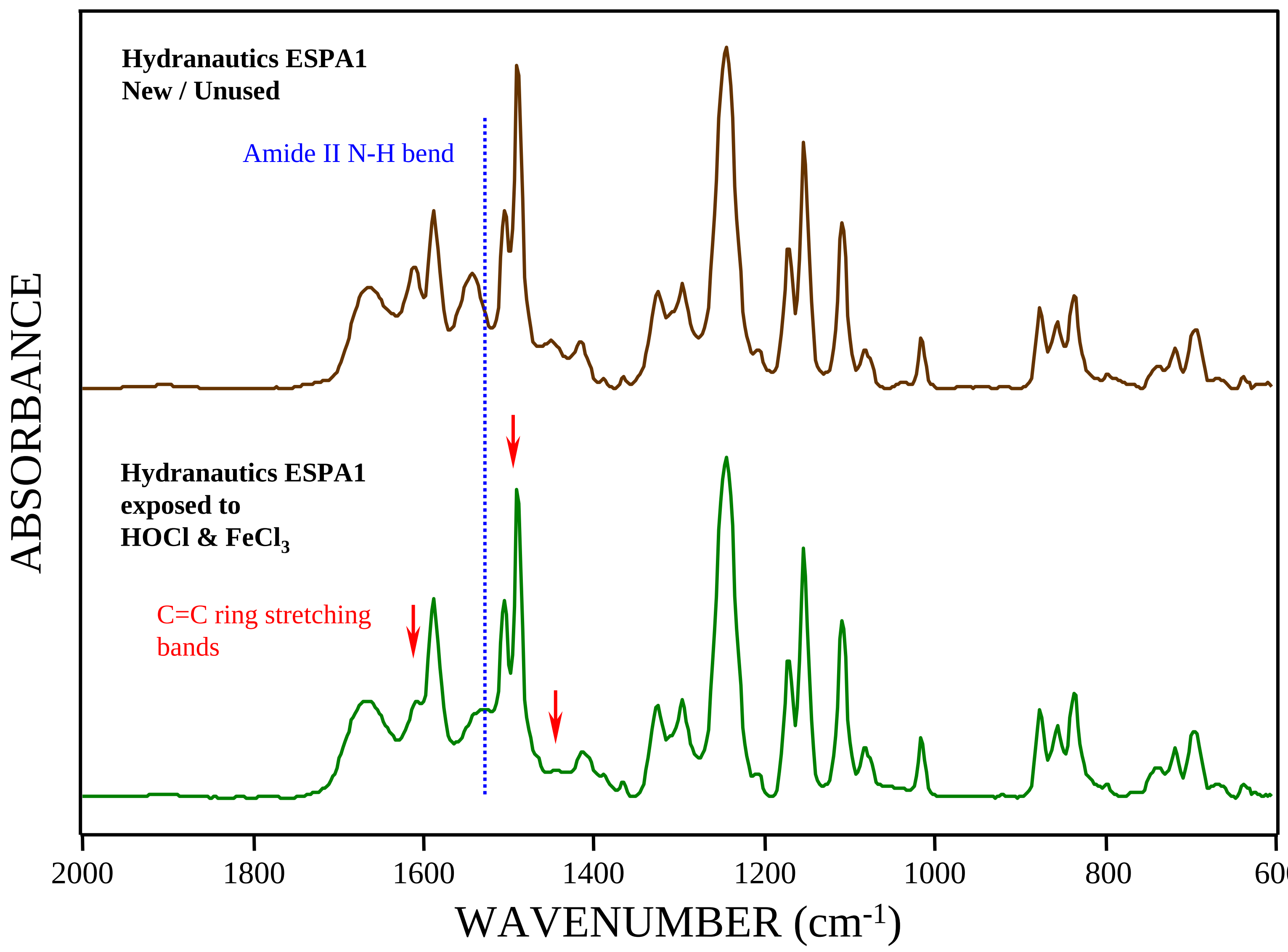

Hydranautics ESPA1
New / Unused
Amide II N-H bend
Hydranautics ESPA1
exposed to
HOCl & $FeCl_3$
C=C ring stretching
bands
ABSORBANCE
2000
1800
1600
1400
1200
1000
800
600
WAVENUMBER ($cm^{-1}$)

Figure 3.

Depth of Penetration of the Evanescent Wave into
Thin Film Composite Polyamide Membrane

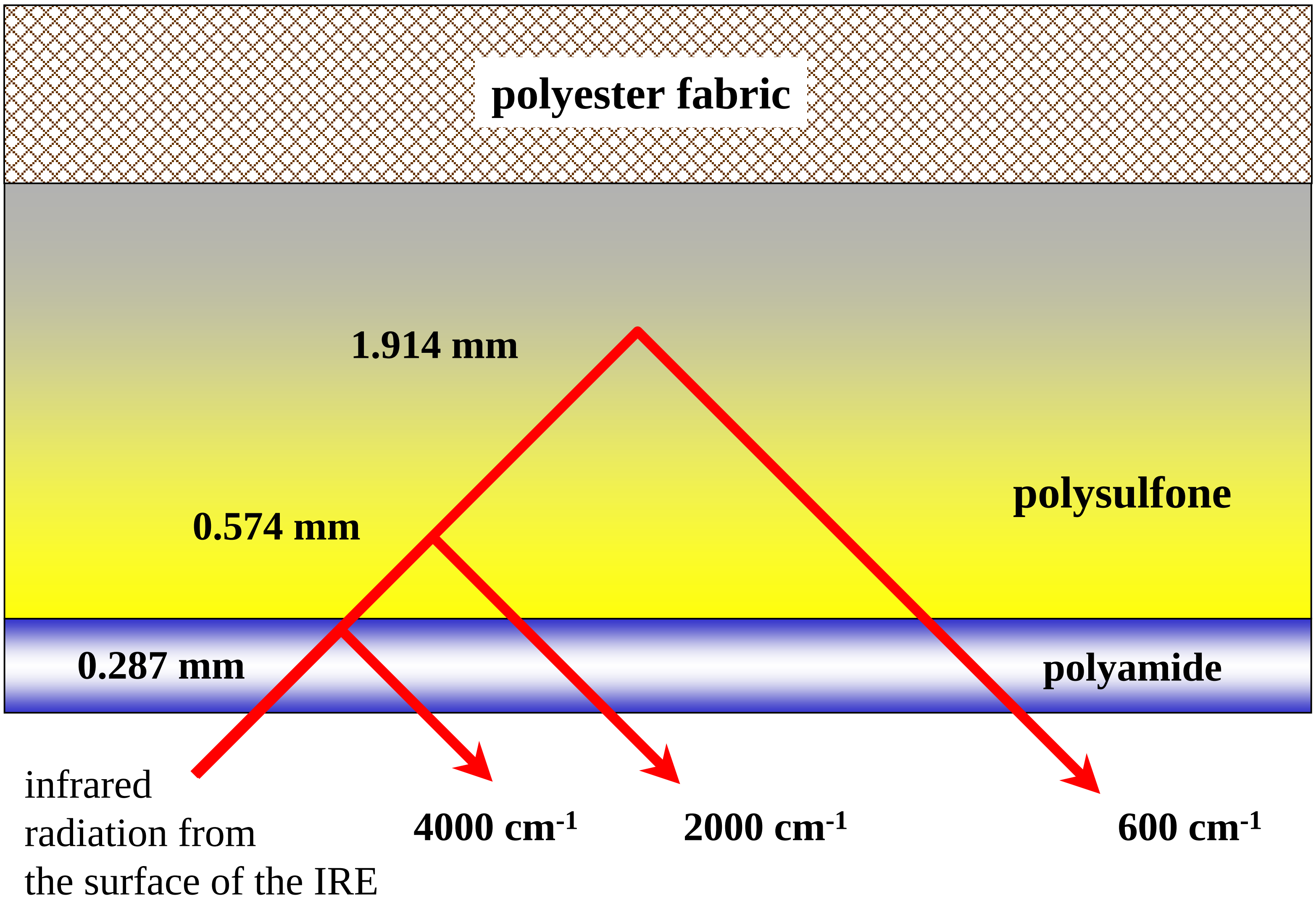
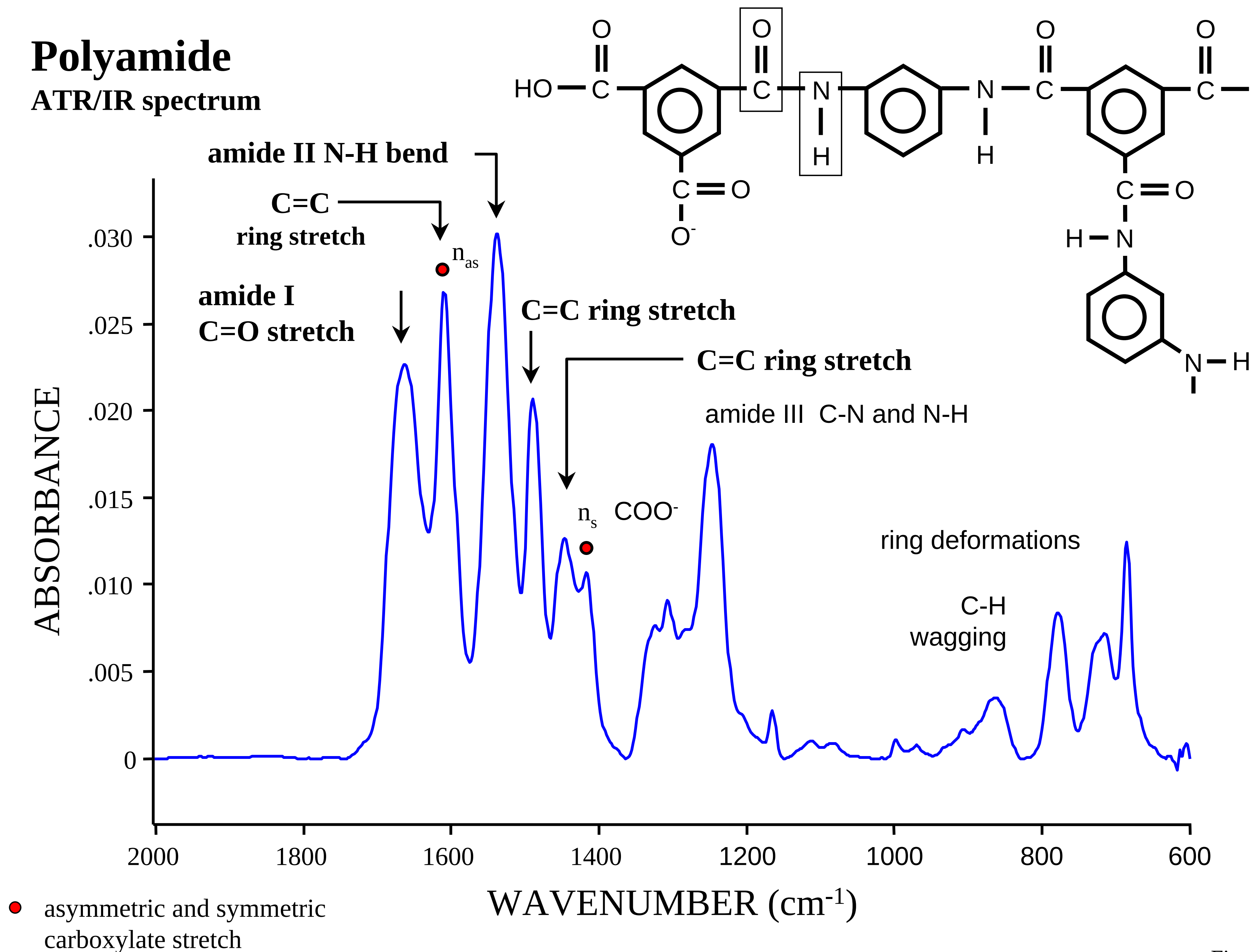



Figure 4.



Polyamide
ATR/IR spectrum
amide II N-H bend
C=C ring stretch
amide I C=O stretch
$n_{as}$
C=C ring stretch
C=C ring stretch
amide III C-N and N-H
$n_s$ $COO^-$
ring deformations
C-H wagging
ABSORBANCE
.030
.025
.020
.015
.010
.005
0
2000
1800
1600
1400
1200
1000
800
600
WAVENUMBER ($cm^{-1}$)
asymmetric and symmetric carboxylate stretch


Figure 5.

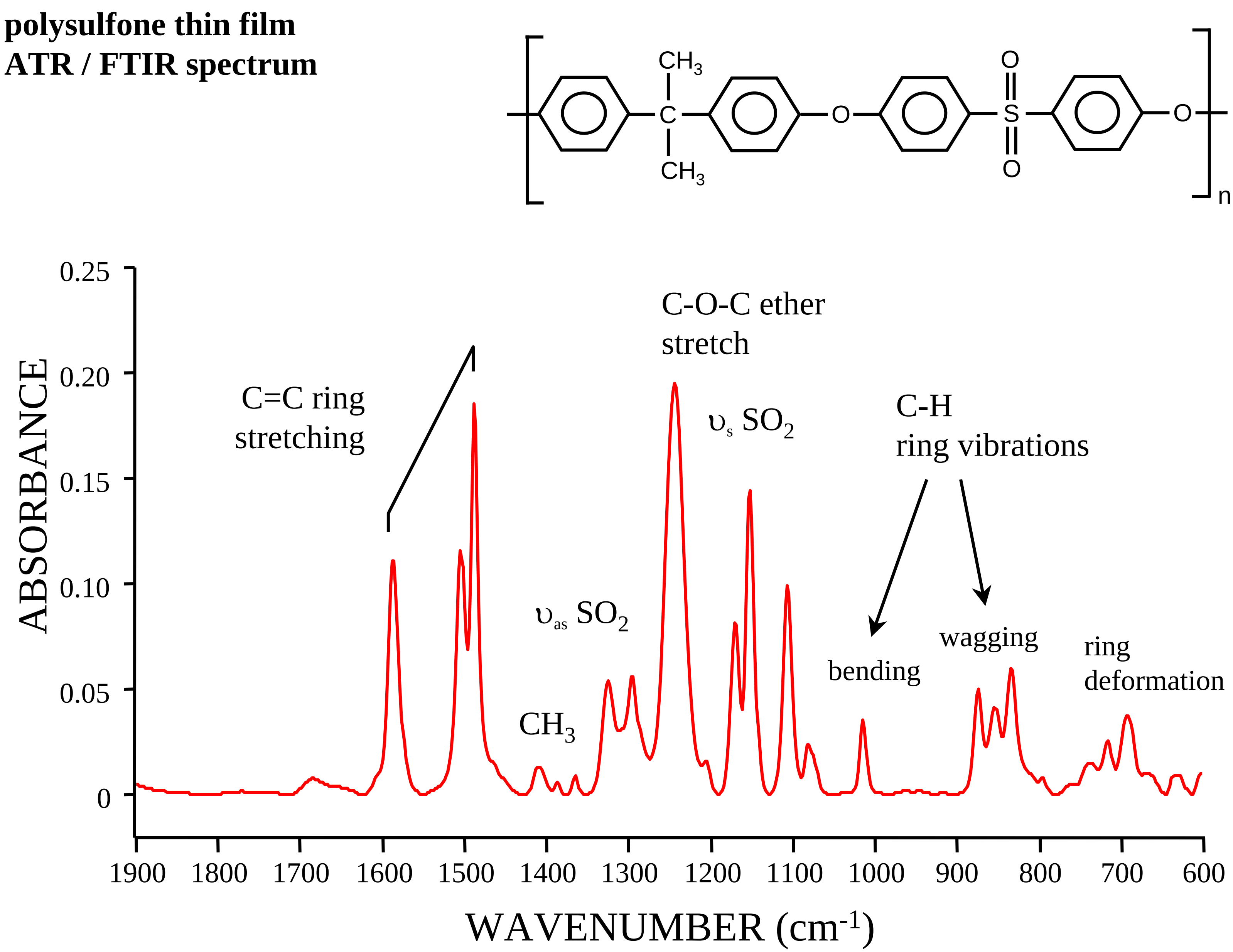

polysulfone thin film
ATR / FTIR spectrum
CH3
C
CH3
O
O
S
O
O
n
C=C ring
stretching
CH3
υas SO2
C-O-C ether
stretch
υs SO2
C-H
ring vibrations
bending
wagging
ring
deformation
ABSORBANCE
0.25
0.20
0.15
0.10
0.05
0
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
WAVENUMBER (cm-1)

Figure 6.

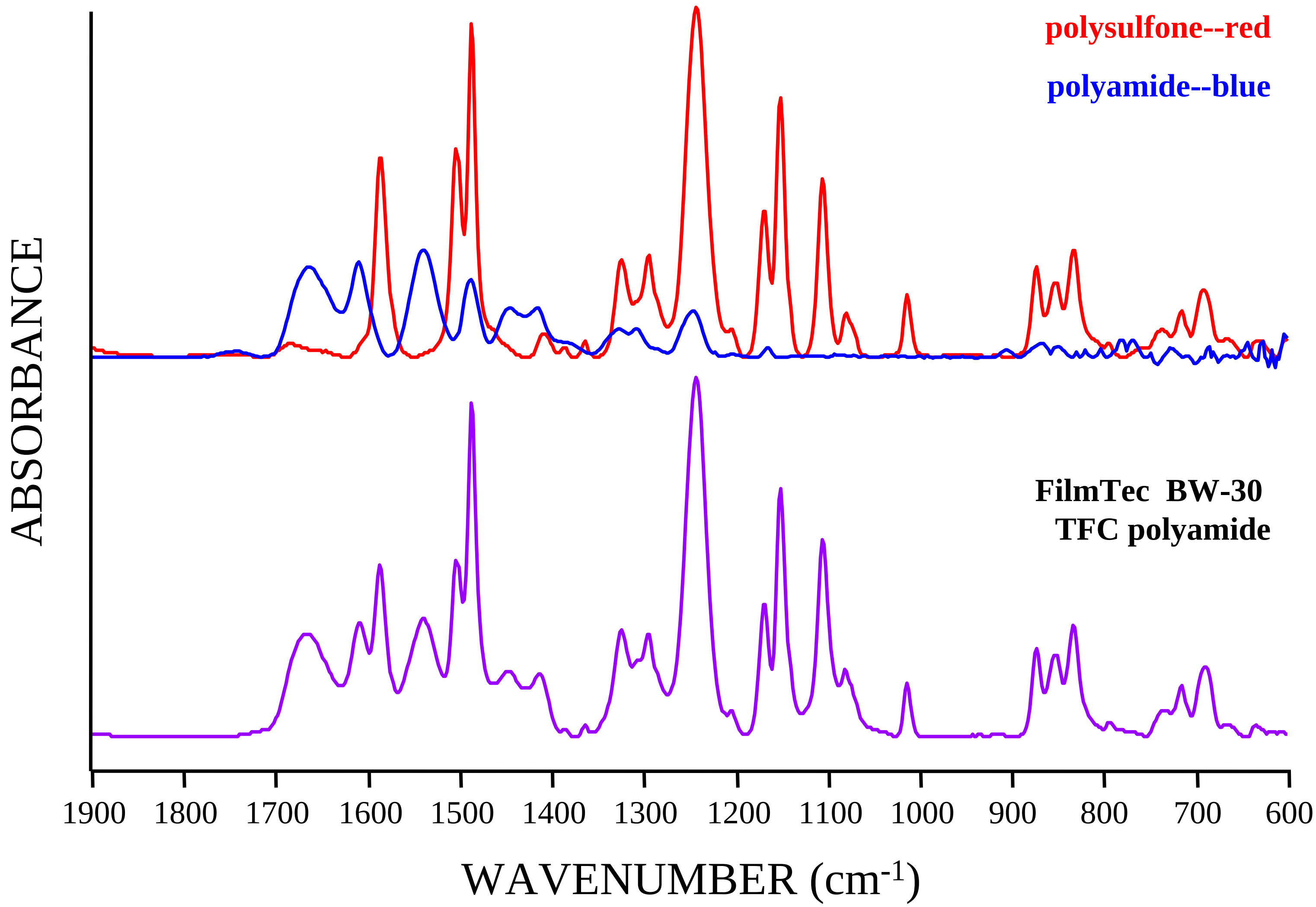
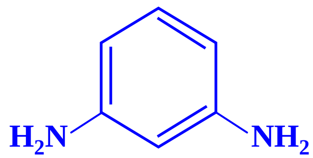
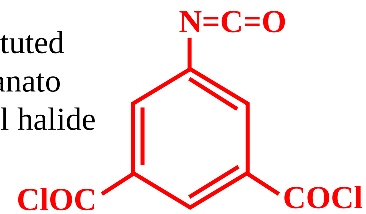

polysulfone--red
polyamide--blue
FilmTec BW-30
TFC polyamide
ABSORBANCE
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
WAVENUMBER (cm-1)

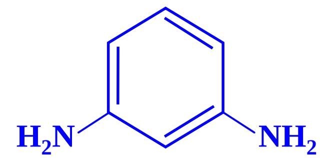
Figure 7.



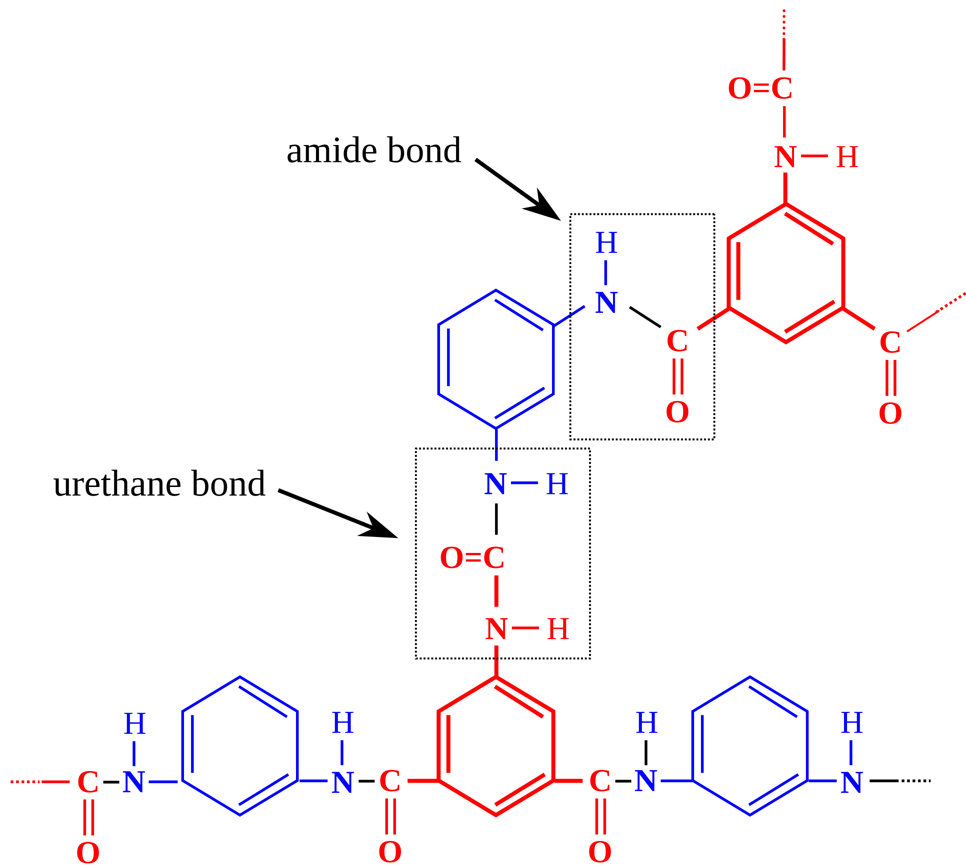
*m*-phenylenediamine

1,3,5-substituted
monoisocyanato
isophthaloyl halide





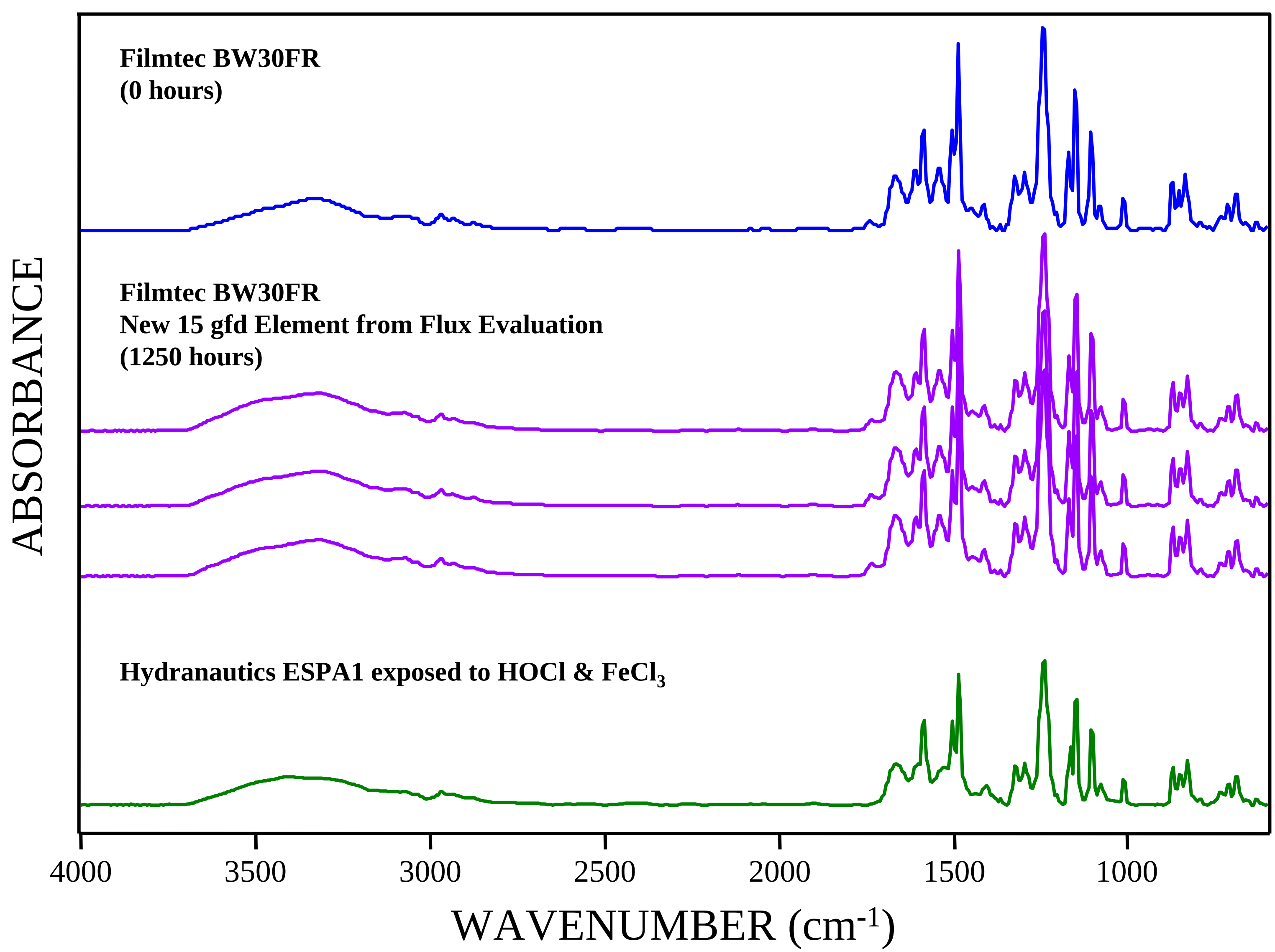
# Polyamide-Urea




**Reaction of one monoisocyanato isophthaloyl halide leads to:**

$$\frac{\textbf{4 N-H groups}}{\textbf{3 C=O groups}} \rightarrow \textbf{1.33 ratio}$$

Figure 8.



Filmtec BW30FR
(0 hours)
Filmtec BW30FR
New 15 gfd Element from Flux Evaluation
(1250 hours)
Hydranautics ESPA1 exposed to HOCl & FeCl3
ABSORBANCE
4000
3500
3000
2500
2000
1500
1000
WAVENUMBER (cm-1)


Figure 9.

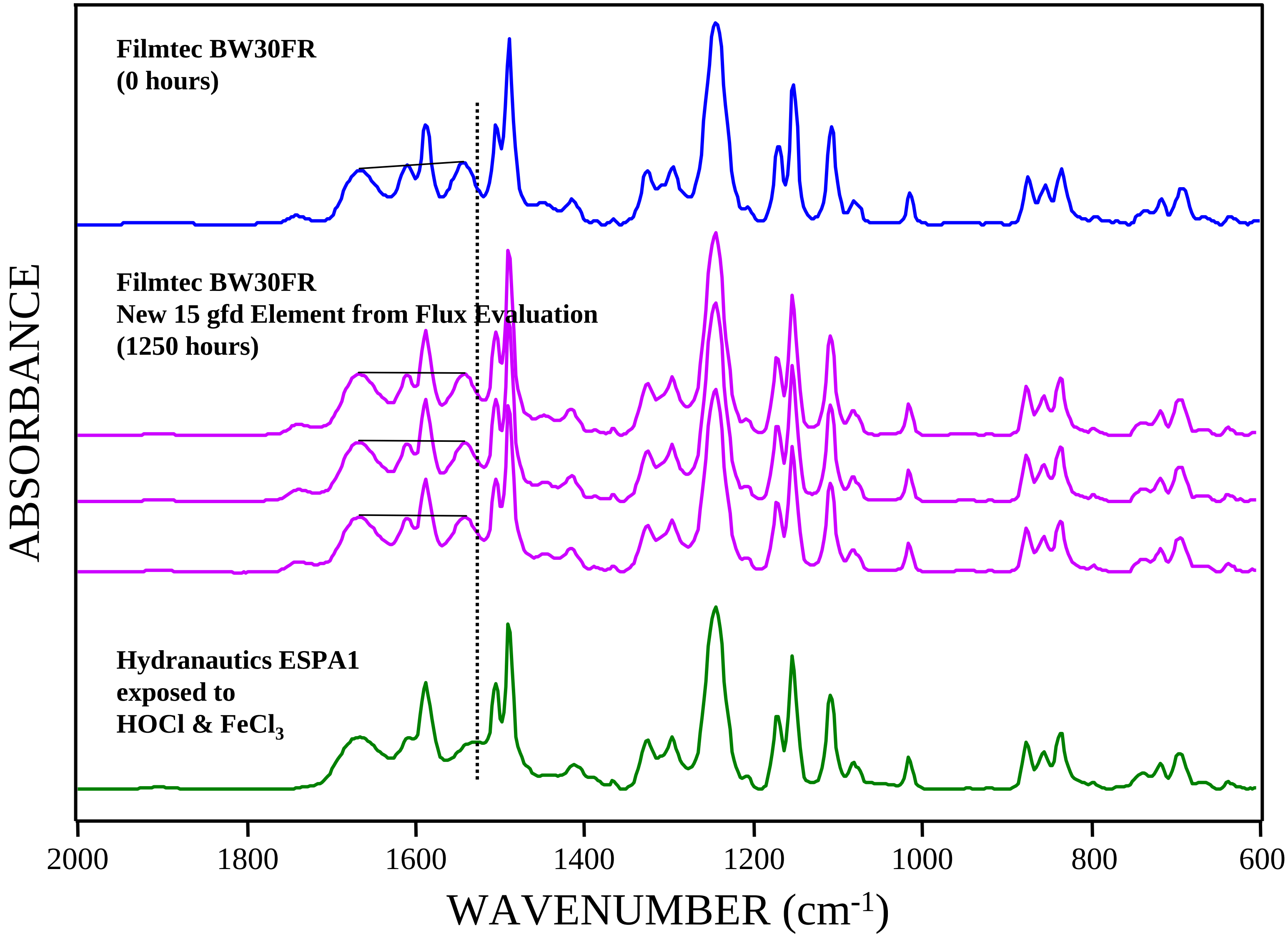

Filmtec BW30FR
(0 hours)
Filmtec BW30FR
New 15 gfd Element from Flux Evaluation
(1250 hours)
Hydranautics ESPA1
exposed to
HOCl & FeCl3
ABSORBANCE
2000
1800
1600
1400
1200
1000
800
600
WAVENUMBER (cm-1)

Figure 10.

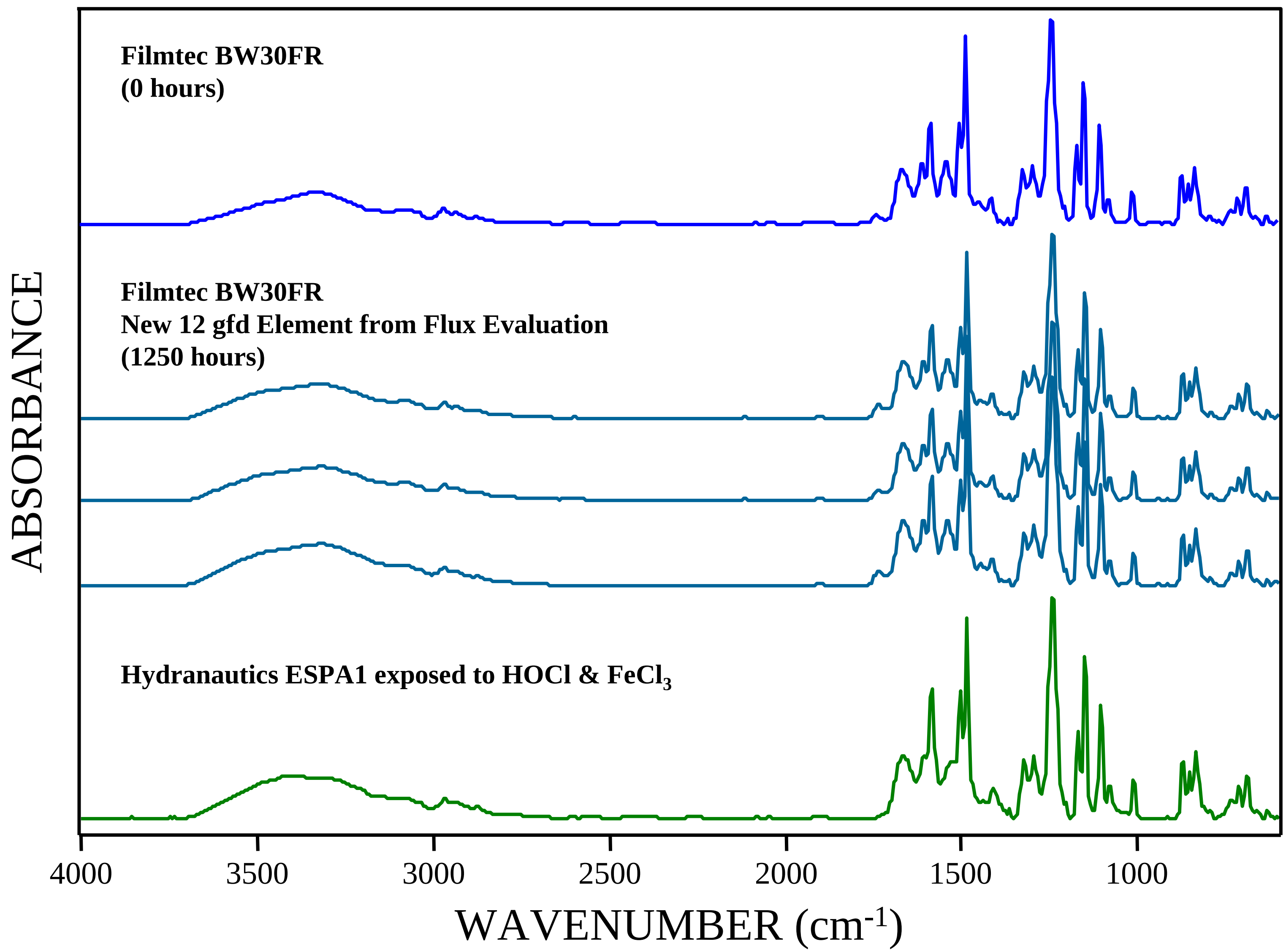
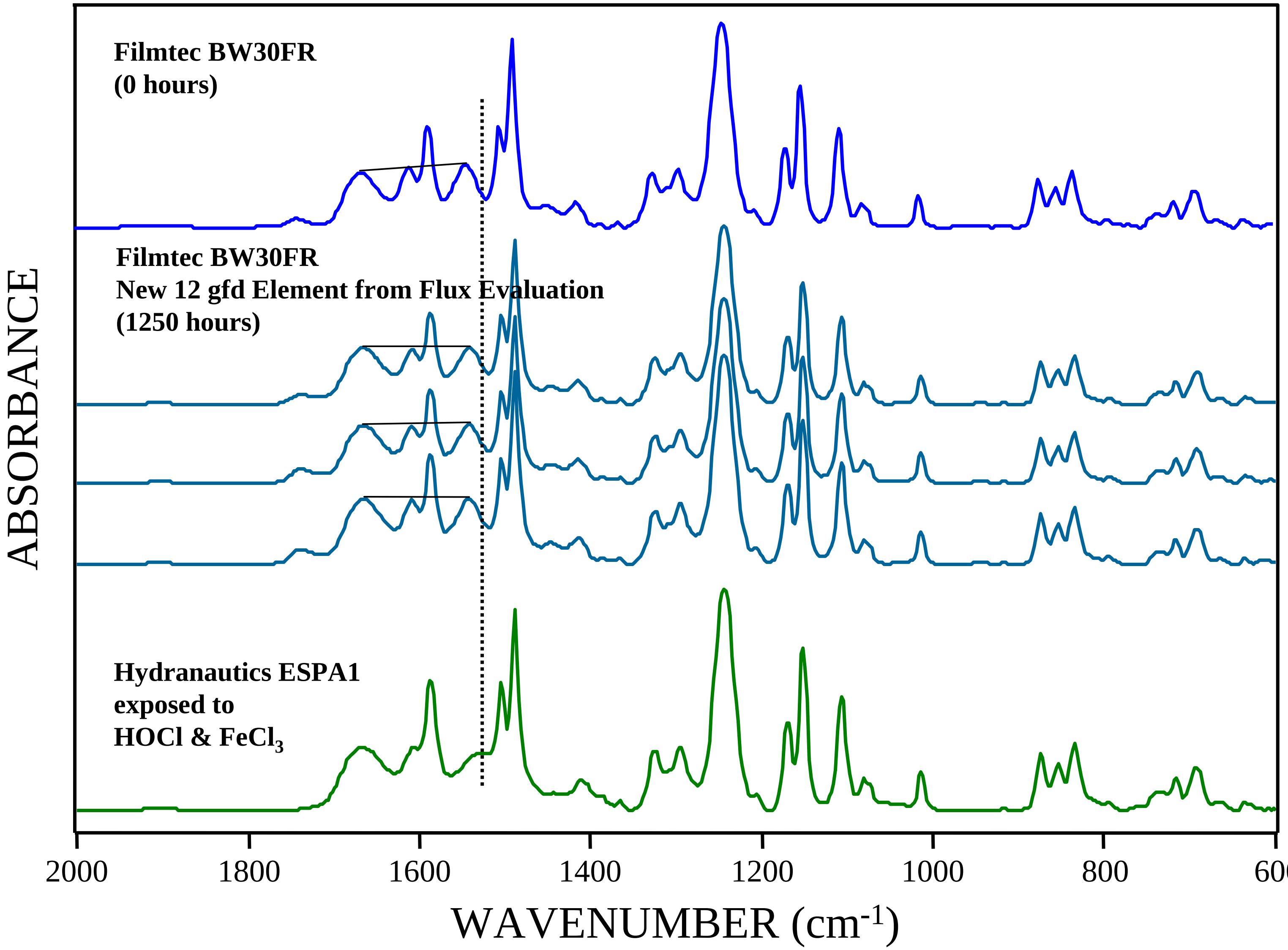
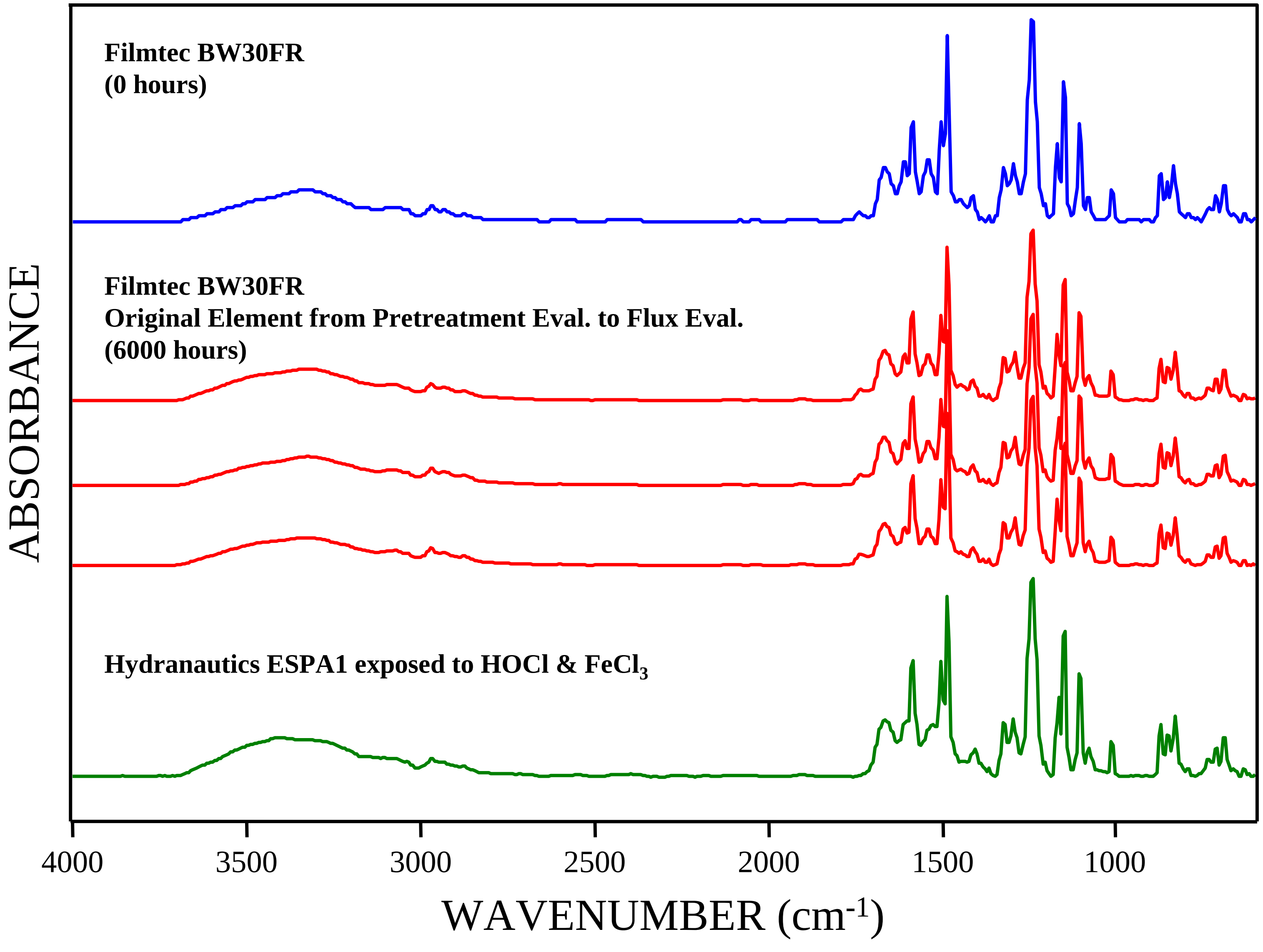

Filmtec BW30FR
(0 hours)
Filmtec BW30FR
New 12 gfd Element from Flux Evaluation
(1250 hours)
Hydranautics ESPA1 exposed to HOCl & $FeCl_3$
ABSORBANCE
4000
3500
3000
2500
2000
1500
1000
WAVENUMBER ($cm^{-1}$)

Figure 11.



Filmtec BW30FR
(0 hours)
Filmtec BW30FR
New 12 gfd Element from Flux Evaluation
(1250 hours)
Hydranautics ESPA1
exposed to
HOCl & $FeCl_3$
ABSORBANCE
2000
1800
1600
1400
1200
1000
800
600
WAVENUMBER ($cm^{-1}$)


Figure 12.



Filmtec BW30FR
(0 hours)
Filmtec BW30FR
Original Element from Pretreatment Eval. to Flux Eval.
(6000 hours)
Hydranautics ESPA1 exposed to HOCl & FeCl3
ABSORBANCE
4000
3500
3000
2500
2000
1500
1000
WAVENUMBER (cm-1)


Figure 13.

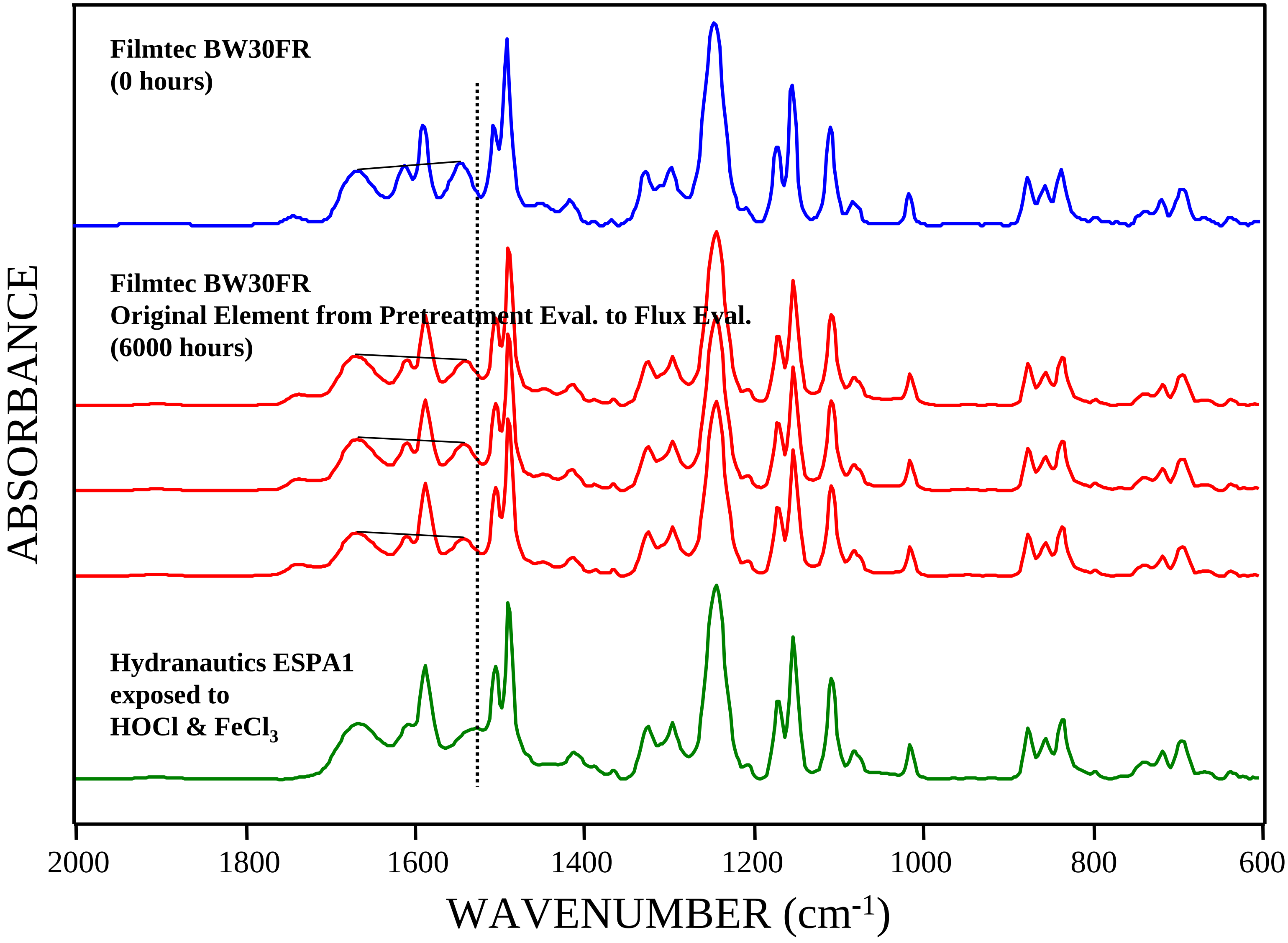

Filmtec BW30FR
(0 hours)
Filmtec BW30FR
Original Element from Pretreatment Eval. to Flux Eval.
(6000 hours)
Hydranautics ESPA1
exposed to
HOCl & FeCl3
ABSORBANCE
2000
1800
1600
1400
1200
1000
800
600
WAVENUMBER (cm-1)

Figure 14.

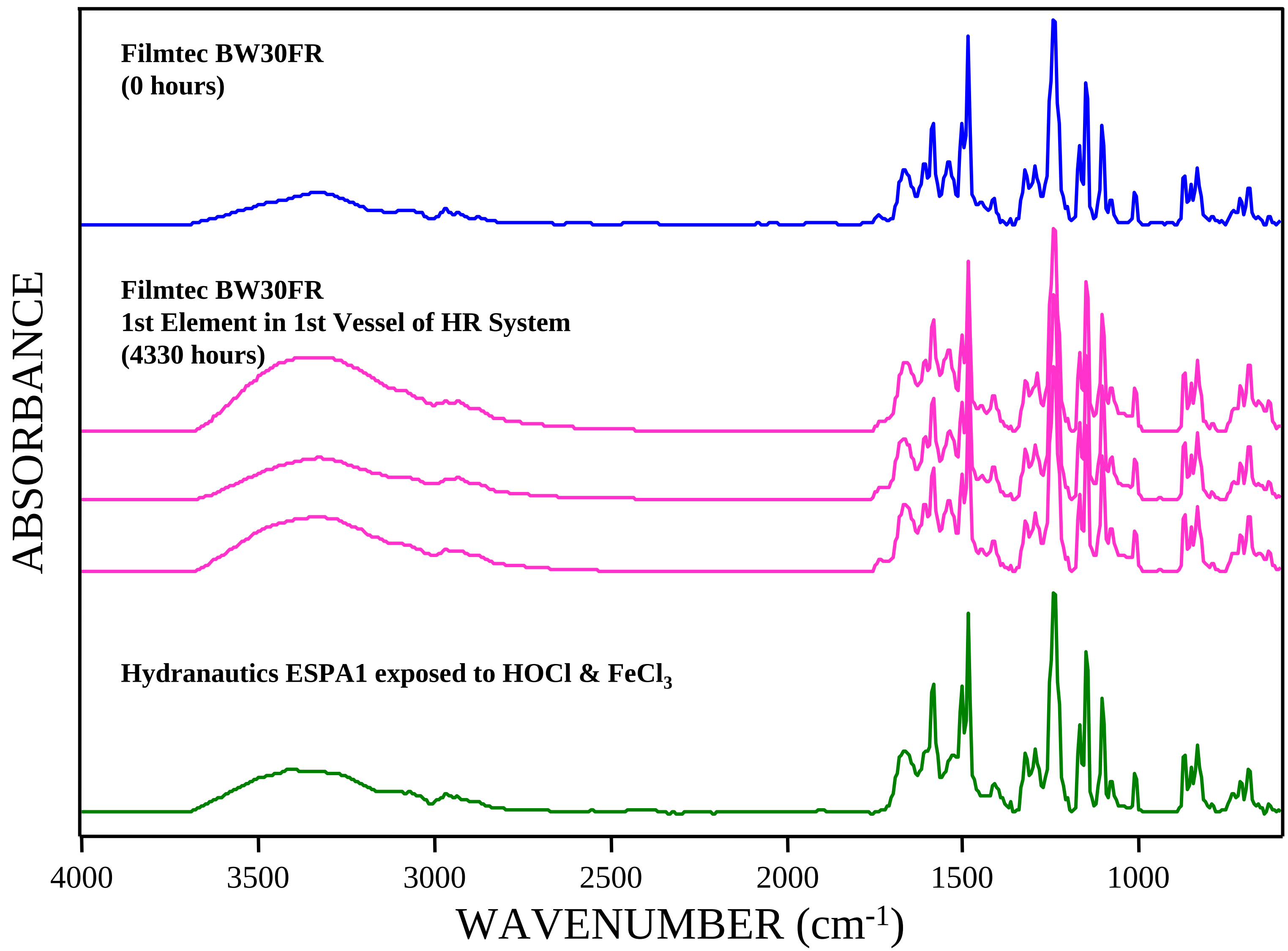

Filmtec BW30FR
(0 hours)
Filmtec BW30FR
1st Element in 1st Vessel of HR System
(4330 hours)
Hydranautics ESPA1 exposed to HOCl & $FeCl_3$
ABSORBANCE
4000
3500
3000
2500
2000
1500
1000
WAVENUMBER ($cm^{-1}$)

Figure 15.

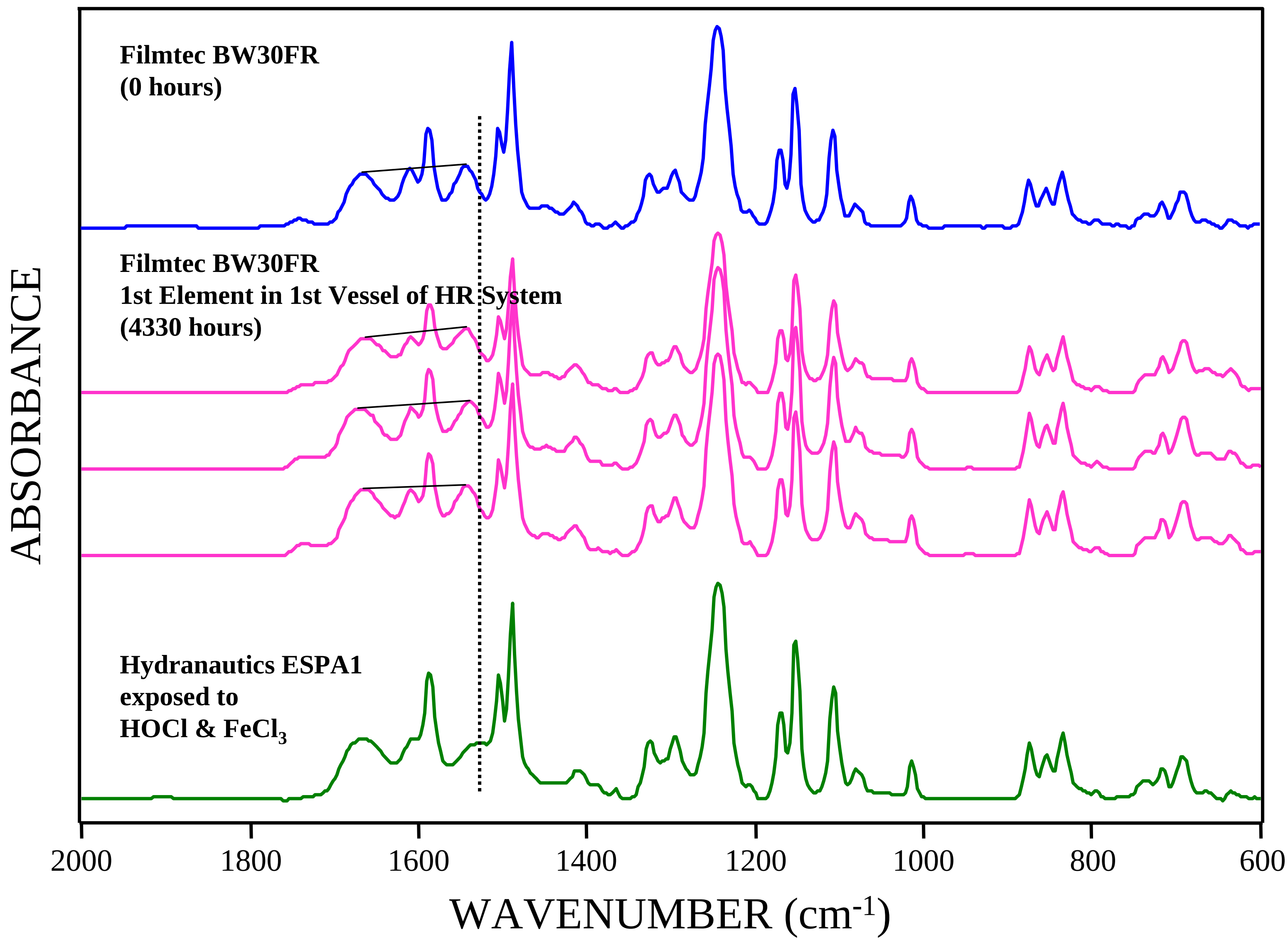

Filmtec BW30FR
(0 hours)
Filmtec BW30FR
1st Element in 1st Vessel of HR System
(4330 hours)
Hydranautics ESPA1
exposed to
HOCl & FeCl3
ABSORBANCE
2000
1800
1600
1400
1200
1000
800
600
WAVENUMBER (cm-1)

Figure 16.

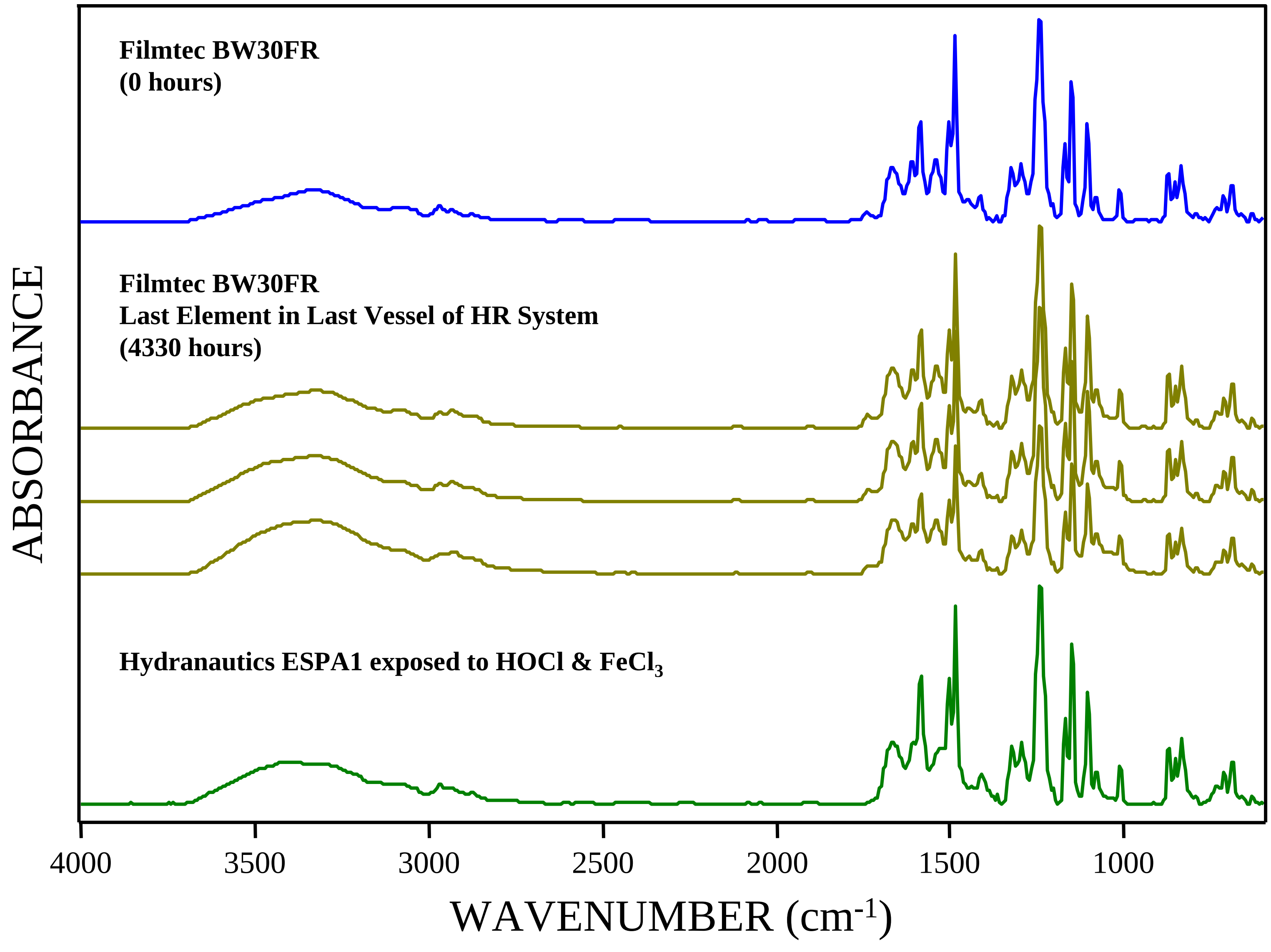
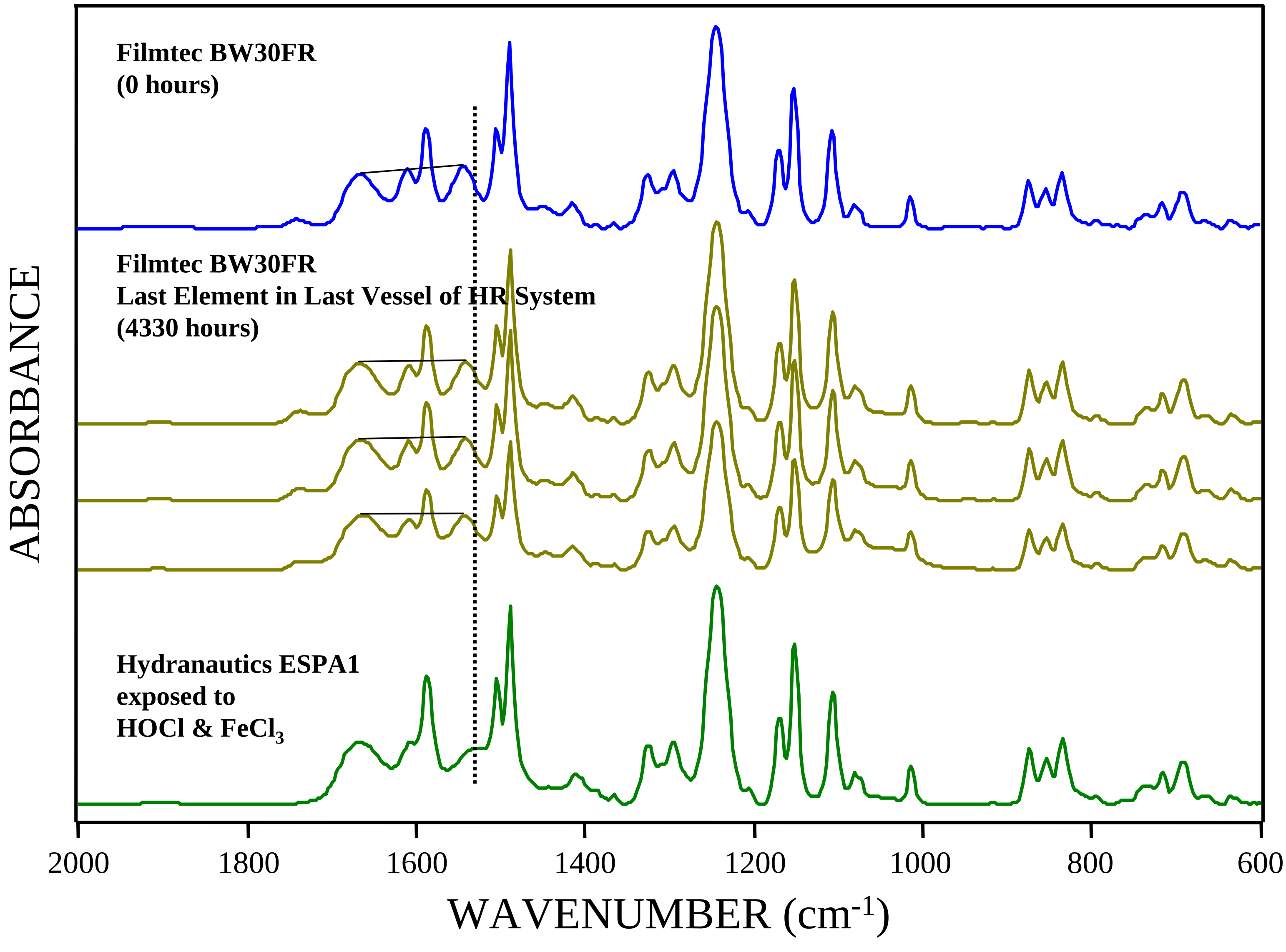

Filmtec BW30FR
(0 hours)
Filmtec BW30FR
Last Element in Last Vessel of HR System
(4330 hours)
Hydranautics ESPA1 exposed to HOCl & $FeCl_3$
ABSORBANCE
4000
3500
3000
2500
2000
1500
1000
WAVENUMBER ($cm^{-1}$)

Figure 17.



Filmtec BW30FR
(0 hours)
Filmtec BW30FR
Last Element in Last Vessel of HR System
(4330 hours)
Hydranautics ESPA1
exposed to
HOCl & $FeCl_3$
ABSORBANCE
2000
1800
1600
1400
1200
1000
800
600
WAVENUMBER ($cm^{-1}$)


Figure 18.

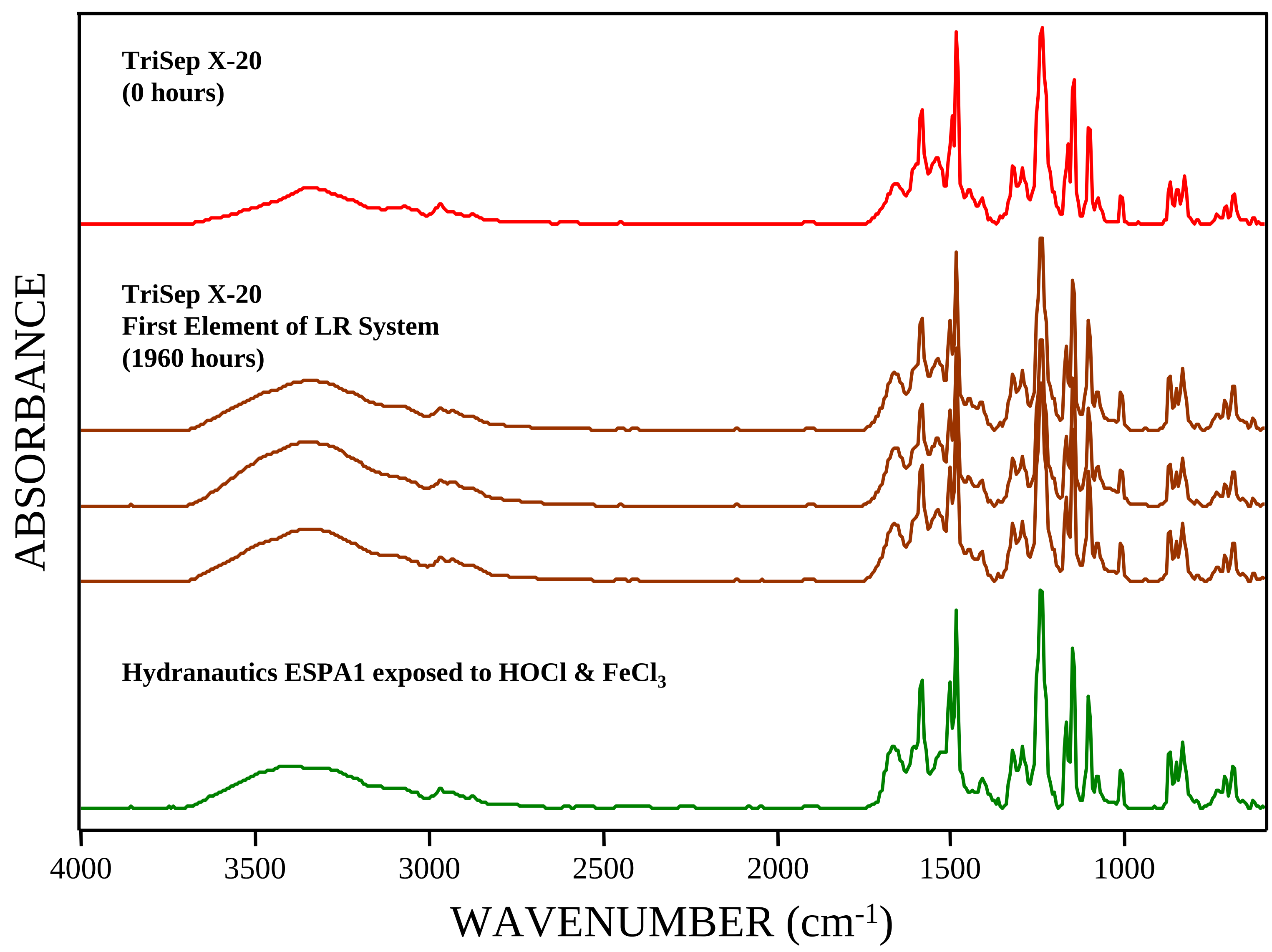
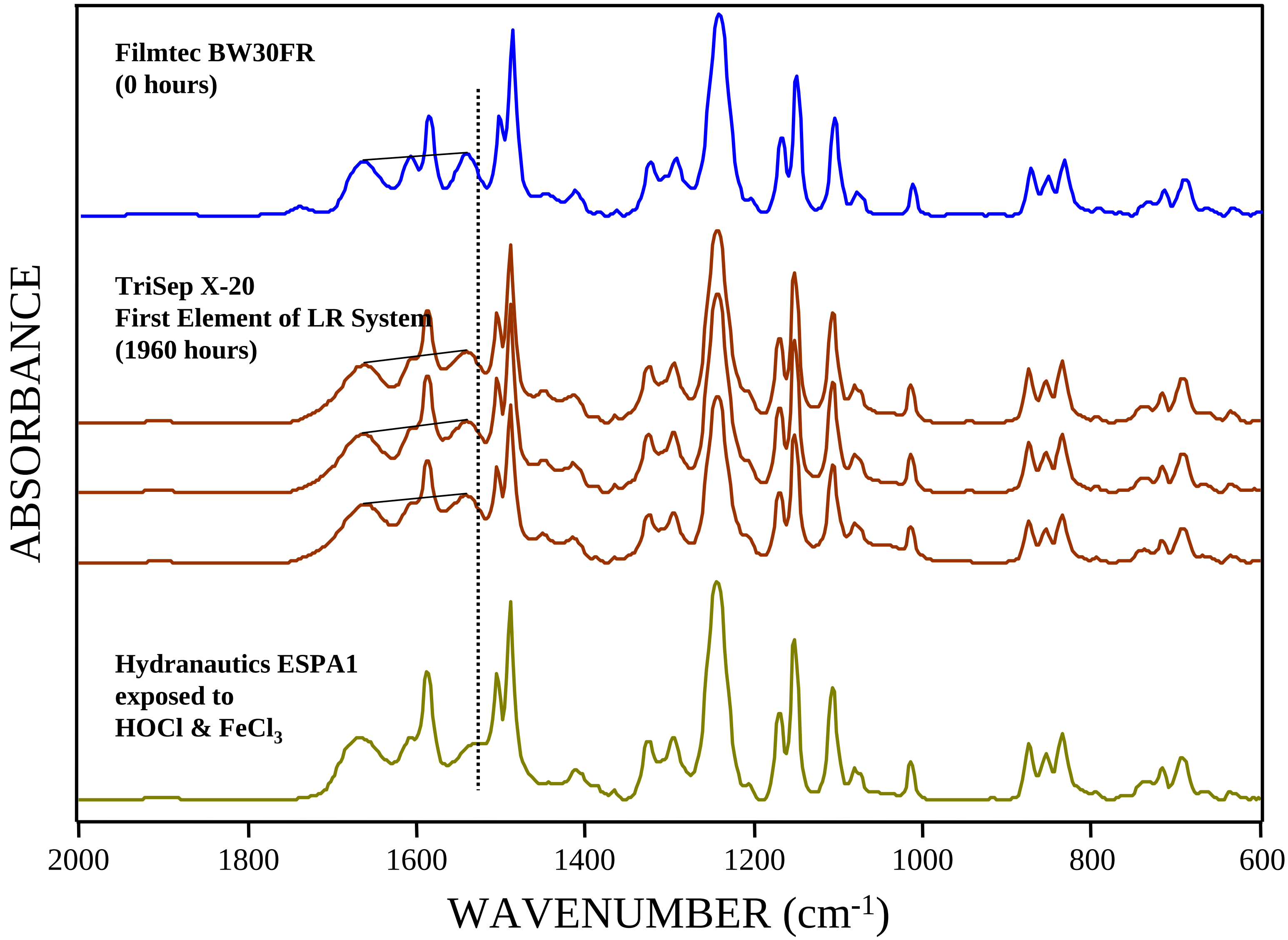

TriSep X-20
(0 hours)
TriSep X-20
First Element of LR System
(1960 hours)
Hydranautics ESPA1 exposed to HOCl & $FeCl_3$
ABSORBANCE
4000
3500
3000
2500
2000
1500
1000
WAVENUMBER ($cm^{-1}$)

Figure 19.



Filmtec BW30FR
(0 hours)
TriSep X-20
First Element of LR System
(1960 hours)
Hydranautics ESPA1
exposed to
HOCl & FeCl3
ABSORBANCE
2000
1800
1600
1400
1200
1000
800
600
WAVENUMBER (cm-1)


Figure 20.

# Appendix E
# Technical Memorandum I.1
# Literature Review: Concentrate Management and Hydrologic and Biologic Characteristics of the St. Johns River Between Lake Monroe and DeLand, FL

# Technical Memorandum I.1

# Literature Review: Concentrate Management and Hydrologic and Biologic Characteristics of the St. Johns River Between Lake Monroe and DeLand FL

**East Central Florida Water Supply Initiative**
**Surface Water Treatability and Demineralization Study**

*Prepared by:*


**CH2M HILL**
**225 E. Robinson Street, Suite 505**
**Orlando, Florida 32801**
*And:*
**Barnes, Ferland and Associates, Inc.**
**3655 Maguire Blvd., Suite 150**
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*Prepared for:*

**St. Johns River Water Management District**
**P.O. Box 1429**
**Highway 100 West**
**Palatka, Florida**
**December 2002**

*BFA* Environmental Consultants
*Barnes, Ferland and Associates, Inc.*

# CONTENTS

# FIGURES

## TABLES



## APPENDIXES

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| Cm | centimeter |
| CWA | Clean Water Act |
| DO | dissolved oxygen |
| EPA | U.S. Environmental Protection Agency |
| DO | dissolved oxygen |
| F.A.C. | *Florida Administrative Code* |
| FDEP | Florida Department of Environmental Protection |
| FFWCC | Florida Fish and Wildlife Conservation Commission |
| FNAI | Florida Natural Areas Inventory |
| GIS | geographic information system |
| HAB | harmful algal blooms |
| IWRM | integrated water resources monitoring |
| LFC | Low Fouling Composite |
| MFL | minimum flow and level |
| mg/L | milligrams per liter |
| mgd | million gallons per day |
| mm | millimeter |
| MS | Microsoft |
| MSJRB | Middle St. Johns River Basin |
| NPDES | National Pollutant Discharge Elimination System |
| NPDOC | non-purgable dissolved organic carbon |
| NTU | nephelometric turbidity unit |
| ppm | Parts per million |
| RCRA | Resource Conservation and Recovery Act |
| RO | reverse osmosis |
| SDWA | Safe Drinking Water Act |

| | |
|---|---|
| SJRWMD | St. Johns River Water Management District |
| STORET | EPA National Water Quality Data Base |
| SWIM | Surface Water Improvement and Management |
| SWQMP | Surface Water Quality Monitoring Program |
| TDS | total dissolved solids |
| TMDL | total maximum daily load |
| TOC | total organic content |
| UCF | University of Central Florida |
| USGS | U.S. Geological Survey |
| USJRB | Upper St. Johns River Basin |
| WQBEL | Water Quality-based Effluent Limits |
| WTP | water treatment plant |

# EXECUTIVE SUMMARY

## PROJECT BACKGROUND

In April 2000, the St. Johns River Water Management District (SJRWMD) adopted the District Water Supply Plan (Vergara, 2000). The Plan addresses current and future water demands, traditional and alternative water sources, and water supply infrastructure improvements required to meet the water supply needs within the SJRWMD's jurisdiction through 2020. Development of alternative water sources, such as surface water and brackish groundwater, will be necessary to supply the increasing demands for water in east central Florida. The East Central Florida Water Supply Initiative St. Johns River Water Supply Project is one of several such projects and will focus on evaluating surface water withdrawn from the St. Johns River as an alternative or supplemental source of water supply for portions of Seminole and Volusia counties. In Phase I, three projects will identify plant locations, facilitate design, and determine the costs of a complete surface water treatment facility (or facilities).

Because surface water is inherently variable in both quantity and quality, water quality monitoring and treatability studies are required before adequate surface water withdrawals, treatment, and storage systems can be designed. As part of the St. Johns River Water Supply Project, CH2M HILL was commissioned to conduct the Surface Water Treatability and Demineralization Concentrate Management Study. The goal of the study is to determine how to treat the surface water to drinking quality standards. Phase I focuses on how to manage the demineralization process. The development of options and costs for treatment to other standards, such as for reuse system augmentation and for recharge into the aquifer will also be evaluated.

The specific study area for this project is the river ecosystem from a point near Lemon Bluff between Lake Harney and Lake Monroe to the confluence of the Wekiva River with the St. Johns River near DeLand (Figure ES-1). Lake Monroe in Sanford is the focus for a potential surface water supply source because of strong local interest by Seminole and Volusia Counties. A pilot membrane treatment plant was operated at the Sanford Wastewater Treatment Facility to determine the treatment requirements.

## TASK I SUMMARY

Task I is a literature review to summarize recent technical information related to the impacts and management of low salinity waste concentrate and to summarize the hydrologic and biologic characteristics of the project reach of the St. Johns River. Data and references are available from the District and the USGS, and also by searching various agency web-sites. Essentially, Task I provides information to be used in the development of a Concentrate Management Plan for a proposed facility of this type.

The SJRWMD and the FDEP have identified surface water discharge to the St. Johns River as the most favorable concentrate disposal option to consider. This was based primarily on the river water quality and on the expected concentrate water quantity and quality. Regulation of discharges to surface waters is based on the classification of the receiving water body. This project reach of the St. Johns River is considered a Class III water body for recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife. Surface water discharges must meet all of the water quality criteria (Chapter 62-302.530) established for the classification of waters or be granted a mixing zone or other administrative relief.

FDEP has the primary responsibility for enforcing the rules and regulations governing the management of demineralization concentrate in Florida. Additional requirements may also come from a broad base of local, state, and federal agencies. Although the FDEP must grant approval for any and all concentrate projects, the involvement of other agencies may be dependant upon project-specific factors such as the selected concentrate management alternative or the location of the project. The specifics of individual demineralization water treatment projects render each concentrate permitting effort unique.

Currently, there are no facilities in Florida that are similar to the proposed facility with regard to facility size, source water quality, and proposed concentrate disposal type.

Numerous sources of information were compiled for the development of a Concentrate Management Plan. These data include:

- Streamflow characteristics
- Raw surface water quality
- Pilot plant waste concentrate quality
- Biological characteristics

The St. Johns River is a large diverse river system with extensive floodplain swamps and marshes. The total drop of the river from its source in marshes south of Melbourne to its mouth in the Atlantic near Jacksonville is less than 30 feet, or about one inch per mile, resulting in a slow-flowing river. The longest river in Florida (310 miles), it is divided into four major drainage basins. The area of interest for the project is the Middle St. Johns River.

The St. Johns River is highly variable in terms of both flow magnitude and water quality. The USGS monitors flow and quality data located along the project reach. These data indicate that low flows tend to occur during the months of April through June and high flows predominate during months September from September through November. River flows generally increase downstream (to the north), because of the greater drainage area and tributary inflows.

Surface water quality along the project reach of the River is seasonally variable. Concentrations are generally are related to the flow magnitude. The primary sources for the St. Johns River are groundwater inflow and surface water inflow. During wet weather, surface water inflow dominates. There is also a continuous discharge of brackish groundwater into the river. During low flow conditions, groundwater inflow makes up a significant portion of total river flow. During periods of low water, tides may cause a reverse flow as far south as Lake Monroe - 161 miles upstream from the river's mouth. In summary, the project reach of the St. Johns River is a slightly brackish surface water. The water has a low turbidity, high color and total organic carbon levels, high hardness, and high TDS.

The pilot testing program, at the Sanford Wastewater Treatment Facility, began in September 2001 and water quality analyses are being conducted both in the field and in analytical laboratories. Phase 1B testing was completed in June 2002. Average concentrate TDS values ranged from 3,085 mg/L to 3,258 mg/L for membrane concentrate. Average concentrate chloride values ranged from 1,139 mg/L to 1,247 mg/L for membrane concentrate. As expected, these values are approximately three to four times higher than the feed concentrations. This relationship is important for risk evaluation. Phase 2 pilot testing should further evaluate seasonal variations of the raw water quality from the river in comparison to the concentrate discharge water quality.

Many plant and animal species within the project reach of the St. Johns River that depend on the river for survival. Existing information was compiled on fish, wildlife, aquatic plants, algae and macroinvertebrates. After reviewing the existing information, a limited field investigation was performed to document the physical environment, water quality, vegetation community and animal community at selected sites along the project reach. The purpose was to identify the characteristics of each area that may be considered when siting a discharge pipe for a river water concentrate. The concentrate discharge location has not yet been determined at this time by HDR. However, this evaluation should include a site-specific survey at potential locations to determine the current presence or absence of rare, threatened, or endangered species and natural communities.

There are many site-specific issues associated with permitting an RO facility for potable water production. However, there are no regulatory exclusions. The permitting process may be lengthy, but it may be reasonably assumed that a facility could be permitted, constructed and operated at some location within the Middle St. Johns River.

To preserve the natural functions or riverine systems, a significant portion of the streamflow regime must be maintained. Therefore, only a share of the resource will be available for water supply purposes. At this time, a withdrawal quantity of about 50 million gallons per day (mgd) is predicted from the St. Johns River within the next ten 10 years. These estimates should be re-evaluated based on the results being established for the Minimum Flows and Levels program.

# INTRODUCTION

## PROJECT BACKGROUND

In April 2000, the St. Johns River Water Management District (SJRWMD) adopted the District Water Supply Plan (Vergara, 2000). The Plan is designed to address current and future water demands, traditional and alternative water sources, and water supply infrastructure improvements required to meet the water supply needs within the SJRWMD's jurisdiction through 2020. Development of alternative water sources such as surface water and brackish groundwater will be necessary to supply the increasing demands for water in east central Florida. The East Central Florida Water Supply Initiative St. Johns River Water Supply Project is part of that plan. It will focus on evaluating surface water withdrawn from the St. Johns River as an alternative or supplemental source of water supply for portions of Seminole and Volusia counties. In Phase I, three projects will identify plant locations, facilitate design through a Pilot Plant project and other assessments, and determine the costs of a surface water treatment facility (or facilities).

Because surface water is inherently variable in both quantity and quality, water quality monitoring and treatability studies are required before adequate surface water withdrawals, treatment, and storage systems can be designed. As part of the St. Johns River Water Supply Project, CH2M HILL was commissioned to conduct the Surface Water Treatability and Demineralization Concentrate Management Study. The purpose of the study was to determine how to treat the surface water to drinking quality standards and how to manage the waste products(Reverse Osmosis concentrate) of that treatment.

## PURPOSE OF TASK I

Task I of the Surface Water Treatability Project is a literature review summarizing recent technical information related to the impacts and management of low salinity waste concentrate and a synopsis of the hydrologic and biologic characteristics of the project reach of the St. Johns River.

A comprehensive review of management of salinity wastes and a literature search product were developed in Technical

Memorandum C.2, Demineralization Concentrate Management Plan, (Reiss Environmental, Inc. 2002) submitted October 2002. Rules and regulations associated with concentrate management were detailed in Technical MemorandumB.5, Applicable Rules and Regulations (Reiss Environmental, Inc. 2001) submitted to the District in November 2001. The discussion of concentrate disposal presented here relies heavily on those two documents.

# OVERVIEW OF CONCENTRATE DISPOSAL OPTIONS

Demineralization concentrate (concentrate) is the by-product produced when brackish water is treated with a pressure-driven membrane process such as reverse osmosis or nanofiltration. This process removes minerals from the water and concentrates them in a waste stream. The resulting concentrate must be managed in an environmentally safe manner (Mickley 1996, 2001). Plant and process design may be important factors in the ability to create a safe disposal (e.g. Gluecksterna and Priela 1997). Developing a plan to manage the concentrate involves careful analysis of many factors. Potential concentrate disposal methods include the following (Andrews and Witt 1993, Reiss Environmental Inc. 2002):

- Placement in deep injection wells
- Discharge to surface waters
- Spreading over land surfaces
- Discharge to wastewater treatment facilities
- Reuse of the waste product

The full range of inland concentrate disposal options include both technologically complex and relatively simple solutions (Andrews and Witt 1993, Electric Power Research Institute 1994, Squire et al 1997). The SJRWMD has identified surface water discharge to the St. Johns River as the most favorable concentrate disposal option to consider based primarily on the river water quality and on the expected concentrate water quantity and quality. At this time, a withdrawal quantity of about 50 million gallons per day (mgd) is estimated from the St. Johns River within the next 10 years. A concentrate discharge volume of about 10-mgd is predicted for disposal. These are preliminary estimates and quantities could change, depending on further evaluations.

A Microsoft (MS) Access database (Membrane_Plants) was developed that provides a summary of all 57 facilities permitted to discharge demineralization concentrate in Florida (Reiss, October 2002). The database table *tblPlant* contains detailed information and requirements for existing permitted facilities that is useful for comparison of the proposed St. Johns River facility. The database includes a summary of information regarding source water quality, concentrate disposal, and permitting requirements. Currently, there are no facilities in Florida that are similar to the proposed facility with regard to facility size, source water quality, and proposed concentrate disposal type. Most facilities use groundwater as a source and injection wells or ocean discharge for concentrate disposal. There are 57 desalination water treatment plants (WTPs) in Florida with capacities greater than 0.1 mgd. None currently use brackish surface water (Reiss Environmental, 2002) or discharge to those waters or other Class III surface waters. Thus the envisioned application is without precedent in this state.

The regulatory approach to disposal of RO concentrate has been treated very differently through time and in different states (e.g. Andrews et al. 1991, Baker et al 1990, Conlon 1994) a proposed discharge to the Middle St. Johns River (including Lake Monroe) would likely require a National Pollutant Discharge Elimination System (NPDES) permit under the industrial wastewater facilities rules. This is because this reach is designated as a Freshwater Class III waterbody - chloride concentration is less than 1,500 milligrams per liter (mg/L) (F.A.C. 62-3.200), although the river downstream of Lake Monroe does have periods of reversed (upstream) flows. As noted in Reiss Environmental (2001), "…each situation is unique and the regulations are complex." That report reviews the subjects of the discharge compliance review, which include antidegradation, water quality-based effluent limits (WQBELs), surface water criteria, mixing zone criteria, toxicity, and issues of existing impairment in the receiving water body. There is potential for major ion toxicity in an RO concentrate (e.g. Mickley 2001) which is a field of active investigation. For some time there has been a discussion of the applicability of standard toxicity testing to brackish concentrate (e.g. Potts and Weinberg 1993). In addition, different mixing zone standards probably would apply to the riverine sections of the study area and to Lake Monroe (62-4.244. *Florida Administrative Code* [F.A.C.]). Riverine mixing zones are defined as a specific distance downstream of the discharge source. A lake mixing zone is a defined as a specific area around the pipe end. The particular hydraulic conditions at potential discharge sites may have to be carefully compared to identify the alternative that minimizes environmental impacts.

The current regulation of concentrate disposal in Florida (summarized in Kimes 1994, also Thomas 1995 and Mandrup-Poulsen 1997)) were recently amended. Florida Senate Bill 536, signed in June 2001, amended the Florida statutes to allow the Florida Department of Environmental Protection (FDEP) to address demineralization rules in ways that would ease concentrate disposal concerns specifically related to "the presence of constituents identified … as naturally occurring in the source water" (Reiss Environmental, 2001). Applicable rule changes are still under consideration. Th ultimate result should be regulation that provides a clearer (and perhaps less onerous) permitting process for demineralization concentrate management. These changes will include specific consideration of toxicity test failure due to naturally occurring constituents.

In summary, although it is a novel situation, there is no reason why a potable water RO facility could not be permitted in the middle St. Johns River, assuming it met the requirements in F.A.C. 62 for an NPDES permit.  This may be an lengthy process, but there may be regulatory changes to the rules governing such a permit that will reduce the effort needed to achieve regulatory satisfaction.

# LITERATURE REVIEW

## BIBLIOGRAPHY DATABASE

A bibliographic database was developed using MS Access software that allows a search of the documents through various topic listings and tables. The bibliography includes a total of 200 entries, with 50 of these considered most relevant. Each entry contains the name of the author, the date of the publication, and the title of the document. References contained in the MS Access database can be queried to generate the following reports:

- Complete alphabetical listing of all 200 references
- A listing of references within the SJRWMD
- A listing of the 50 most pertinent references
- Topic category - concentrate disposal
- Topic category - water quality
- Topic category - hydrology
- Topic category - biological

Sources used to develop this database included libraries of the Water Management Districts and the U.S. Geological Survey (USGS). Many of the concentrate disposal-related references were obtained from the existing bibliography database prepared by the SJRWMD district-wide concentrate management consultant (Reiss Environmental, Inc.).

Data and references were also obtained by searching the various agency websites listed below.

- U.S. Environmental Protection Agency (EPA) (www.epa.gov)
- EPA – Surf Your Watershed (www.cfpub.epa.gov/surf/
- USGS (www.usgs.gov)
- U.S. Fish and Wildlife Service (www.fws.gov)
- U.S. Army Corps of Engineers (www.usace.army.mil)
- FDEP (www.dep.state.fl.us)
- Florida Fish and Wildlife Conservation Commission (FFWCC) (www.floridaconservation.org)
- SJRWMD (www.sjrwmd.com)

- Volusia County Environmental Mgmt. (www.volusia.org\environmental\)
- Brevard County (www.natres.countygovt.brevard.fl.us)
- Orange County (www.orangecountyfl.net/dept/CEsrvcs/epd/)
- Seminole County (www.co.seminole.fl.us/envsrvs/)
- Lake County (www.lakegovernment.com/water.htm)
- University of Florida Lake Watch (www.lakewatch.ifas.ufl.edu)

The database is an electronic ACCESS file provided electronically as as part of the final report for the study.

# CURRENT RELATED PROJECTS

Several SJRWMD projects were directly related to the Surface Water Treatability and Demineralization Concentrate Management Study. Project coordination and sharing of data between these projects provided additional support for this project.

### Investigation of Demineralization Concentrate Management

The SJRWMD is investigating the feasibility of alternative water supply strategies and has identified brackish groundwater, brackish surface water, and seawater as potential sources of supply to meet future demands (CH2M HILL 1996a, CH2M HILL 1996b). These alternative water sources will require treatment using demineralization technologies. These technologies are primarily pressure-driven membrane processes that include reverse osmosis or nanofiltration. During this process, minerals in the source water, including salts, are removed, producing potable water as well as a by-product known as demineralization concentrate.

Developing acceptable management strategies for demineralization concentrate is the goal of the Investigation of Demineralization Concentrate Management Project. In addition, the project will identify any required technical studies, data collection, or analysis needed to formulate, implement, and monitor the effectiveness of management strategies. A primary component of the Project will be the development of a

Demineralization Concentrate Management Plan. The plan outlined environmentally acceptable options for concentrate management.

This project was coordinated for the District by Reiss Environmental, Inc., of Winter Park and was scheduled for completion in early 2003. The management plan considered technologies for demineralization, existing disposal projects, environmental and cultural impacts of disposal, current and future regulations, and disposal alternatives.

**Middle St. Johns River Basin SWIM Program**

In year 2000, the District's Governing Board established a Surface Water Improvement and Management (SWIM) program encompassing the entire middle basin. Nineteen water segments in the basin are identified as impaired waters on the FDEP 2000 303(d) list (FDEP 2000). The impairment of those segments reflects a combination of past unregulated land use and waste disposal practices and increased quantities and velocities of stormwater runoff resulting from urban development. There are a number of previous and existing projects in the Middle Basin including work in and around Lake Jesup and the Little Wekiva River as well as an active ecosystem management effort in Lake George. SWIM efforts to improve water quality and to enhance natural systems in the basin include the Five-Year Lake Jesup Restoration Initiative and the Little Wekiva River Watershed Management Plan.

Two recent studies provide an inventory of existing conditions in the Middle Basin. URS Inc. prepared a report for the SJRWMD titled *Middle St. Johns River Basin Final Reconnaissance Report (*URS 2001). This report provides a summary of the issues and activities that exist within the basin and the strategies needed to address them. The elements addressed within this report are water quality, water quantity, ecosystems, and water supply. The report was used as a resource guide in the development of the January 2002 *Middle St. Johns River Basin (MSJRB) Surface Water Improvement and Management (SWIM) Plan* (SJRWMD 2002). The purpose of the MSJRB SWIM Plan is define a realistic course of action, identifying the projects and the effort needed to accomplish them, consistent with the levels and trends of SWIM funding. The plan focuses on four initiatives:

- Water quality enhancement, with emphasis on nutrient loading reduction and lake protection
- Watershed master planning, with emphasis on completing hydrologic models of sub-basins
- Stormwater retrofitting of areas built prior to 1983
- Compliance and rule enforcement of the existing permitted stormwater systems

**Minimum Flows and Levels Project**

Florida law (Chapter 373, Florida Statutes) requires Florida's water management districts to establish minimum flows for water courses and minimum levels for ground and surface waters that represent the limit at which further withdrawals would cause significant harm to the water resources or ecology of an area. The goal of the minimum flows and levels program is "to establish ecologically based minimum flows and levels that will be implemented through the District's water supply planning, consumptive use permitting, and environmental resource permitting programs and to protect groundwater aquifers, wetlands, water bodies, and water courses from significant harm caused by water withdrawals or diversions." Minimum flows and levels (MFLs) are being developed by the District to ensure that water withdrawals from the St. Johns River will not harm the river, its tributaries, and associated wetlands. Establishing MFLs will help determine how much river water is available for other uses, while protecting the upstream and downstream river system.

The Middle St. Johns River streamflow characteristics currently are being assessed by the District and the USGS as part of a federal-state cooperative program. Minimum flows and levels for the St. Johns River at State Roads 44 and 50 and at Lake Monroe (Mace 2002) are targeted for adoption during 2003.

**Surface Water Quality Monitoring Program**

The SJRWMD's Surface Water Quality Monitoring Program (SWQMP) was established in 1983. The SWQMP currently maintains a surface water quality monitoring network of 72 stations located throughout the SJRWMD that are sampled six times each year. The goal of the surface water monitoring program is "to monitor, assess, and report on the water, sediment, and biological quality of District surface waters." The SWQMP, through its own sampling network and with data acquired by other agencies, performs a District-wide assessment of water quality. This assessment is directed toward: 1) establishing background conditions; 2) determining temporal trends; and 3) identifying areas of poor or affected water quality.

SJRWMD makes a considerable effort to coordinate the District's monitoring activities with those of FDEP, other state agencies, and local governments. The program participates in FDEP's Integrated Water Resources Monitoring (IWRM) Tier 1 Network. Data generated under the program are sent to the EPA's National Water Quality DataBase (STORET) and used by FDEP for Florida's Biennial 305(b) Report. The program provides support for modeling efforts involving surface water quality and produces an annual district-wide assessment of surface water quality status and trends and other assessments.

**Surface Water Treatment Plant Siting Study**

As part of the St. Johns River Water Supply Project SJRWMD commissioned HDR, Inc., to conduct a study to determine potential locations for a surface WTP. This work focuses on locating a site for the following WTP elements:

- Plant site
- River intake
- Raw water storage facility
- Demineralized concentrate disposal area
- Pipeline corridors

The study used a multilevel screening process. The first two levels included preliminary screening to determine a general site location and the third level included a detailed analysis to select a specific site. The primary study area is an area located approximately 5 miles either side of the St. Johns River between the upstream end of Lake Monroe and the City of De Land.

Three to five candidate sites will be carried forward for a more detailed analysis. This analysis will include an evaluation of natural resource impacts, clarification of land use, and assessment of economic impacts. Cost estimates will be developed for each of the project components for each of the candidate sites. On the basis of this evaluation, the site will be ranked and one candidate site and pipeline corridor will be identified.

# AVAILABLE GIS COVERAGES

During the literature review, many geographic information system (GIS) coverages were found to be available from various government agencies. These coverages may be downloaded from their websites or obtained through the agency GIS sections. The following GIS coverages may be useful for this project, primarily to evaluate potential environmental constraints.

**St. Johns River Water Management District**

- 2002 Acquisition Map
- Basin and Sub-Basin Boundaries
- Floodplains within SJRWMD
- Flow and Salinity (Hydrodynamics) Models
- Hydrologic Basins and Public Supply Withdrawals in the SJRWMD
- Lake Monroe Conservation Area
- Major Surface Water Programs
- Regionally Significant Habitat in the SJRWMD
- River Lakes Conservation Area
- Roads and SJRWMD
- SJRWMD Major Basins And Planning Units
- Seminole Ranch Conservation Area
- Upper St. Johns River Basin (USJRB) Project
- USJRB Restoration Projects
- Water Quality Status and Trends in Northeast Florida

**Florida Department of Environmental Protection**

- Bathymetry
- Drainage Basins
- Ecosystem management
- Future land use
- FFWCC management areas
- Hydrologic features
- Lakes
- Major rivers
- Manatee protection zones
- Marinas
- Outstanding Florida Waters aquatic preserves
- Parks and recreation areas
- SJRWMD land use
- Special Outstanding Florida Waters

- STORET 305b
- Surface water class boundaries
- USGS gauging stations
- Water quality 303d, 1998
- Water quality 305b, 2000

**Florida Fish and Wildlife Conservation Commission**

- Integrated wildlife habitat ranking system
- Strategic habitat conservation areas
- Biodiversity hot spots
- Priority wetlands for listed species
- Bald eagle nest sites
- Wildlife observation database
- Wading bird rookeries
- Critical wildlife areas

# SUMMARY OF ST. JOHNS RIVER DATA

## BASIN CHARACTERISTICS

### General

The St. Johns River is an ancient intracoastal lagoon system. As sea levels dropped, barrier islands prevented water from flowing east to the ocean. The water collected in the flat area behind the islands forming the St. Johns River. The St. Johns River is the longest river in Florida (310 miles) and is divided into four major drainage basins (Figure 1). Because the river flows north, the upper basin is the southernmost area that includes its marshy headwaters in Indian River and Brevard counties. The middle basin is the area in central Florida where the river widens, forming lakes Harney, Jesup, and Monroe. The Lake George Basin consists of the St. Johns River drainage area from the mouth of the Wekiva River to the mouth of the Oklawaha River, located in parts of Volusia, Lake, Marion, and Putnam counties. The lower basin is the area in northeast Florida from Putnam County to the river's mouth in Duval County, where the river empties into the Atlantic Ocean. The initial stated boundaries for this project were the south (upstream) end of Lake Monroe and the St. Johns River near DeLand. However, the boundaries for ecosystem investigation in this report were extended for several reasons. The southern boundary was extended to the Government Cut area of the river south of Lake Monroe based on developing information from the plant siting study. Also, as the investigation of ecosystem characteristics developed, it became apparent that the boundaries of technical studies on the river ecosystem were not divided on the same boundaries as the project area. Also, the downstream and, particularly, the upstream ecosystem can have significant effects on the project study area. Therefore information on the river basin between the outlet of Lake Poinsett to the inlet of Lake George was collected (Figure 2).

The total drop of the river from its source in marshes south of Melbourne to its mouth in the Atlantic near Jacksonville is less than 30 feet, or about one inch per mile, resulting in a slow-flowing river. Salt water enters the river at its mouth in Jacksonville. In periods of low water, tides may cause a reverse flow as far south as Lake Monroe - 161 miles upstream from the river's mouth. Major tributaries, or smaller streams and rivers that flow into the St. Johns River, include the Wekiva River, the Econlockhatchee River and the Ocklawaha River. St. Johns River discharge and water quality are measured by the USGS at five stations within this area.

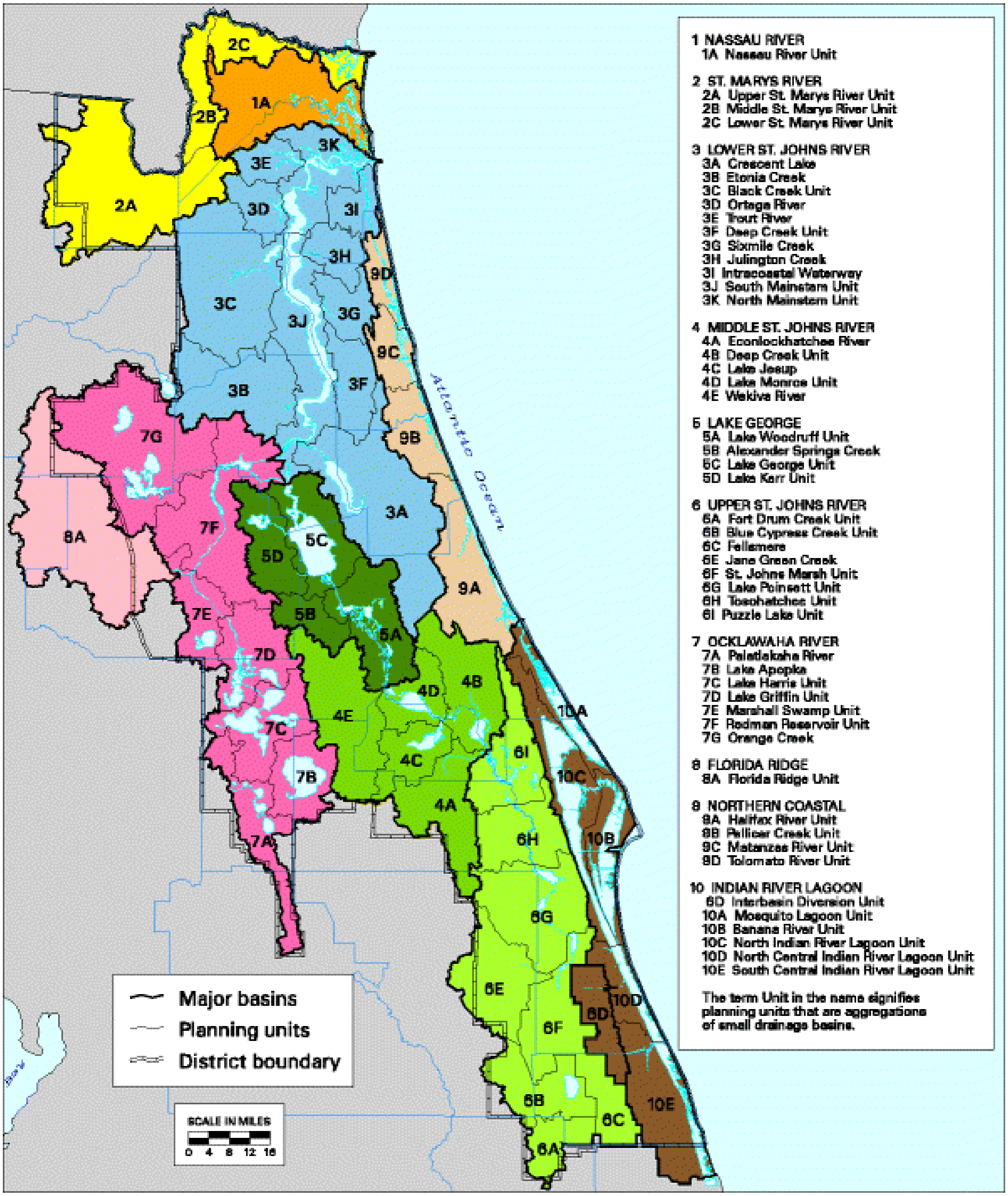


Figure 1 - St. Johns River and major drainage basins (source: SJRWMD GIS)

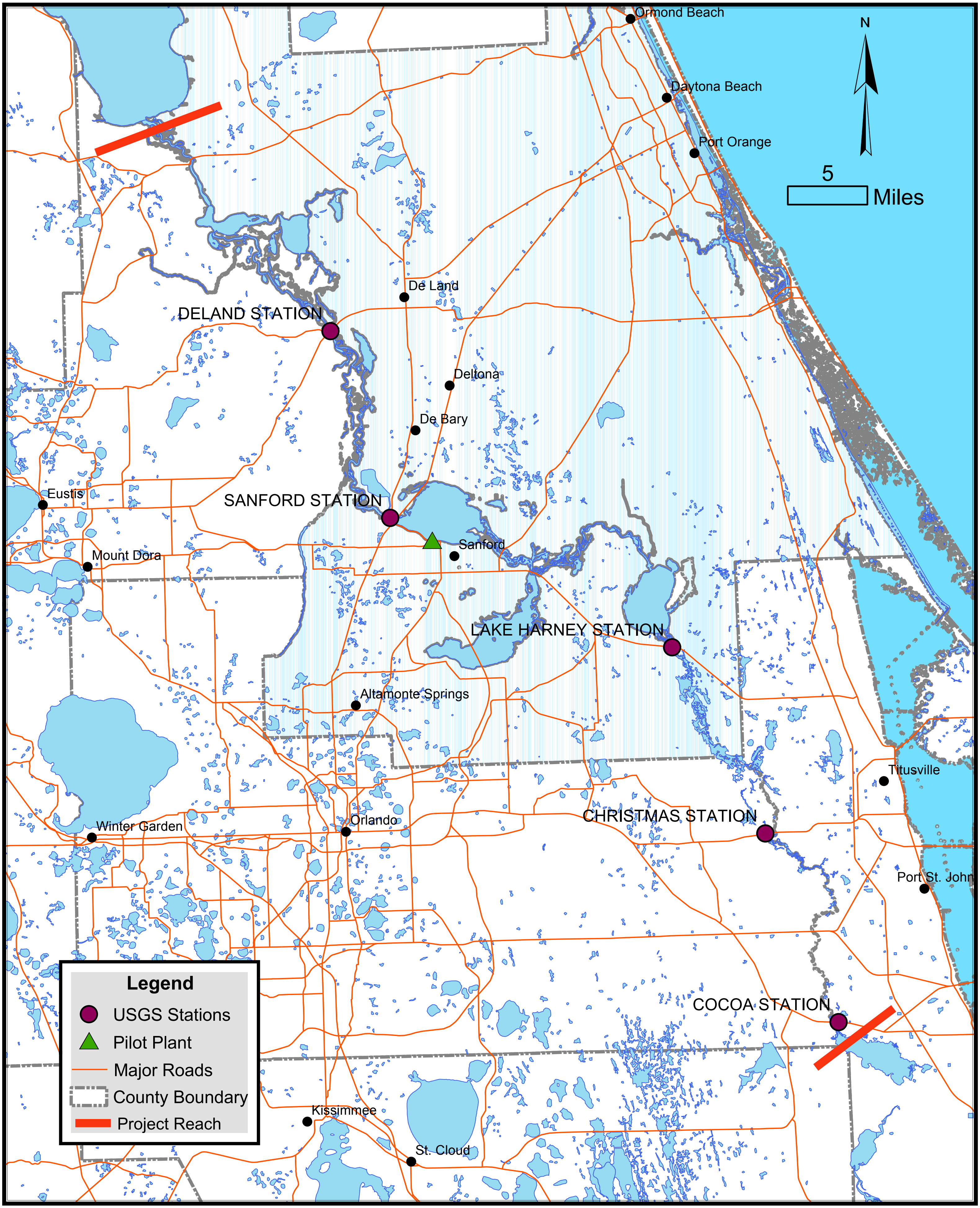


**Figure 2 - Location of Study Area, Pilot Plant and USGS Stations**

## Lake Monroe

Lake Monroe in Sanford is the focus for a potential surface water supply source due to strong local interest. It is a “river run” lake; that is, the lake is an enlargement of the river channel and the river runs through the lake. The lake is about 6 miles long and 4 miles wide with a surface area of 9,406 acres. It is on average about seven feet deep. The lake is considered the upstream end of the commercially navigable portion of the St. Johns River. The City of Sanford occupies the southern shore of Lake Monroe. With the advent of commercial steamboat service in the mid-1800s, Lake Monroe became an important distribution point for goods essential for the growth of Central Florida (US Army COE 1971). The lake is now used extensively for recreational purposes (fishing and boating).

The Lake Monroe watershed is heavily developed, although wetlands exist on the eastern and western shores of the lake. It is within the highest growth potential area of Seminole County. A large amount of acreage in the I-4/SR 46 corridor is designated as higher intensity planned development that allows industrial, office, commercial, and multifamily developments. The area immediately upstream of Lake Monroe includes mixed land uses (residential, commercial, and agricultural). Extensive residential areas exist northwest and northeast of Lake Monroe in DeBary and the City of Deltona respectively. The lake currently receives wastewater discharges from Deltona. The City of Sanford, which formerly discharged into Lake Monroe, has shifted to water reuse and effluent spray-fields on the south side of Lake Jesup. Florida Power and Light- Sanford Power Plant operates a power plant along the St. Johns River just north (downstream) of Lake Monroe (USACE 1981). This is a permitted industrial wastewater facility and discharges water used for cooling processes to a small lake adjacent to the river.

Lake Monroe exhibits eutrophication and is listed as a potentially impaired water body (FDEP 2000: 303d List) by FDEP. The water quality parameters of concern in Lake Monroe are low dissolved oxygen (DO), high nutrients, lead, un-ionized ammonia, and selenium levels (FDEP, 1998). A bulkhead has been constructed along a large portion of the southern shoreline and a portion of Hwy. 17/92 runs along the bulkhead. There are no treatment areas for road stormwater runoff in this area.

# ST. JOHNS RIVER STREAMFLOW CHARACTERISTICS

Surface water sources can be highly variable in terms of both flow magnitude and water quality. The primary sources for the St. Johns River are groundwater inflow and surface water inflow. During wet weather, surface water inflow dominates. There is also a continuous discharge of brackish groundwater into the river because the potentiometric head of the Floridan aquifer (pressure within the aquifer) is higher than the downward force exerted by the river. During low flow conditions, groundwater inflow makes up a significant portion of total river flow.

To preserve the natural functions or riverine systems, a significant portion of the streamflow regime must be maintained. Therefore, only a share of the resource will be available for water supply purposes. SJRWMD Special Publication No. SJ96-SP1 (CH2M HILL 1996a) provides a discussion of hydrologic factors affecting water supply development of the St. Johns River and preliminary estimates of maximum available quantities. At this time, a withdrawal quantity of about 50 MGD is predicted from the St. Johns River within the next 10 years. These estimates should be reevaluated based on the results being established for the MFL program. The District has developed a hydrology based MFL approach to define the protective long-term hydrologic regime for this system. Adopted MFLs are implemented through consumptive use, environmental resource permitting and water supply planning programs, and other District programs. Additionally, District staff is conducting applied research projects that will update MFL definitions in 40C-8, F.A.C.

St. Johns River streamflow and water quality characteristics will be used in a risk-based assessment of concentrate management options in project Task J of this project. The USGS monitors historical flow data at five established stations located along the St. Johns River (Figure 2). Mean daily and monthly flow statistics for the period or record reported by USGS on their website (WWW.USGS.GOV/NWIS) are provided in Table 1. Flow and TDS concentration from January 2000 to May 2002 are provided for all the stations except Lake Harney in Figures 3 through 6. These data were collected biweekly between June 2000 and May 2002 as part of an intensive study of the river. Reverse river flows have occurred at all station in Table 1. Very low and zero flow values are shown in the CFS figures but negative flows dip below the bottom of the graph. This is particularly evident at the

Sanford and DeLand stations (Figures 5 and 6). Very low daily minimum flow values at Christmas and Cocoa represent periods of extreme drought.

**Table 1. Summary of Average Daily Mean Flow Statistics for the USGS Monitoring Stations on the St. Johns River for the USGS Period of Record (WWW.USGS.gov)**

| Description | DELAND | SANFORD | LK. HARNEY | CHRISTMAS | COCOA |
|---|---|---|---|---|---|
| USGS Station Number | 2236000 | 2234500 | 2234000 | 2232500 | 2232400 |
| Drainage Area (square miles) | 3070 | 2582 | 2043 | 1539 | 1331 |
| Period of Record (years) | 68 | 9 | 18 | 68 | 48 |
| Daily Minimum Flow (cfs) | -3,260 | -1,860 | -77 | -137 | -125 |
| Daily Mean Flow (cfs) | 3,033 | 2,003 | 1,823 | 1,286 | 998 |
| Daily Maximum Flow (cfs) | 17,100 | 9,020 | 9,880 | 11,600 | 10,700 |
| 80% Exceedance (cfs) | 4,534 | 4,025 | 3,210 | 2,045 | 1,582 |
| 50% Exceedance (cfs) | 2,596 | 1,603 | 1,209 | 960 | 697 |
| 20% Exceedance (cfs) | 1,392 | 559 | 547 | 345 | 225 |

**Figure 3. Flow and TDS for the USGS DeLand, FL Station, June 2000-May 2002 Bi-weekly Values**

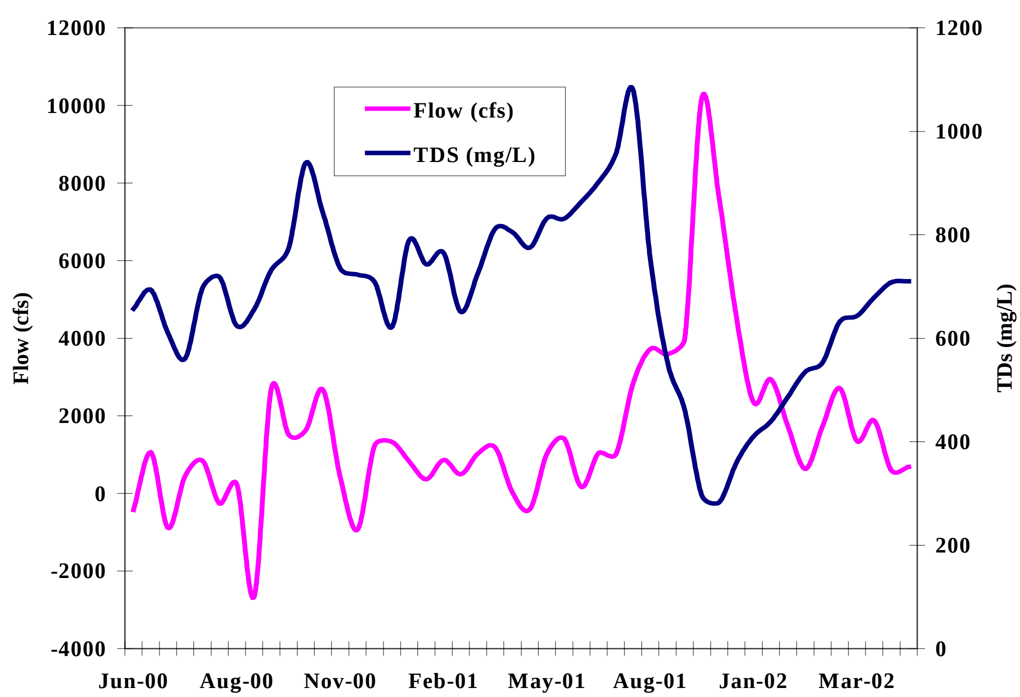

**Figure 4. Flow, conductivity and TDS for the USGS Sanford, FL Station, June 2000 – May 2002 Bi-weekly Values**

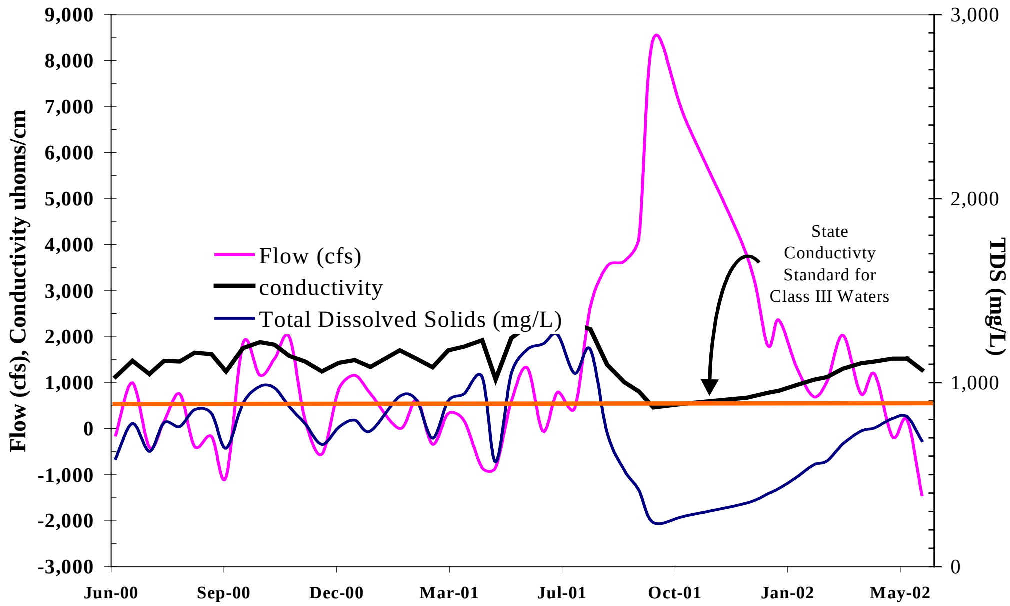


**Figure 5. Flow and TDS for the USGS Christmas, FL Station, June 2000-May 2002 Bi-weekly Values**

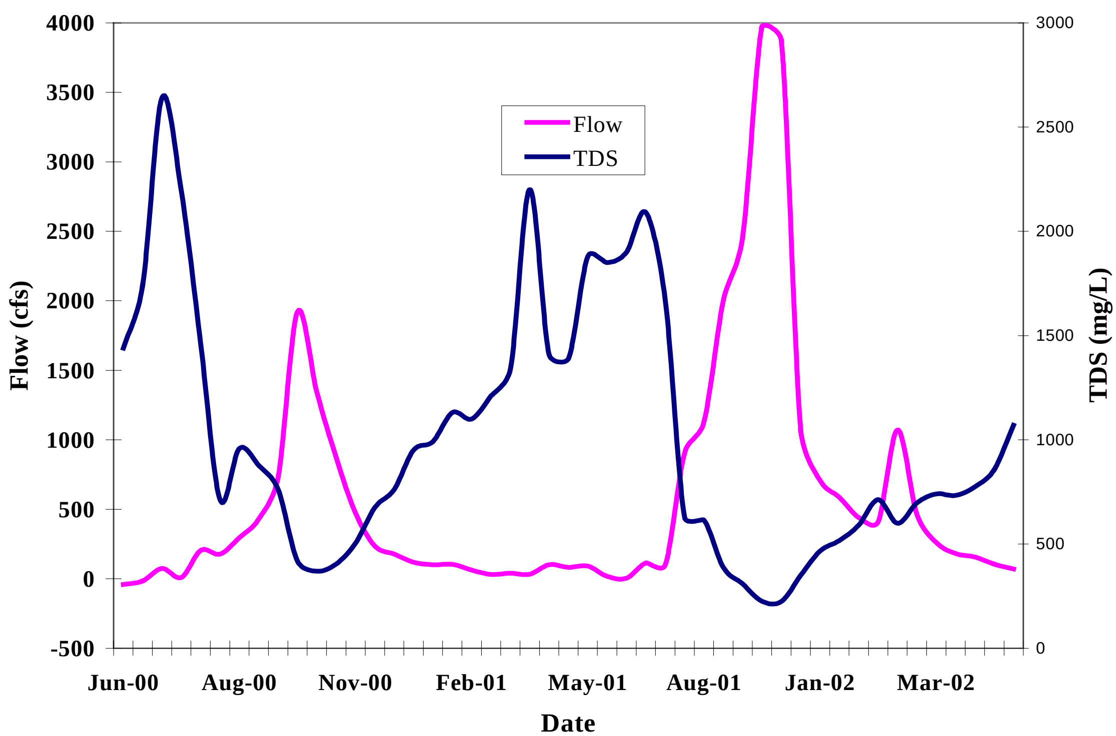

**Figure 6. Flow and TDS for the USGS Cocoa, FL Station, June 2000-May 2002 Bi-weekly Values**

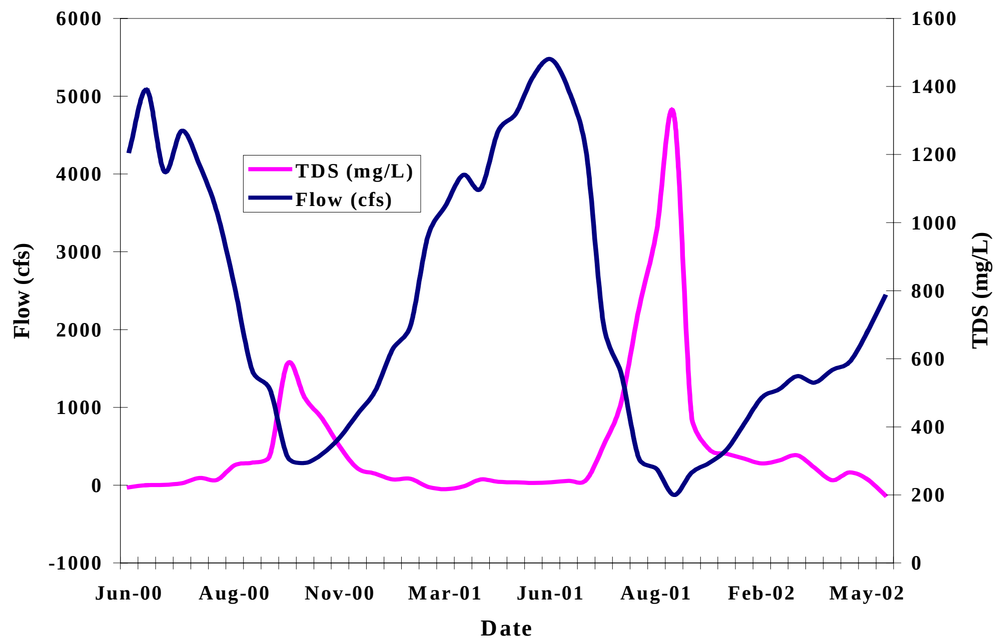


Figure 4, the Sanford station, also shows conductivity data, which shows the temporal extent of conditions considered for regulatory purposes as brackish (as opposed to a freshwater classification)

Although two of these stations used in this review (Table 1: Christmas and Cocoa) are well upstream, outside the study area, they are included because the total dissolved solids (TDS) concentrations in the study reach (important to the effects of reverse osmosis [RO] concentrate) may be significantly affected by upstream conditions.

Mean monthly flow statistics (USGS website: WWW.USGS.GOV/NWIS historic database) are summarized in Table 2. These data indicate that low flows tend to occur during the months of April through June and high flows predominate from September through November. The end of the highest flows are expected in October at the end of the summer rainy season. River flows generally increase downstream (to the north) because of the greater drainage area and tributary inflows. The unequal period of record also should be considered when comparing the streamflow characteristics of these five stations.

**Table 2. Summary of Mean Monthly Flow for the USGS Monitoring Stations on the St. Johns River (from www.usgs.gov/nwis-historicdata)**

| Description | DeLand | Sanford | Lk. Harney | Christmas | Cocoa |
|---|---|---|---|---|---|
| USGS Station Number | 2236000 | 2234500 | 2234000 | 2232500 | 2232400 |
| Drainage Area (square miles) | 3070 | 2582 | 2043 | 1539 | 1331 |
| Period of Record (years) | 68 | 9 | 18 | 68 | 48 |
| January | 2,787 | 2,554 | 1,845 | 995 | 740 |
| February | 2,520 | 1,993 | 1,459 | 894 | 700 |
| March | 2,564 | 1,939 | 1,370 | 960 | 799 |
| April | 2,402 | 1,588 | 1,451 | 785 | 646 |
| May | 1,540 | 1,056 | 754 | 426 | 376 |
| June | 1,775 | 831 | 1,023 | 639 | 492 |
| July | 2,934 | 1,178 | 1,535 | 1,166 | 875 |
| August | 3,448 | 1,663 | 2,091 | 1,491 | 1,123 |
| September | 3,983 | 2,509 | 2,738 | 2,088 | 1,544 |
| October | 4,816 | 3,425 | 2,859 | 2,703 | 2,119 |
| November | 4,331 | 3,434 | 2,551 | 1,951 | 1,517 |
| December | 3,264 | 2,634 | 2,185 | 1,303 | 1,025 |
| **Mean Annual Streamflow** | 3,030 | 2,067 | 1,822 | 1,283 | 996 |

# ST. JOHNS RIVER RAW WATER QUALITY

Available raw water quality for USGS sampling stations within the larger area under consideration was characterized for this project. The USGS conducted biweekly sampling beginning January 2000 along the project reach of the St. Johns River at the Cocoa, Christmas, Sanford, and DeLand monitoring stations. Some historical data also were available for these stations and the Lake Harney Station. Figure 2 shows these station locations, and Appendix A contains biweekly USGS surface water quality results. Table 3 provides a comparison of selected water quality results at four USGS stations along the St. Johns River within and upstream of the study reach.

While there are other water quality data available for this area of the river, (primarily from the Volusia County Environmental Health Department Laboratory Services) they were not included in this evaluation. The USGS data were selected for this study for reasons of consistency and quality. The USGS data set includes flow with water quality information, while the other datasets generally do not. The USGS data is of the highest quality and consistency. The other water quality data on the river may also prove useful if and when a decision is made to build an RO plant. However, a lengthy QA process will be necessary to ensure that data from the various sources is compatible and equally accurate. The USGS data provided a sufficient and consistent basis for this report.

The project reach of the St. Johns River is slightly brackish (Table 3). The Middle St. Johns River water has high total dissolved solids (TDS) concentrations, low turbidity, high total organic content (TOC), and high hardness. Average chloride values range from 250 mg/L to 364 mg/L. The average TDS concentrations range from 681 mg/L to 1,011 mg/L. Hardness in the river ranges from 232 mg/L to 346 mg/L and is primarily noncarbonate hardness due to the low alkalinity levels in the St. Johns River. Average TOC values range from 26 mg/L at the southern monitoring stations to 15 mg/L at the northern monitoring stations.

Surface water quality along the project reach of the St. Johns River is seasonally variable and concentrations are generally but weakly related to the flow magnitude. Figures 3 through 6 show the TDS concentrations for each of these USGS stations during the period from January 2000 to May 2002. During wet weather, low TDS surface water inflow dominates and TDS concentrations will be relatively low. Also, at the De Land monitoring station, the brackish groundwater effect is partially offset by the significant inflow of non-brackish groundwater from freshwater springs and tributaries, including the Wekiva River and Blue Springs.

Total tributary area also plays a significant role in expected TDS concentration and other in-stream water quality parameters. As tributary area increases, both surface water inflow and groundwater inflow will increase. It is the relative contribution of each of these major sources that will define water quality at any point and time. Tributary area increases from 1,331 square miles at Cocoa to 3,066 square miles at De Land. The tributary areas at the intermediate sampling stations are 1,539 square miles at Christmas and 2,582 square miles at Sanford.

**Table 3. Summary of Selected Raw Water Quality Results from USGS Monitoring Stations on the St. Johns River Unpublished Data, USGS Altamonte Springs, FL. 2000 – 2002 Intensive Study Data**

| Description | Units | DeLand | | | Sanford | | | Christmas | | | Cocoa | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Minimum | Maximum | Mean | Minimum | Maximum | Mean | Minimum | Maximum | Mean | Minimum | Maximum |
| Alkalinity (as CaCO3) | mg/L | 81 | 48 | 118 | 69 | 42 | 108 | 66 | 23 | 137 | 67 | 42 | 95 |
| pH | | 7.5 | 6.6 | 8.2 | 8.0 | 6.7 | 9.6 | 7.3 | 6.3 | 8.8 | 7.8 | 6.9 | 9.1 |
| Specific Conductivity | uS/cm | 1194 | 456 | 2010 | 1316 | 452 | 2380 | 1589 | 402 | 3900 | 1200 | 351 | 2620 |
| Temperature | Deg C | 24 | 12 | 31 | 25 | 10 | 32 | 23.7 | 9.3 | 30.2 | 24.3 | 8.9 | 32.1 |
| Total Hardness (as CaCO3) | mg/L | 232 | 99 | 350 | 241 | 92 | 390 | 346 | 100 | 830 | 298 | 99 | 630 |
| Turbidity | NTU | 3.3 | 0.5 | 8.7 | 5.4 | 0.9 | 45.0 | 6.2 | 0.2 | 15.0 | 5.6 | 0.3 | 20.0 |
| Dissolved Oxygen | mg/L | 5.6 | 0.5 | 9.3 | 7.7 | 1.7 | 13.8 | 5.5 | 0.1 | 9.7 | 7.1 | 2.4 | 10.7 |
| Total Phosphorus (as P) | mg/L | 0.07 | 0.02 | 0.22 | 0.08 | 0.03 | 0.38 | 0.10 | 0.02 | 0.28 | 0.09 | 0.03 | 0.39 |
| Ammonia (as N) | mg/L | 0.10 | 0.01 | 0.50 | 0.09 | 0.01 | 0.81 | 0.20 | 0.02 | 1.70 | 0.10 | 0.01 | 0.40 |
| Total NO2 + NO3 (as N) | mg/L | 0.12 | 0.02 | 0.44 | 0.08 | 0.02 | 0.28 | 0.10 | 0.02 | 0.40 | 0.07 | 0.02 | 0.70 |
| Nitrite (as N) | mg/L | 0.02 | 0.01 | 0.16 | 0.02 | 0.01 | 0.20 | 0.01 | 0.01 | 0.06 | 0.01 | 0.01 | 0.06 |
| Dissolved Organic Carbon | mg/L | 15.5 | 1.6 | 35.0 | 19.5 | 3.4 | 33.0 | 24.8 | 2.1 | 34.0 | 25.7 | 2.2 | 42.0 |
| Color | Cu | 97 | 10 | 320 | 111 | 10 | 320 | 139 | 40 | 320 | 140 | 50 | 400 |
| Bromide | mg/L | 1.3 | 0.5 | 8.7 | 1.4 | 0.5 | 8.3 | 1.5 | 0.4 | 6.6 | 1.5 | 0.3 | 17.0 |
| Chloride | mg/L | 259 | 92 | 459 | 299 | 92 | 560 | 364 | 75 | 1150 | 250 | 61 | 647 |
| Sulfate | mg/L | 84.9 | 7.9 | 187.0 | 94.3 | 7.9 | 200.0 | 167 | 14 | 534 | 126 | 12 | 380 |
| Total Dissolved Solids (TDS) | mg/L | 681 | 283 | 1080 | 758 | 239 | 1260 | 1011 | 224 | 2640 | 752 | 200 | 1480 |
| Magnesium | mg/L | 21.2 | 8.0 | 36.0 | 23.5 | 7.6 | 40.0 | 30.4 | 7.0 | 90.0 | 21.9 | 6.2 | 48.0 |
| Sodium | mg/L | 142 | 49 | 260 | 168 | 49 | 300 | 199 | 37 | 620 | 128 | 30 | 310 |
| Barium | ug/L | 24 | 15 | 97 | 29 | 16 | 45 | 52 | 20 | 120 | 53 | 20 | 120 |
| Strontium | ug/L | 1149 | 570 | 2070 | 1342 | 580 | 2400 | 2797 | 780 | 6400 | 2708 | 750 | 6500 |
| Calcium | mg/L | 55 | 26 | 80 | 55 | 24 | 89 | 84 | 28 | 180 | 78 | 29 | 170 |
| Total Iron | ug/L | 191 | 50 | 570 | 268 | 60 | 1200 | 562 | 190 | 1410 | 347 | 120 | 710 |
| Silica | mg/L | 5.7 | 1.8 | 11.0 | 4.8 | 0.1 | 12.0 | 4.6 | 0.4 | 14.0 | 5.3 | 0.1 | 15.0 |

The USGS Sanford sampling station is located at the northern end of Lake Monroe just upstream of the confluence with the Wekiva River (Figure 2). Under normal and high flow conditions, the effects of the fresh water from the Wekiva on the St. Johns River water quality generally are seen downstream of the Wekiva confluence in the De Land area. During drought conditions, the St. Johns River may experience reverse flow, and fresh water from the Wekiva may influence the Sanford sampling station at the outlet of the lake.

The influence of groundwater inflow on in-stream quality will vary with location as well as with river basin inflow, tributary area, and spring flow influences. During low flow conditions, groundwater inflow makes up a significant portion of total river flow. The concentration of several constituents in the river may double or triple during a severe drought. SJRWMD Technical Publication SJ84-8 describes this effect for the middle basin during the drought of 1980-1981. Several underwater springs discharge into the St. Johns River that moderate water temperature and introduce saltier water.

The District Water Management Plan (SJRWMD, May 2000) references two studies that periodically summarize the surface water quality conditions within the SJRWMD including the St. Johns River. These studies include the SJRWMD Surface Water Quality Status and Trends Assessment and the biennial FDEP 305(b) Report. An update report of the District Surface Water Quality Status and Trends Assessment is expected during September 2002.

The Clean Water Act (CWA) Section 305(b) requires each state to conduct water quality surveys to determine whether its waterways are healthy enough and of sufficient quality to meet their designated use. The related reports from each state are commonly referred to as the 305(b) reports. Designated use relates to the functional classifications of surface waters (Chapter 62-302, F.A.C.). This project reach of the St. Johns River is considered a Class III water body for recreation, propagation, and maintenance of a healthy, well-balanced population of fish and wildlife. Most of the surface waters in the SJRWMD are Class III waters.

Section 303(d) of the CWA requires states to develop a list of waters not meeting water quality standards or not supporting their designated uses. Results from the 305(b) report are used to prepare state biennial 303(d) lists of impaired waters requiring total maximum daily load (TMDL) development. TMDLs establish the maximum amount of a pollutant that a water body can assimilate without causing exceedances of water quality standards. Figure 7 and Figure 8 show 303(d)-listed segments along the St. Johns River in Volusia and Orange counties, respectively. Lake Monroe is identified as an impaired water body (303d), primarily because of low DO, high nutrient, lead, un-ionized ammonia, and selenium levels. The projected year of TMDL development for Lake Monroe is 2008. Other impaired segments include most of the St. Johns River along eastern Orange County and Lake Harney. Resulting actions of the Middle Basin SWIM Plan may provide measures to attain the necessary reduction in pollutant loading.

Potential addition of a RO concentrate discharge into Lake Monroe will likely be carefully considered for contribution to the existing impairment of this section, which is not acceptable under Florida Statues (FAC 62- various sections).

# BIOLOGICAL CHARACTERISTICS

### Aquatic Plants

The Middle St. Johns River is a diverse and complex biological community. In freshwater and saltwater, a variety of floating and rooted macrophytes are important to provide food and habitat/nurseries for fish and other wildlife and to filter pollutants from the water. Underwater (submerged) plants also are important because they add DO the water so that aquatic animals can breathe, and their roots help stabilize sediments. They act as surfaces for organisms (snails, algae and insects) to hold onto. By monitoring plant distribution and abundance from year to year, scientists can indirectly measure water quality and biological health. The FDEP monitors native and invasive aquatic plants annually within the project reach of the Middle St. Johns River.

Common submerged vegetation within the project reach may include elodea, milfoil, bladderwort, eelgrass, coontail, Illinois pondweed, and hydrilla (an exotic invasive species). The freshwater emergent species include bulrush, cattail, maidencane, rush, and common reed. The most common floating plants are water lily, spatterdock, pickerelweed, duckweed, and two exotic invasive species, water hyacinth and water lettuce. (References in Lowe et al. 2002; Brezonik and Fox 1976, Ross and Jones 1979).

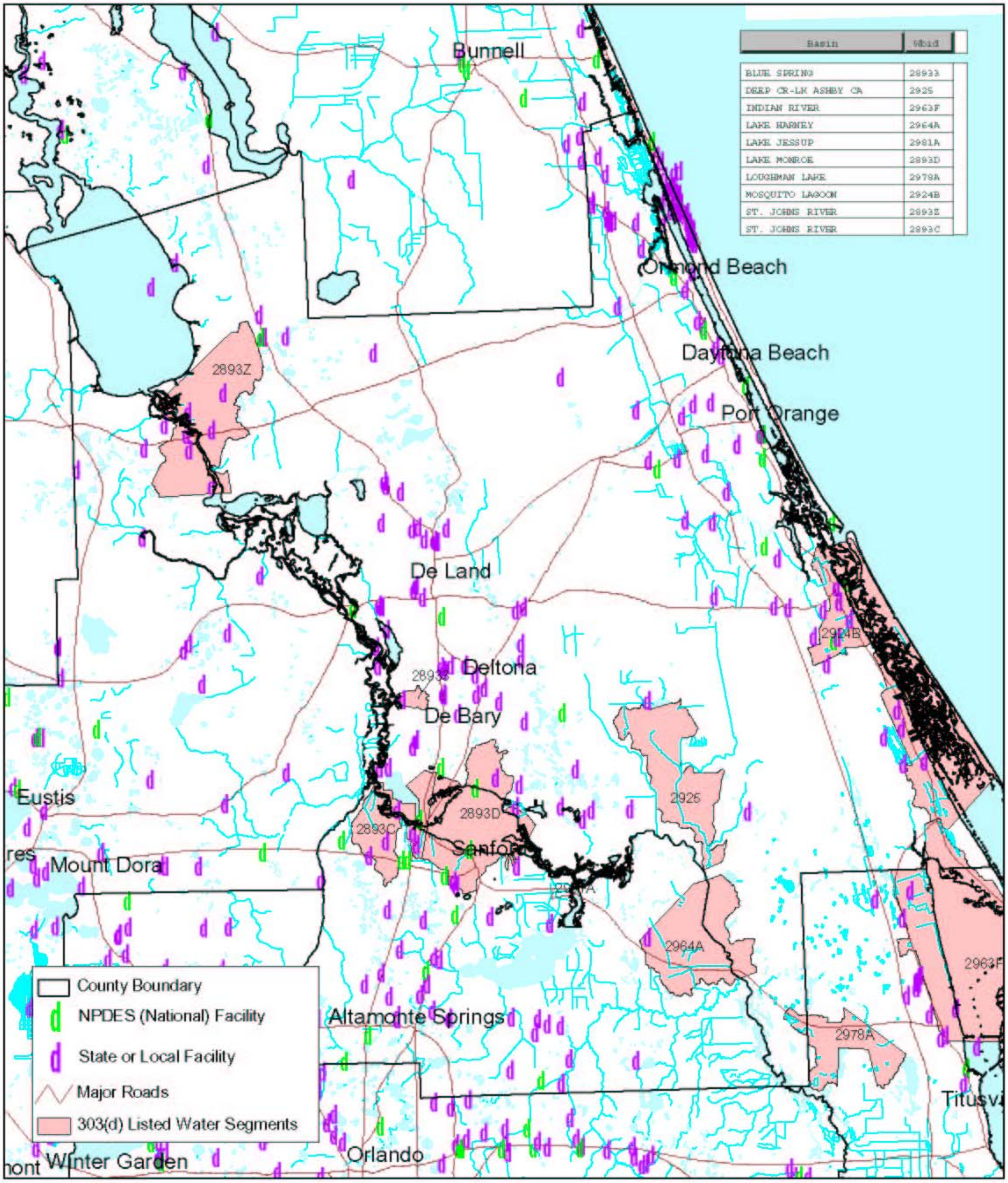


Figure 7 – Location of 303(d) listed water segments along the St. Johns River in Volusia County (source: www.dep.state.fl.us/water/tmdl/303drule.html)

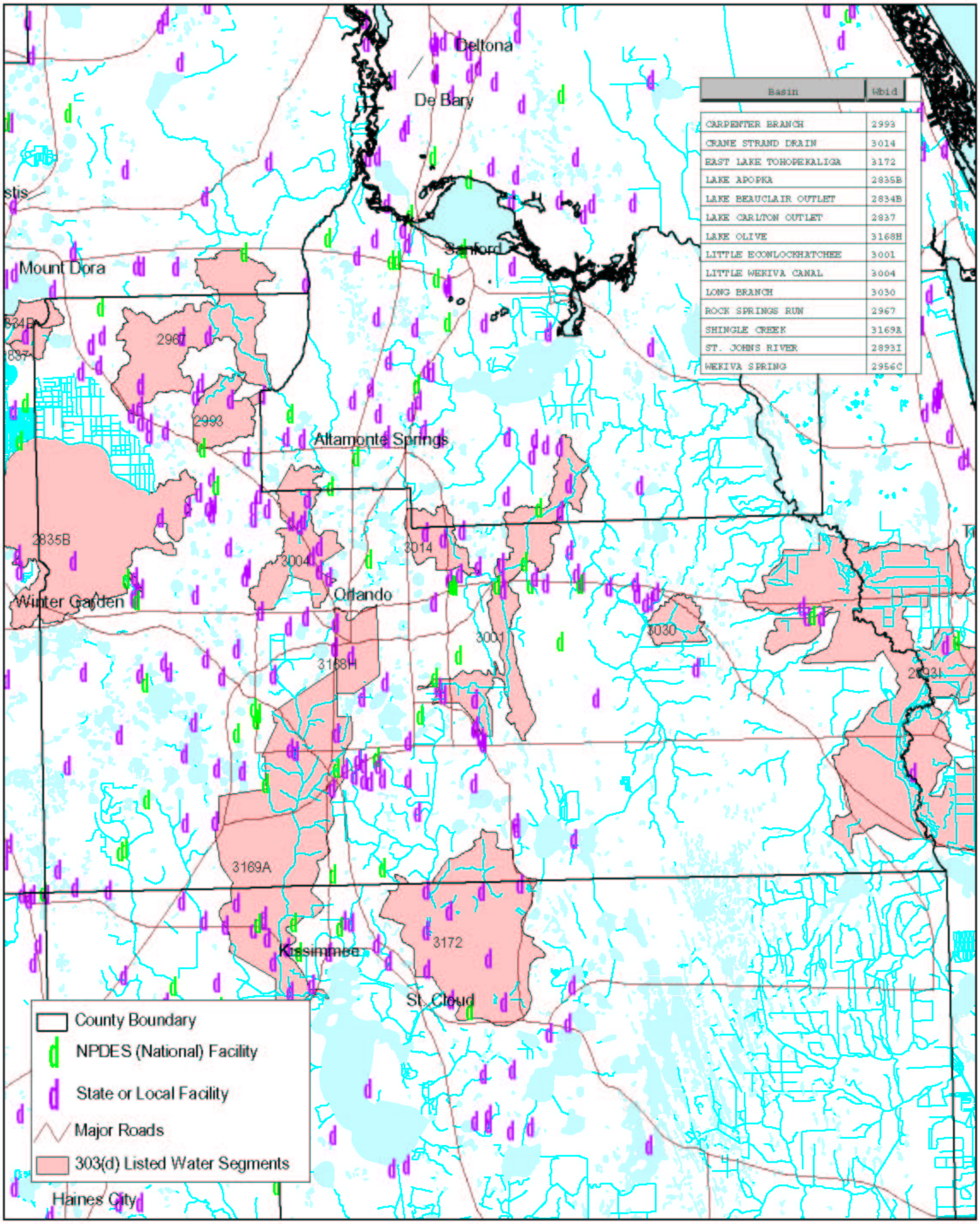


**Figure 8 – Location of 303(d) listed water segments along the St. Johns River in Orange County (source:www.dep.state.fl.us/water/tmdl/303drule.html)**

The presence of exotic aquatic weeds has become troublesome in terms of acres of surface water infested, rate of expansion, environmental and economic impacts, and financial resources necessary to manage it. As a contractor for the FDEP, the District maintains control of nuisance aquatic vegetation in eight public lakes and rivers, including the St. Johns River. The goal of the invasive plant management program is "to maintain control of nuisance aquatic vegetation to improve flood protection, navigation, recreation, and water quality and to control nuisance upland vegetation for protection of plant and animal communities."

Invasive exotics could present a serious surface water intake clogging problem because the use of herbicides must be restricted or prohibited in the immediate vicinity of the intake. SJRWMD Special Publication SJ93-SP9 (Fox et al. 1993) provides an assessment of the potential for hydrilla to affect the use of Lake Washington as a water supply source.

**Algae**

The phytoplankton community consists of free-living algae which are suspended in the water column. Because algae are primary producers and form the base of the food web, higher organisms depend on them for food and for the oxygen released during the process of photosynthesis. These tiny plants have an extremely high rate of reproduction. In the presence of sufficient light and high nutrient levels, their populations can expand rapidly into blooms that can contribute to oxygen depletion, and fish kills. These results are damaging to the ecosystem and pose aesthetic problems that interfere with recreational use (Cox and Moody 1980, Williams et al 2001). Excessive phytoplankton population growth is often the first indicators of anthropogenic stress on a system.

The periphyton community is made up of algae attached to the surfaces of underwater vegetation, rocks, and other substrates. Because of the sedentary nature of periphyton, the community composition, structure, and biomass are sensitive to changes in water quality and can be used as indicators of ambient conditions.

Changes in the phytoplankton (free-water) and periphyton (attached) algal communities can be particularly useful as assessment tools, because of their rapid responses to environmental stress. Algal and macroinvertebrate community studies (see Macroinvertebrates, below) provide valuable assessments of the overall health of aquatic systems.

Harmful algal blooms (HABs) are population increases of phytoplankton (particularly certain species of blue-green algae, also called cyanobacteria) above normal background levels and are defined by their negative impacts on the environment, the economy, and human health. Historically, many of Florida's largest and most-used freshwater and estuarine systems have been plagued by occasional blooms of harmful algae. During the last decade, however, the frequency, duration, and concentration levels of these blooms in freshwater and brackish water have increased significantly, primarily due to changes in land use, changes in hydrology, increases in nutrient runoff, loss of aquatic vegetation, and a climate that is conducive to algal growth. Excess pollutants and sediments in the stormwater runoff and other discharges fuel the growth of algae, which cover the surface of the water to a degree that restricts the amount of sunlight reaching underwater plants. This condition kills the plants needed by fish and other aquatic animals for food and habitat. In some water bodies, the natural flow of water has been altered for roads, flood control, aesthetics, erosion control, and water level maintenance. These alterations limit the ability of the waterways to naturally cleanse themselves, which further aggravates the degraded water conditions.

During 1998, The Florida Harmful Algal Bloom Task Force was established to determine the extent to which HABs pose a problem for the State of Florida. Blue-green algae (cyanobacteria) were identified as top research priorities because of their potential to produce toxic chemicals and to contaminate natural water systems. Primary problems associated with toxins from blue-green algae include damage to the nervous system or liver of animals that ingest the toxin. However, information regarding toxins from blue-green algae and risks to humans, fish, and wildlife is limited. Williams, et al. (2001) provides an assessment of cyanotoxins in Florida's lakes, reservoirs, and rivers, including the St. Johns River. This report indicates that of the 69 samples collected from the SJRWMD region, 56 (81%) contained potentially toxic cyanobacteria. Because of the concern regarding HABs, algal toxin testing is being performed as a separate project in the Lake Monroe area to evaluate surface water treatability.

Current research in the best ways to remove potential organic toxins as well as taste and odor problems also associated with algal blooms is ongoing. Conventional treatment methods such as powdered activated carbon, flocculation, and ozonation can remove the harmful compounds, and research is focused on optimizing the removal as well as other approaches (e.g. Bolto 1999, Bolto et al 1999, Gillogly et al. 1999, Cook et al. 2000, Levin et al. 2002). Maintenance of appropriate raw water quality is, of course, the best method of ensuring that the water can be used for drinking.

**Macroinvertebrates**

Macroinvertebrates are invertebrate animals (animals without a back bone) retained by U.S. Standard No. 30 mesh sieve. They are a major food resource for the fish community. Macroinvertebrate data are valuable for assessing ecosystem response to environmental stress, which may include toxic substances, low DO, poor substrate quality, or a combination of factors. Advantages of using algae and benthic invertebrates include their ease of sampling, their strategic positions in the food web, and their ability to respond quickly to a human, physical, or water quality disturbance. SJRWMD Special Publication SJ2000-SP7 (Water and Air Research, Inc. 2000) provides a preliminary analysis of benthic macroinvertebrate data from 148 surface water sites within the SJRWMD. A goal of this project was to determine the degree to which biological communities in the District's water bodies have been impaired by organic and toxic metal contamination of sediments.

In 1979, the FDEP (then the Florida Department of Environmental Regulation [FDER]) produced a technical report series, titled *Biological Aspects of Water Quality in Florida* (Ross and Jones 1979) that includes a summary of numerous macroinvertebrate sampling events. The Part 2 document contains data for the St. Johns River and probably is the most complete data set available. Since these data were collected, changes in water quality and discharge may have affected the macroinvertebrate community. The FDEP has not performed a great amount of additional sampling within the St. Johns River since that study. However, some data may be available from the FDEP Laboratory's database (SysBios). Once suitable sites for concentrate discharge have been identified by HDR, site specific field surveys may be considered to collect baseline macroinvertebrate data.

## Fish

The fish community in the project reach is extremely diverse, including freshwater, estuarine/marine, and anadromous and caladeelamous species (McLane 1950). Table 4 identifies fish species that probably exist within the project reach of the St. Johns River. This list was compiled by staff of the FFWCC Melbourne and DeLeon Springs field offices, who are familiar with the project reach of the St. Johns River.

The Middle St. Johns River and its lakes are renowned for sport fishing. Largemouth bass, bluegill, redear sunfish, bream, stripers, American shad, and black crappie are common game fish species. Striped bass and sunshine bass are stocked in many waters and provide additional recreation. The following is a general summary of the sport fishing experienced in the middle basin, according to the FFWCS (http://Floridaconservatation.org/fishing/forecast Summer 2002).

Within the St. Johns River, good catches of striped bass and sunshine bass are taken upstream (south) of Lake Monroe, near the river's confluence with Lake Jesup. Sunshine bass and striped bass are caught in the spring, starting near the confluence of the Wekiva and St. Johns River and in the first 2 miles up the Wekiva River.

Lake Monroe has an exceptional crappie season from December through March. Sunshine bass also are caught on a regular basis in all but the hottest summer months. Striped mullet, Atlantic croaker and other species are frequently caught from the seawall adjacent to U.S. Highway 17 along the southern shore of the lake. Lake Harney has an excellent bass and crappie fishery in early spring, as well as good bream fishing in late spring and summer. American shad (an anadramous species) are caught during their spawning run from January through April between Puzzle Lake and Lake Monroe.

Lakes Beresford, Woodruff, and Dexter periodically produce excellent catches of bass, crappie, bream, sunshine bass, and stripers, depending on water levels and season. The St. Johns River proper between the lakes provides a well-protected area with good success for finding bass, crappie, and bream along the edges of vegetation and near structure such as channel markers. Striped bass and sunshine bass also can be caught from areas where small streams or creeks such as Spring Run and Get-Out Creek meet the river.

## Table 4. Fish Species that Likely Exist within the St. Johns River Study Area Reach

*Jenkins and Cox are fishery experts in the Florida Fish and Wildlife Conservation Commission who provided the data based on internal FFWCC reports and their expertise in this area.General specie lists are available on [http://www.floridaconservation.org/fishing](http://www.floridaconservation.org/fishing) . The table below was modified by Cox and Jenkins from a table on the. Status information was taken from USFWS threatened and endangered species lists.*

| Scientific Name | Common Name | Status | Jenkins | Cox |
|---|---|---|---|---|
| Acipenser brevirostrum | shortnose sturgeon | F,E | X | |
| Acipenser oxyrinchus | Atlantic sturgeon | F,S | X | |
| Agonostomus monticola | mountain mullet | M,B | X | |
| Alosa aestivalis | blueback herring | Fa | | X |
| Alosa mediocris | hickory shad | Fa | | X |
| Alosa sapidissima | American shad | Fa | | X |
| Ameiurus brunneus | snail bullhead | F | X | |
| Ameiurus natalis | yellow bullhead | F | | X |
| Ameiurus nebulosus | brown bullhead | F | | X |
| Amia calva | bay anchovy | F | | X |
| Anchoa mitchilli | bay anchovy | M,B | | X |
| Anguilla rostrata | American eel | Fc | | X |
| Aphredoderus sayanus | pirate perch | F | | X |
| Archosargus probatocephalus | sheepshead | M,B | X | |
| **Bagre marinus** | | | X | |
| Bairdiella chrysoura | silver perch | M,B | X | |
| **Brevoortia smithi** | | | X | |
| **Caranax hippos** | | | X | |
| Centropomus undecimalis | snook | M,B,S | X | |
| Clarias batrachus | walking catfish | F,Xi | | X |
| Ctenopharyngodon idella | grass carp | F,Xir | X | |
| Cynoscion nebulosus | spotted seatrout | M,B | X | |
| Cyprinodon variegatus hubbsi | sheepshead minnow | F,S | | X |
| **Dasyatis hastata** | | | X | |
| Dasyatis sabina | Atlantic stingray | M,B | | X |
| Diapterus auratus | Irish pompano | M,B | X | |
| Dormitator maculatus | fat sleeper | F,B | X | |
| Dorosoma cepedianum | gizzard shad | F | | X |
| Dorosoma petenense | threadfin shad | F | | X |
| Elassoma evergladei | Everglades pygmy sunfish | F | | X |
| Elops saurus | ladyfish | M,B,F | X | |
| Enneacanthus gloriosus | bluespotted sunfish | F | | X |
| Enneacanthus obesus | banded sunfish | F | | X |
| Erimyzon sucetta | lake chubsucker | F | | X |

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| Scientific Name | Common Name | Status | Jenkins | Cox |
|---|---|---|---|---|
| Esox americanus | redfin pickerel | F | | X |
| Esox niger | chain pickerel | F | | X |
| Etheostoma edwini | brown darter | F | | X |
| Etheostoma fusiforme | swamp darter | F | | X |
| Fundulus auroguttatus | banded topminnow | F | X | |
| Fundulus chrysotus | golden topminnow | F | | X |
| Fundulus confluentus | marsh killifish | M,F,B | | X |
| Fundulus seminolis | Seminole killifish | F | | X |
| Gambusia holbrooki | mosquitofish | F | | X |
| Gobiosoma bosci | naked goby | F,B | | X |
| Heterandria formosa | least killifish | F | | X |
| Hoplosternum littorale | Brown hoplo | F, Xi | | X |
| Ictalurus punctatus | channel catfish | F | | X |
| Jordanella floridae | flagfish | F | | X |
| Labidesthes sicculus | brook silverside | F | | X |
| Leiostomus xanthurus | spot | M,B | X | |
| Lepisosteus osseus | longnose gar | F | | X |
| Lepisosteus platyrhincus | Florida gar | F | | X |
| Lepomis auritus | redbreast sunfish | | | X |
| Lepomis gulosus | warmouth | F | | X |
| Lepomis macrochirus | bluegill | F | | X |
| Lepomis marginatus | dollar sunfish | F | | X |
| Lepomis microlophus | redear sunfish | F | | X |
| Lepomis punctatus | spotted sunfish | F | | X |
| Lucania goodei | bluefin killifish | F | | X |
| Lucania parva | rainwater killifish | B | | X |
| Lutjanus griseus | gray snapper | M,B | X | |
| Megalops atlanticus | tarpon | M,B | X | |
| **Membras martinica** | | | X | |
| Menidia beryllina | inland silverside | B,F | | X |
| Microgobius gulosus | clown goby | M,B | | X |
| Micropogonias undulatus | Atlantic croaker | M,B | | X |
| Micropterus salmoides | largemouth bass | F | | X |
| Morone chrysops X M. saxatilis | sunshine bass | F, manmade hybrid | | X |
| Morone saxatilis X M. chrysops | palmetto bass | F, manmade hybrid | X | |

## Table 4. Fish Species that Likely Exist within the St. Johns River Study Area Reach

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| Scientific Name | Common Name | Status | Jenkins | Cox |
|---|---|---|---|---|
| Morone saxatilis | striped bass | F, anadromous further north | | X |
| Mugil cephalus | striped mullet | M,B,F | | X |
| Mugil curema | white mullet | M,B | X | |
| Notemigonus crysoleucas | golden shiner | F | | X |
| Notropis chalybaeus | ironcolor shiner | F | X | |
| Notropis emiliae | pugnose minnow | F | | X |
| Notropis maculatus | taillight shiner | F | | X |
| Notropis petersoni | coastal shiner | F | | X |
| Noturus gyrinus | tadpole madtom | F | | X |
| Opisthonema oglinum | Atlantic thread herring | M,B | | X |
| Paralichthys lethostigma | southern flounder | M,B | | X |
| Percina nigrofasciata | blackbanded darter | F | | X |
| Petromyzon marinus | sea lamprey | M,B | | X |
| Poecilia latipinna | sailfin molly | F | | X |
| Pomoxis nigromaculatus | black crappie | F | | X |
| Pteronotropis hypselopterus | sailfin shiner | F | X | |
| Pteronotropis welaka | bluenose shiner | F,S | X | |
| Pterygoplichthys multiradiatus | radiated ptero | F,Xi | | X |
| Strongylura marina | Atlantic needlefish | M,B,F | | X |
| Syngnathus scovelli | gulf pipefish | M,B,F | X | |
| Oreochromis (Tilapia) aurea | blue tilapia | F,Xi | | X |
| Trinectes maculatus | hogchoker | Fc | | X |
| Status Explanation:<br>F = Freshwater<br>E = Endangered<br>S = Special Concern<br>M = Marine (saltwater)<br>B = Brackish (estuarine)<br>Fa = anadromous<br>Fc = catadromous<br>Xi = exotic | | | | |

During low flow periods, the rivers salinity may increase because more inflow is from brackish groundwater (Steward 1984). Saltwater fish can migrate upriver; snook and porpoises have been seen in Lake George; and redfish, flounder, and tarpon have been caught from Lake Monroe (Hoen 1998, Ross et al 1979).

Fish are sensitive to low DO levels that sometimes result in fish kills. Heavy rains and cloudy skies sometimes result in fish kills. The heavy rains wash organic debris into waterways and stir up the bottom sediments. As debris decays, the process uses DO in the water faster than it can be replenished. At the same time, the overcast skies reduce sunlight so that algae do not produce oxygen, and the result is that there is not enough DO in the water for fish to breath. Fish need DO levels of about five parts per million (ppm). Fish mortality begins when levels reach 1 or 2 ppm. The effects of water levels and flows on fish population dynamics have been studied and are presented in SJRWMD Special Publication SJ2002-SP1 (Hill and Chicra, 2002).

**Wildlife**

Wildlife diversity in the basin varies inversely with human impacts. The FFWCC has used GIS technology in working with existing resource data layers to identify and rank landscape level habitat areas that are important to a broad array of wildlife species. Cox and Kautz (2000), conducted a mapping study titled, *Habitat Conservation Needs of Rare and Imperiled Wildlife in Florida.* There are 124 rare vertebrate species found in Florida that are included in the study. Figure 9 shows a resulting study area map of important habitats or species richness, which probably reflects conservation priorities. Generally, important conservation areas occur within the Lake George Basin and the USJRB. The MSJRB less species richness because it is more urbanized.

The FFWCC Office of Environmental Services has developed an Integrated Wildlife Habitat Ranking System (Endries et al. 2001). GIS methodology was used to identify and rank habitat areas, which are important to a broad array of wildlife species. These species include mammals, birds, amphibians, and reptiles, which are considered rare or focal species, including wildlife that are officially listed as endangered, threatened, or species of special concern. Figure 10 shows the integrated wildlife habitat ranking (habitat value) within the study area. This Integrated Wildlife Habitat Ranking System resulted in a scored color-coded GIS map

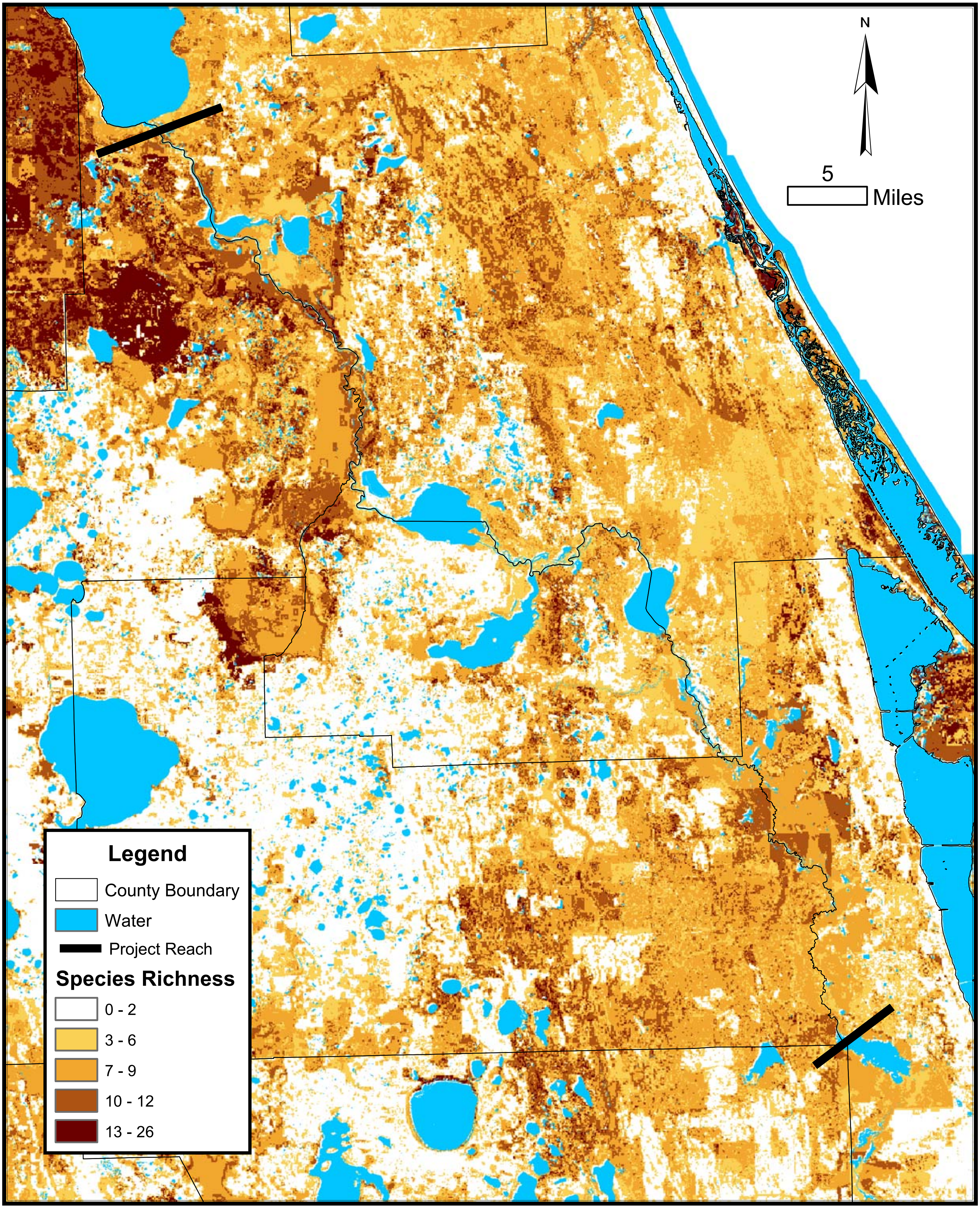


**Figure 9 - Important Conservation Areas of Rare and Imperiled Wildlife (Cox and Kautz**

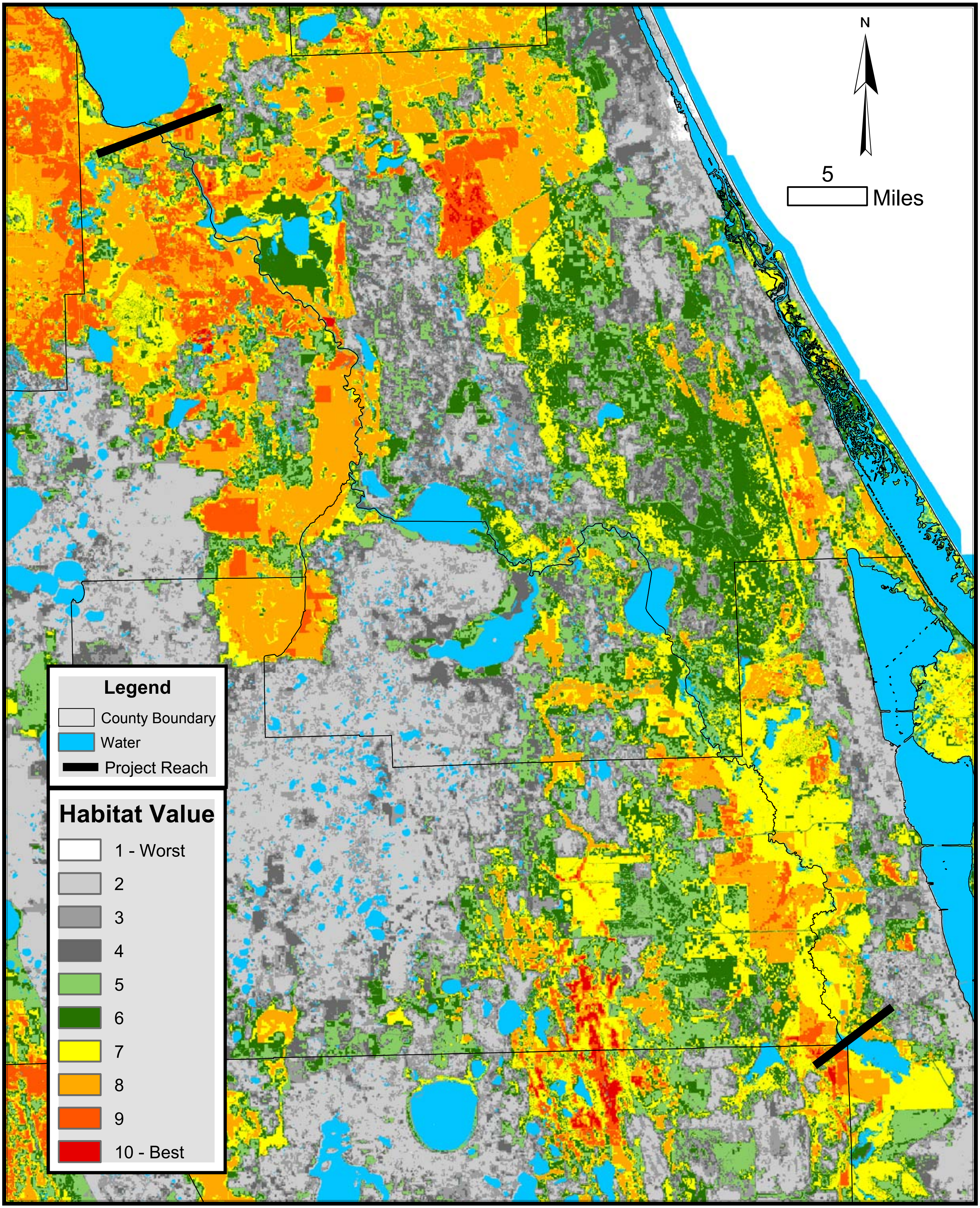


**Figure 10 - Integrated Wildlife Habitat Ranking System Map (FFWCC, 2001)**

that depicts habitat values ranging from 1 to 10 based on a composite score of many important variables, which collectively represent quality habitat. Generally, the habitat value in the study area is best within the Lake George Basin, good within the Lower St. Johns River Basin, and worst in the MSJRB.

The SJRWMD contracted the Florida Natural Areas Inventory (FNAI) to identify rare and endemic species at risk within District Wetlands. Table 5a provides a list of the rare species in the area and Table 5b provides a list of sensitive plants and animals. FNAI maintains comprehensive, statewide data on Florida rare and endemic species and natural communities. SJRWMD Special Publication SJ2001 (Natural Areas Inventory 2001) contains numerous tables that list rare species by natural wetland community type for all counties within the SJRWMD. Tables 5a and 5b identify the rare wetland species that potentially occur within the study area (including Brevard, Orange, Seminole, Lake and Volusia counties).

SJRWMD Technical Publication SJ2001-3 (Minno et al 2001) provides an assessment of rare, threatened, and endangered species in the Upper St. Johns River Basin, the northern end of which is included in the study area.

The U.S. Fish and Wildlife Service's website (www.FWS.com) provides a list of federally listed species in Florida by county. Table 6 is a composite list of the species' endangered, threatened, and critical habitats that occur within the study area (includes Brevard, Orange, Seminole, Lake, and Volusia counties). A black bear corridor exists near S.R. 46, and the Wekiva River and Lake George are home to the second largest population of bald eagles in the lower 48 states. Both species are considered threatened.

The endangered West Indian Manatee is one of the most unique and best known Florida animals. Manatee habitat and high-use areas have been documented by several agencies. Within the State of Florida, management and regulatory authority pertaining to manatee conservation is vested in the FDEP. The FDEP Marine Research Institute in St. Petersburg tracks the locations of manatee deaths. USGS biologists with the Sirenia Project in Gainesville, Florida, are conducting long-term studies on the manatee's life history, population dynamics, and ecological requirements, and have pioneered several important tools, including a computerized photo-identification catalog and a radio-tag assembly for tracking manatees by satellite. Scientists also are studying manatee feeding habits and seagrass ecology in high-use manatee areas; the long-term, post-release success of manatees rehabilitated in captivity; manatee population genetics; and the effects of eliminating industrial warm water discharges on manatee habitats. Warm water discharges from industrial sources help keep manatees warm in cold weather. The results of these studies will assist natural resources managers in determining factors important to manatee distribution patterns, fitness, and ultimate survival. USGS Sirenia Project personnel are active members of the Florida Manatee Recovery Team, an interagency team under the direction of the U.S. Fish and Wildlife Service, which guides manatee research and management activities.

Appendix B shows the locations of manatee protection zones along the project reach from Lake Monroe to Lake George. Manatees prefer shoreline areas, 1 to 2 meters in depth, where submerged aquatic plants occur. At Lake Monroe, the northern and northeastern shorelines are higher-use areas for manatees.

In summary, many wildlife species exist within the project reach of the St. Johns River that depends on the river for survival. The concentrate discharge location has not been determined at this time; however, this evaluation should include a site-specific survey at potential locations to determine the current presence or absence of rare, threatened, or endangered species and natural communities.

**Table 5a. Florida Natural Area Inventory Rare Species Found in Natural Wetland Communities within Brevard, Orange, Seminole, Lake, and Volusia Counties (Florida Natural Areas Inventory 2001)**

| | | NATURAL WETLAND COMMUNITIES (italics = no occurrence in FNAI database but presumed in county) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Counties Found | Basin Marsh | Basin Swamp | Baygall | Blackwater Stream | Bog | Bottomland Forest | Clastic Upland Lake | Coastal Interdunal Swale | Depression Marsh | Dome Swamp | Flatwoods/ Prairie Lake | Floodplain Forest | Floodplain Marsh | Floodplain Swamp | Freshwater Tidal Swamp | Hydric Hammock | Marsh Lake | River Floodplain Lake | Sandhill Upland Lake | Seepage Slope | Sinkhole Lake | Slough | Spring-run Stream | Strand Swamp | Swamp Lake | Wet Flatwoods | Wet Prairie |
| **Latin Name** | **Common Name** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **FISH** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Acipenser brevirostrum* | Shortnose sturgeon | V | | | | X | | | | | | | | | | | | | | | | | | | | | | | |
| *Acipenser oxyrinchus oxyrinchus* | Atlantic sturgeon | B | | | | X | | | | | | | | | | | | | | | | | | | | | | | |
| *Agonostomus monticola* | Mountain mullet | V | | | | X | | | | | | | | | | | | | | | | | | | | | | | |
| *Ameiurus brunneus* | Snail bullhead | V, L, S, O | | | | X | | | | | | | | | | | | | | | | | | | | | | | |
| *Cyprinodon variegatus hubbsi* | Lake Eustis pupfish | L, O | | | | | | | | | | | | | | | | | | | X | | | | | | | | |
| *Enneacanthus chaetodon* | Blackbanded sunfish | L | | X | | X | | | | | | | | | | X | | | | | | | | | | | | | |
| *Gobiomorus dormitor* | Bigmouth sleeper | B | | | | X | | | | | | | | | | | | | | | | | | | | | | | |
| *Gobionellus pseudofasciatus* | Slashcheek goby | B | | | | X | | | | | | | | | | | | | | | | | | | | | | | |
| *Microphis brachyurus* | Opossum pipefish | B | | | | X | | | | | | | | | | | | | | | | | | | | | | | |
| *Petromyzon marinus* | Sea lamprey | V, L, S | | | | X | | | | | | | | | | | | | | | | | | | | | | | |
| *Pteronotropis welaka* | Bluenose shiner | V, L, S | | | | X | | | | | | | | | | | | | | | | | | | X | | | | |
| **AMPHIBIANS** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Notophthalmus perstriatus* | Striped newt | V, L, S, O | | | | | | | | | X | | | | | | | | | | | | X | | | | | | |
| *Rana capito* | Gopher frog | V, B, L, S, O | | | | | | | | | X | | | | | | | | | | X | | | | | | | | |
| **REPTILES** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Alligator mississippiensis* | American alligator | V, B, L, S, O | X | | | X | | X | X | X | X | | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X |
| *Clemmys guttata* | Spotted turtle | V, L | X | X | | X | | | | | X | X | | | | X | | X | | | | | | | | | | X | |
| *Crotalus adamanteus* | Eastern diamondback rattlesnake | V, B, L, O | X | X | X | | X | X | | X | X | X | | X | | X | X | X | | | | X | | X | | X | | X | X |
| *Drymarchon corais couperi* | Eastern indigo snake | V, B, L, S, O | | | | | | | | | | | | | | | | X | | | | | | | | | | X | |
| *Pseudemys concinna suwanniensis* | Suwannee cooter | L | | | | X | | | | | | | | | | | | | | | | | | | X | | | | |
| **BIRDS** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Accipiter cooperii* | Cooper's hawk | V, B, L, S, O | | X | X | | | X | | | | X | | X | | X | | X | | | | X | | X | | X | | X | X |
| *Ajaia ajaja* | Roseate spoonbill | V, B, S, O | X | | | | | | | | X | | | | X | | | | | | | | | | | | | | |
| *Aramus guarauna* | Limpkin | V, B, L, S, O | | | | X | | | | | | | | | X | X | | | | | | | | | X | | | | |
| *Ardea alba* | Great egret | V, B, L, S, O | X | X | | X | | X | | X | X | X | | X | X | X | X | X | X | | X | | X | X | X | X | | X | X |
| *Buteo brachyurus* | Short-tailed hawk | V, B, L, S, O | X | X | | | | | | | X | X | | | | X | X | X | | | | X | | X | | X | | X | X |
| *Caracara plancus* | Crested caracara | V, B | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| *Egretta caerulea* | Little blue heron | V, B, L, S, O | X | X | | | | | | X | X | X | | | X | X | X | X | | | | | | X | | X | | | X |
| *Egretta thula* | Snowy egret | V, B, L, S, O | X | X | | | | | | X | X | X | | | X | X | X | X | | | | | | X | | X | | | X |

**Table 5a. Florida Natural Area Inventory Rare Species Found in Natural Wetland Communities within Brevard, Orange, Seminole, Lake, and Volusia Counties (Florida Natural Areas Inventory 2001)**

| | | | NATURAL WETLAND COMMUNITIES (italics = no occurrence in FNAI database but presumed in county) | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Counties Found | Basin Marsh | Basin Swamp | Baygall | Blackwater Stream | Bog | Bottomland Forest | Clastic Upland Lake | Coastal Interdunal Swale | Depression Marsh | Dome Swamp | Flatwoods/ Prairie Lake | Floodplain Forest | Floodplain Marsh | Floodplain Swamp | Freshwater Tidal Swamp | Hydric Hammock | Marsh Lake | River Floodplain Lake | Sandhill Upland Lake | Seepage Slope | Sinkhole Lake | Slough | Spring-run Stream | Strand Swamp | Swamp Lake | Wet Flatwoods | Wet Prairie |
| **Latin Name** | **Common Name** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Egretta tricolor* | Tricolored heron | V, B, L, S, O | X | X | | | | | | | X | X | | | X | | X | X | | | | | | X | | X | | | X |
| *Elanoides forficatus* | Swallow-tailed kite | V, B, L, S, O | X | X | | | | | | | | | | X | | X | | X | | | | | | | | X | | X | X |
| *Elanus leucurus* | White-tailed kite | V, B | X | | | | | | | | X | | | | X | | | | | | | | | X | | | | | X |
| *Eudocimus albus* | White ibis | V, B, L, S, O | X | X | | | | | | X | X | X | | | X | X | X | X | | | | | | X | | X | | | X |
| *Falco columbarius* | Merlin | V, B, L, S, O | X | | | | | X | | | | | | | | | X | X | | | | | | | | X | | X | X |
| *Falco peregrinus* | Peregrine falcon | V, B, L, S, O | X | | | | | | | | | | | | X | | X | | | | | | | | | | | | X |
| *Grus canadensis pratensis* | Florida sandhill crane | V, B, L, S, O | X | | | | | | | | X | | | | | | | | | | | | | | | | | | X |
| *Haliaeetus leucocephalus* | Bald eagle | V, B, L, S, O | X | X | | X | | | X | | | | X | X | X | X | X | X | X | X | X | | | | X | | X | X | X |
| *Ixobrychus exilis* | Least bittern | V, B, L, S, O | X | | | | | | | | X | | | | X | | | | | | | | | | | | | | |
| *Laterallus jamaicensis* | Black rail | V, B, L, S, O | X | | | | | | | | X | | | | X | | | | | | | | | | | | | | |
| *Mycteria americana* | Wood stork | V, B, L, S, O | X | X | | X | | | X | X | X | X | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X | X |
| *Nyctanassa violacea* | Yellow-crowned night-heron | V, B, L, S, O | X | X | | X | | X | | X | | X | | X | X | X | X | X | | | | | | X | X | X | | X | X |
| *Nycticorax nycticorax* | Black-crowned night-heron | V, B, L, S, O | X | X | | X | | X | | X | | X | | X | X | X | X | X | | | | | | X | X | X | | X | X |
| *Pandion haliaetus* | Osprey | V, B, L, S, O | X | X | | X | | | X | | | | X | X | X | X | X | X | X | X | X | | | | X | X | X | X | X |
| *Picoides villosus* | Hairy woodpecker | V, B, L, S, O | | X | X | | | X | | | | | | X | | X | | X | | | | | | X | | X | | X | |
| *Plegadis falcinellus* | Glossy ibis | V, B, L, S, O | X | X | | X | | | X | X | | X | X | | X | X | X | X | | X | X | | X | X | X | X | X | | X |
| *Recurvirostra americana* | American avocet | B | X | | | | | | | | X | | | | X | | | | | | | | | | | | | | |
| *Rynchops niger* | Black skimmer | V, B | | | | | | | | | | | X | | | | | | X | X | X | | X | | | | X | | |
| *Sterna antillarum* | Least tern | V, B, L, O | | | | | | | | | | | X | | | | | | X | X | X | | X | | | | X | | |
| **MAMMALS** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Corynorhinus rafinesquii* | Rafinesque's big-eared bat | V, B, L, S, O | | | | | | X | | | | X | | X | | X | | X | | | | | | | | | | X | |
| *Lasiurus cinereus* | Hoary bat | O | | | X | | | X | | | | X | | X | | X | | X | | | | | | | | | | X | X |
| *Mustela frenata olivacea* | Southeastern weasel | V, L | X | X | X | | X | X | | X | X | X | | X | X | X | X | X | | | | | | X | | X | | X | X |
| *Mustela frenata peninsulae* | Florida long-tailed weasel | V, B, L, S, O | X | X | X | | X | X | | X | X | X | | X | X | X | X | X | | | | X | | X | | X | | X | X |
| *Neofiber alleni* | Round-tailed muskrat | V, B, L, S, O | X | | | | | | | | X | | | | X | | | | | | | | | | | | | | |
| *Trichechus manatus* | Manatee | V, B, L, S | | | | X | | | | | | | | | | | | | | | | | | | X | | | | |
| *Ursus americanus floridanus* | Florida black bear | V, B, L, S, O | X | X | X | | X | X | | X | X | X | | X | X | X | X | X | | | | | | X | | X | | X | |

## Table 5a. Florida Natural Area Inventory Rare Species Found in Natural Wetland Communities within Brevard, Orange, Seminole, Lake, and Volusia Counties (Florida Natural Areas Inventory 2001)

| NATURAL WETLAND COMMUNITIES (italics = no occurrence in FNAI database but presumed in county) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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| **Latin Name** | **Common Name** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| **PLANTS** | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Andropogon arctatus* | Pine-woods bluestem | B | | | | | | | | | | | | | | | | | | | | X | | | | | | X | X |
| *Aristida rhizomophora* | Florida three-awned grass | V, B, L | | | | | | | | | X | | | | | | | | | | | X | | | | | | X | |
| *Asplenium auritum* | Auricled spleenwort | V | | | | | | | | | | | | | | | | X | | | | | | X | | X | | | |
| *Asplenium serratum* | American bird's nest fern | V | | | | | | | | | | X | | | | | | | | | | | | X | | X | | | |
| *Calamovilfa curtissii* | Curtiss' sandgrass | B | | | | | | | | | X | | | | | | | | | | | | | | | | | X | X |
| *Carex chapmanii* | Chapman's sedge | L, S | | | | | | | | | | | | X | | | | X | | | | | | | | | | | |
| *Cheiroglossa palmata* | Hand fern | V, B, S, O | | | | | | | | | | | | | | | | X | | | | | | | | X | | | |
| *Coelorachis tuberculosa* | Piedmont jointgrass | V, B, L, S, O | | | | | | | | | X | | | | | | | | X | | X | | | | | | | | X |
| *Cucurbita okeechobeensis ssp okeechobeensis* | Okeechobee gourd | V | | | | | | | | | | | | | | | | X | | | | | | | | | | | |
| *Dennstaedtia bipinnata* | Hay scented fern | B, S | | | | | | | | | | | | | | | | X | | | | | | | | | | | |
| *Drosera intermedia* | Spoon-leaved sundew | L | | | | | | | | | X | | | | | | | | | | | | | | | | | X | |
| *Hartwrightia floridana* | Hartwrightia | V, L | | | X | | X | | | | | | | | | | | | | | | | | | | | | X | |
| *Hasteola robertiorum* | Florida hasteola | L | | | | | | | | | | | | | | | | X | | | | | | | | | | | |
| *Helianthus carnosus* | Lake-side sunflower | V | | | | | | | | | | | | | | | | | | | | | | | | | | X | |
| *Illicium parviflorum* | Star anise | V, L, S, O | | | X | | | X | | | | | | | | | | X | | | | | | | X | | | | |
| *Minuartia godfreyi* | Godfrey's sandwort | V | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Myriophyllum laxum* | Piedmont water-milfoil | V | | | | X | | | | | | | | | | X | | | | | | | | | | | | | |
| *Najas filifolia** | Narrowleaf naiad | L | | | | | | | | | | | | | | | | | | | X | | | | | | | | |
| *Nemastylis floridana* | Celestial lily | V, B, S, O | | | | | | | | | | X | | | | | | | | | | X | | | | | | X | X |
| *Nemastylis floridana* | Fall-flowering ixia | L | | | | | | | | | | X | | | | | | | | | | | | | | | | X | X |
| *Peperomia humilis* | Terrestrial peperomia | V, B, O | | | | | | | | | | | | | | | | X | | | | | | X | | | | | |
| *Peperomia obtusifolia* | Blunt-leaved peperomia | B | | | | | | | | | | X | | | | | | | | | | | | | | X | | | |
| *Pecluma plumula* | Plume polypody | V, B, L, S | | X | | | | X | | | | | | X | | X | | X | | | | | | | | | | | |
| *Pecluma ptilodon* | Swamp plume polypoda fern | V, B, L, S, O | | | | | | X | | | | | | X | | X | X | X | | | | | | | | | | | |
| *Platanthera integra* | Yellow fringeless orchid | O | | | | | | | | | | | | | | | | | | | | X | | | | | | | X |
| *Salix floridana* | Florida willow | L, S, O | | | | | | X | | | | | | | | | | X | | | | | | | X | | | | |
| *Schwalbea americana* | Chaffseed | V, B | | | | | | | | | | | | | | | | | | | | | | | | | | | X |
| *Vicia ocalensis* | Ocala vetch | L | | | | | | | | | | | | | | | | | | | | | | | X | | | | |
| *Zephyranthes simpsonii* | Rain lily | V, B, S, O | | | | | | | | | | X | | | | | | | | | | | | | | | | X | X |

**Table 5b. List of Sensitive Plants and Animals in the Upper St. Johns River Basin (River basin south of SR 46 Seminole County). Sources: Minno et al. 2001).**

## Endangered Plants

*Adiantum tenerum* (Brittle Maidenhair Fern)

*Asclepias curtissii* (Curtiss' Milkweed)

*Asplenium auritum* (Auricled Spleen-Wort)

*Asplenium serratum* (Bird's Nest Spleenwort)

*Calopogon multiflorus* (Many-Flowered Grass Pink)

*Campyloneurum phyllitidis* (Long Strap Fern)

*Conradina grandiflora* (Large-Flowered Rosemary)

*Dennstaedtia bipinnata* (Hay Scenten Fern, Bipinnate Cuplet Fern)

*Deeringothamnus pulchellus* (White Squirrel-Banana)

*Derringothamnus rugelii* (Yellow Squirrel-Banana)

*Dicerandra immaculata* (Olga's Mint)

*Helianthus carnosus* (Flatwoods Sunflower)

*Hexalectris spicata* (Crested Coralroot)

*Illicium parviflorum* (Star Anise)

*Lechea divaricata* (Spreading Pinweed)

*Linera subcoriacea* (Bog Spicebush)

*Monotropsis odorata* (Pygmy-Pipes)

*Nemastylis floridana* (Fall-Flowering Ixia)

*Ophioglossum palmatum* (Hand Fern)

*Pecluma dispera* (Widespread Polypody)

*Pecluma plumula* (Plume Polypody)

*Pecluma ptilodon* (Swamp Plume Polypody)

*Peperomia humilis* (Peperomia)

*Peperomia obtusifolia* (Florida Peperomia)

*Schwalbea americana* (Chaff Seed)

*Spiranthes brevilabris* (Small Ladies'-Tresses)

*Tillandsia fasciculata* (Common Wild-Pine)

*Tillandsia utriculata* (Giant Wild-Pine)

*Warea carteri* (Carter's Mustard)

## Threatened Plants

*Andropogon arctatus* (Pine-Woods Bluestem)

*Calamovilfa curtissii* (Curtis' Sandgrass)

*Eulophia alta* (Wild Coco)

*Garberia heterophylla* (Garberia)

*Habenaria nivea* (Snowy Orchid)

*Lechea cernua* (Scrub Pinweed)

*Lilium catesbaei* (Catesby Lily)

*Matelea gonocarpos* (Angle-Pod)

*Nolina atopocarpa* (Florida Beargrass)

*Pinguicula caerulea* (Blue Butterwort)

*Pinguicula lutea* (Yellow Butterwort)

*Platanthera blephariglottis* (White-Fringed Orchid)

*Platanthera ciliaris* (Yellow-Fringed Orchid)

*Platanthera flava* (Southern Rein Orchid)

*Pogonia ophioglossoides* (Rose Pogonia)

*Pteroglossapis ecristata* (Non-crested Eulophia)

*Sarracenia minor* (Hooded Pitcher-Plant)

*Spiranthes laciniata* (Lace-Lip Ladies' Tresses)

*Spiranthes longilabris* (Long-Lip Ladies' Tresses)

*Sacoila lanceolata* (Leafless Beaked Orchid)

*Tillandsia balbisiana* (Reflexed Wild-Pine)

*Zephranthes atamasco* (Rainlily)

*Zephranthes simpsonii* (Simpson's Zephyr-Lily)

*Zephranthes treatiae* (Treat's Zephyr-Lily)

## Rare Plants

*Baptisia perfoliata* (Catbells)

*Centrosema arenicola* (Sand Butterfly Pea)

*Cheilanthes alabamensis* (Alabama Lip Fern)

*Coelorachis cylindrica* (Carolina Jointgrass)

*Coelorachis tuberculosa* (Piedmont Jointgrass)

*Cuscuta exaltata* (Tall Dodder)

*Cynanchum northropiae* (Fragrant Swallowwort)

*Dicerandra thinicola* (Titusville Balm)

*Dicranopteris flexuosa* (Drooping Forked Fern)

*Digitaria simpsonii* (Simpson's Crabgrass)

*Eleocharis parvula* (Dwarf Spikerush)

*Eleocharis quadrangulata* (Squarestem Spikerush)

*Flaveria trinervia* (Clustered Yellowtops)

*Hypoxis sessilis* (Glossyseed Yellow Stargrass)

*Lindera benzoin* (Northern Spicebush)

*Minuartia godfreyi* (Godfrey's Stitchwort)

*Orobanche minor* (Hellroot)

*Persea humilis* (Scrub Bay)

*Platanthera integra* (Orange Reinorchid)

*Rhynchosia cinerea* (Brown-Haired Snoutbean)

*Schizachyrium niveum* (Pinescrub Bluestem)

*Selaginella ludoviciana* (Gulf Spike-Moss)

*Solidago arguta* var. *caroliniana* (Carolina Goldenrod)

*Stillingia sylvatica* L. ssp. *tenuis* (Queen's Delight)

*Stylisma abdita* (Showy Dawnflower)

*Trachelospermum difforme* (Climbing Dogbane)

*Trichostema setaceum* (Narrowleaf Bluecurls)

*Websteria confervoides* (Algal Bulrush)

## Invertebrates

### Endangered Invertebrates

#### Mallophaga

*Ardeicola loculator*

*Ciconiphilus quadripustulatus*

*Colpocephalum mycteriae*

*Colpocephalum scalariforme*

*Craspedorrhynchus obscurus*

*Falcolipeurus quadriguttatus*

*Neophilopterus heteropygus*

## Threatened Invertebrates

**Odonata:**

*Libellula jesseana* (Purple Skimmer)

**Malophaga**

*Acutifrons mexicanus*

*Bruelia deficiens*

*Colpocephalum flavescens*

*Colpocephalum polybori*

*Craspedorrhynchus halieti*

*Degeeriella discocephalus*

*Degeeriella rufa carruthi*

*Esthiopterum brevicephalum*

*Falcolipeurus josephi*

*Gruimenopon canadense*

*Helenomus assimilis*

*Kurodaia haliaeeti*

*Trichodectes pinguis euarctidos*

**Coleoptera**

*Aphodius troglodytes* (Gopher Tortoise Aphodius)

*Ataenius sciurus* (Fox Squirrel Scarab)

*Chelyoxenus xerobatis* (Gopher Tortoise Hister Beetle)

*Copris gopheri* (Gopher Tortoise Copris)

*Onthophagus polyphemi* (Gopher Tortoise Onthophagus)

*Trox howelli* (Caracara Trox)

## Species of Special Concern

**Odonata:**

*Progomphus alachuensis* (Tawny Sanddragon)

*Gomphus cavillaris* (Sandhill Clubtail)

*Didymops floridensis* (Maidencane Cruiser)

*Nehalennia pallidula* (Everglades Sprite)

**Orthoptera**

*Schistocerca ceratiola* (Rosemary Grasshopper)

**Coleoptera**

*Aphodius aegrotus* (Small Pocket Gopher Scarab)

*Aphodius laevigatus* (Large Pocket Gopher Scarab)

*Peltotrupes profundus* (Florida Deepdigger Scarab)

*Hypotrichia spissipes* (Florida Hypotrichia)

**Diptera:**

*Eutrichota gopheri* (Tortoise Burrow Anthomyiid)

## Rare Invertebrates

**Odonata:**

*Gomphaeschna antilope* (Taper-Tailed Darner)

**Orthoptera:**

*Melanoplus indicifer* (East Coast Scrub Grasshopper)

**Coleoptera:**

*Cicindela scabrosa* (Florida Scrub Tiger Beetle)

*Phyllophaga elizoria* (Elizoria June Beetle)

*Phyllophaga elongata* (Elongate June Beetle)

*Trigonopeltastes floridana* (Scrub Palmetto Scarab)

*Ischyrus dunedinensis* (Scrub Ischyrus)

**Lepidoptera:**

*Atrytone arogos arogos* (Arogos Skipper)

*Atrytonopsis hianna loammi* (Southern Dusted Skipper)

*Euphyes berryi* (Berry's Skipper)

## Amphibians

## Species of Special Concern Amphibians

*Rana capito* (Gopher Frog)

## Reptiles

## Threatened Reptiles

*Drymarchon corais couperi* (Eastern Indigo Snake)

## Species of Special Concern Reptiles

*Alligator mississippiensis* (American Alligator)

*Gopherus polyphemus* (Gopher Tortoise)

*Pituophis melanoleucus mugitus* (Florida Pine Snake)

## Rare Reptiles

*Crotalus adamanteus* (Eastern Diamondback Rattlesnake)

*Lampropeltis calligaster* (Mole Snake)

*Lampropeltis triangulum elapsoides* (Scarlet Kingsnake)

*Rhadinaea flavilata* (Pine Woods Snake)

*Sceloporus woodi* (Florida Scrub Lizard)

*Tantilla relicta pamlica* (Coastal Dunes Crowned Snake)

## Birds

## Endangered Birds

*Ammodramus savannarum floridanus* (Florida Grasshopper Sparrow)

*Falco peregrinus* (Peregrine Falcon)

*Grus americana* (Whooping Crane)

*Mycteria americana* (Wood Stork)

*Picoides borealis* (Red-Cockaded Woodpecker)

*Rostrhamus sociabilis plumbeus* (Snail Kite)

## Threatened Birds

*Aphelocoma coerulescens* (Florida Scrub-Jay)

*Caracara plancus* (Crested Caracara)

*Falco sparverius paulus* (Southeastern American Kestrel)

*Grus canadensis pratensis* (Florida Sandhill Crane)

*Haliaeetus leucocephalus* (Bald Eagle)

*Sterna antillarum* (Least Tern)

## Species of Special Concern Birds

*Aramus guarauna* (Limpkin)

*Egretta caerulea* (Little Blue Heron)

*Egretta thula* (Snowy Egret)

*Egretta tricolor* (Tricolored Heron)

*Eudocimus albus* (White Ibis)

*Speotyto cunicularia floridana* (Florida Burrowing Owl)

## Rare Birds

*Accipiter cooperii* (Cooper's Hawk)

*Aimophila aestivalis* (Bachman's Sparrow)

*Ardea alba* (Great Egret)

*Buteo brachyurus* (Short-Tailed Hawk)

*Elanoides forficatus* (Swallow-Tailed Kite)

*Elanus leucurus* (White-Tailed Kite)

*Falco columbarius* (Merlin)

*Ixobrychus exilis* (Least Bittern)

*Laterallus jamaicensis* (Black Rail)

*Nyctanassa violacea* (Yellow-Crowned Night-Heron)

*Nycticorax nycticorax* (Black-Crowned Night-Heron)

*Pandion haliaetus* (Osprey)

*Picoides villosus auduboni* (Hairy Woodpecker)

*Plegadis falcinellus* (Glossy Ibis)

*Rallus longirostris scottii* (Florida Clapper Rail)

*Recurvirostra americana* (American Avocet)

## Mammals

## Endangered Mammals

*Geomys pinetis goffi* (Goff's Pocket Gopher) Probably extinct.

## Threatened Mammals

*Ursus americanus floridanus* (Florida Black Bear)

## Species of Special Concern Mammals

*Podomys floridanus* (Florida Mouse)

*Sciurus niger shermani* (Sherman's Fox Squirrel)

## Rare Mammals

*Corynorhinus rafinesquii* (Rafinesque's Big-Eared Bat)

*Mustela frenata peninsulae* (Florida Long-Tailed Weasel)

*Neofiber alleni* (Round-Tailed Muskrat)

**Table 6. Federally Listed Species Potentially Found within the Larger Study Area (www.fws.gov)**

| Category | Species Common Name | Species Scientific Name | Code | County |
|---|---|---|---|---|
| **Mammals** | West Indian Manatee | | E/CH | V,L,B,S |
| | Southeastern Beach Mouse | | T | B |
| **Birds** | Bald Eagle | | T | V,L,B,S |
| | Everglade Snail Kite | | E | V,L,B |
| | Piping Plover | | T | V,B |
| | Florida Scrub-Jay | | T | V,L,B,S |
| | Wood Stork | | E | V,L,B,S |
| | Red-cockaded Woodpecker | | E | V,L,B,S |
| | Audubon's Crested Caracara | | T | |
| **Fish** | None | | | |
| **Reptiles** | Eastern Indigo Snake | | T | V,B,S,O |
| | Sand Skink | | T | L,O |
| | Atlantic Salt Marsh Snake | | T | V,B |
| **Amphibians** | None | | | |
| **Mollusks** | None | | | |
| **Crustaceans** | None | | | |
| **Plants** | Britton's Beargrass | | E | L,O |
| | Florida Bonamia | | T | L,O |
| | Pygmy Fringetree | | E | L,O |
| | Scrub Plum | | E | L,O |
| | Lewton's Polygala | | E | L,O |
| | Wide-leaf Warea | | E | L,O |
| | Papery Whitlow-wort | | T | L,O |
| | Scrub Wild Buckwheat | | T | L,O |
| | Pigeon Wings | | T | L,O |
| | Rugel's Pawpaw | | E | V |
| | Carter's Mustard | | E | B |
| | Scrub Lupine | | E | O |
| | Beautiful Pawpaw | | E | O |
| | Sandlace | | E | O |

# CONCENTRATE MANAGEMENT OPTIONS

## WASTE CONCENTRATE CHARACTERISTICS

To evaluate the treatment requirements of the Middle St. Johns River, a pilot-scale water treatment plant was designed and constructed at the City of Sanford Water Reclamation Facility at Lake Monroe (Figure 2). The pilot plant is a small-scale version of a real water treatment plant, where actual testing and treatment of the water is being performed. The information collected from a pilot plant is used to select the right treatment technologies for the St. Johns River, as well as to provide data for use in designing a full-scale treatment facility.

The pilot testing program began in September 2001 and fieldwork is ongoing. Water quality analyses were conducted both in the field and in analytical laboratories. Results of the testing are provided in Table 7. The pilot testing program generally involved collecting data from four different types of tests:

- Bench-scale testing
- Flat sheet membrane testing
- Pretreatment selection testing (Phases 1A and 1B)
  Long-term verification or high recovery testing (Phases 2A and 2B)

On the basis of the results of the bench-scale and flat sheet testing, three pretreatment processes and four single element membranes were selected for further testing. The pretreatment selection testing is reported in *Technical Memorandum Interim Pilot Report Phase 1A Pilot Protocol Phases 1B and 2* (CH2M HILL April 2002).

## REGULATORY ISSUES FOR CONCENTRATE DISPOSAL

The information presented in this section was taken from Technical Memorandum B.5 by Reiss Environmental, Inc., dated January 2002. A section on surface water concentrate management also will be included in Reiss' final Concentrate Management Report, which is due in early 2003.

**Table 7. Raw/Feed Water and Concentrate Discharge Water Quality for Phase 1B, Super P Pretreatment Chain, at the Lake Monroe Pilot Plant**

*NPDOC – Non-purgable organic carbon. TDS – Total Dissolved Solid. T = Total. UV-254 –Standard Method5910 for indication of aggregate concentration of UV-absorbing organics. Blanks indicate that the analysis was not performed.*

| Raw Water | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date** | **NPDOC** | **TDS** | **Ba** | **Ca** | **Mg** | **Na** | **Fe (T)** | **SiO2** | **Sr** | **Cl** | **Br** | **SO4** | **UV-254** | **color** | **pH** | **Alkalinity** | **Conductivity** |
| | **mg/L** | **mg/L** | **µg/L** | **mg/L** | **mg/L** | **mg/L** | **mg/L** | **mg/L** | **µg/L** | **mg/L** | **mg/L** | **mg/L** | **1/cm** | **cpu** | | **mg/LCaCO3** | **µmhos/cm** |
| 04/02/2002 | 21.7 | | 0.14 | 67.8 | 23.2 | 179 | 0.40 | < 1 | 1.1 | ND | 0.1 | ND | 0.7143 | 93 | 7.5 | 68 | 1513 |
| 04/05/2002 | 23.8 | 905 | 0.14 | 67.8 | 27.2 | 199 | 0.40 | < 1 | 1.1 | 348 | 0.1 | 152 | 0.7480 | 90 | 8.6 | 72 | 1530 |
| 04/08/2002 | 23.5 | 903 | 0.14 | 66.0 | 27.0 | 195 | 0.40 | < 1 | 1.2 | 353 | 0.2 | 150 | 0.7400 | 88 | 7.9 | 72 | 1583 |
| 04/12/2002 | 22.3 | 971 | 0.15 | 61.3 | 24.9 | 193 | 0.40 | < 1 | 1.2 | 362 | 0.2 | 223 | 0.7277 | 88 | 7.9 | 69 | 1568 |
| 04/16/2002 | 24.3 | 904 | 0.13 | 36.1 | 19.8 | 141 | NR | 3 | 1.8 | | 0.2 | 168 | 0.7190 | 79 | 7.7 | 69 | 1674 |
| 04/19/2002 | 22.0 | 822 | 0.13 | 63.0 | 28.9 | 152 | 0.40 | < 1 | 1.1 | 331 | 0.1 | 141 | 0.7310 | 99 | 7.6 | 69 | 1555 |
| 04/23/2002 | 24.8 | 883 | 0.14 | 44.2 | 12.7 | 146 | NR | 3 | 1.8 | | 0.2 | 141 | 0.7163 | 80 | 9.6 | 78 | 1579 |
| 04/26/2002 | 22.8 | 815 | 0.06 | 55.9 | 26.3 | 135 | 0.40 | < 1 | 1.1 | 345 | 0.3 | 141 | 0.7107 | 86 | 9.4 | 73 | 1579 |
| 04/30/2002 | 26.8 | 926 | 0.13 | 37.7 | 20.1 | 150 | NR | 4 | 1.9 | | 0.5 | 163 | 0.7223 | 82 | 9.9 | 75 | 1721 |
| 05/03/2002 | 27.9 | 846 | 0.11 | 44.2 | 21.0 | 162 | 0.25 | 5 | 2 | 368 | 1.1 | 118 | 0.6993 | 78 | 8.4 | 80 | 1729 |
| 05/10/2002 | 23.2 | 863 | 0.05 | 31.4 | 21.6 | 191 | 0.08 | 4 | 1.7 | 348 | 0.3 | 139 | 0.6733 | 76 | 9.2 | 86 | 1706 |
| 05/17/2002 | 24.7 | 930 | 0.12 | 37.1 | 24.3 | 237 | 0.17 | 7 | 1.8 | 368 | 1.3 | 127 | 0.6733 | 52 | 8.5 | 82 | |
| 05/21/2002 | 25.2 | | 0.09 | 61.4 | 24.9 | 242 | | | 1.8 | | | | 0.6757 | 67 | 7.3 | 80 | 1849 |
| 05/24/2002 | 12.8 | 709 | 0.08 | 37.5 | 21.4 | 175 | 0.11 | 6 | 1.5 | 229 | 0.9 | 98 | 0.4113 | 50 | 8.5 | 103 | 1520 |
| 05/28/2002 | 17.0 | | 0.06 | 58.6 | 23.1 | 201 | | | 1.5 | | | | 0.4113 | 50 | 7.3 | 84 | 1595 |
| 05/31/2002 | 17.3 | 876 | 0.05 | 60.9 | 22.6 | 195 | 0.18 | 5 | 1.5 | 331 | 0.9 | 131 | 0.4653 | 56 | 7.7 | 90 | 1553 |
| 06/04/2002 | 15.7 | | 0.03 | 67.3 | 23.4 | 169 | 0.04 | | 1 | | | | | | 7.6 | 92 | 1529 |
| 06/07/2002 | 18.6 | 890 | 0.04 | 60.2 | 24.6 | 183 | 0.14 | 5 | 1.5 | 362 | 1.0 | 131 | 0.5230 | 53 | 7.6 | 83 | 1611 |
| 06/11/2002 | | 812 | 0.05 | 51.2 | 26.0 | 256 | | 4 | | 370 | 1.1 | 133 | | | 7.8 | 84 | 1832 |
| 06/14/2002 | 19.2 | 859 | 0.03 | 48.1 | 24.0 | 203 | 0.17 | 6 | 1.2 | 323 | 1.0 | 135 | 0.5077 | 54 | 7.1 | 80 | 1688 |
| **Average** | 21.8 | 870 | 0.09 | 52.9 | 23.4 | 185 | 0.25 | 5 | 1.5 | 341 | 0.6 | 143 | 0.6428 | 73 | 8.2 | 79 | 1627 |
| **Minimum** | 12.8 | 709 | 0.03 | 31.4 | 12.7 | 135 | 0.04 | 3 | 1.0 | 229 | 0.1 | 98 | 0.4113 | 50 | 7.1 | 68 | 1513 |
| **Maximum** | 27.9 | 971 | 0.15 | 67.8 | 28.9 | 256 | 0.40 | 7 | 2.0 | 370 | 1.3 | 223 | 0.7480 | 99 | 9.9 | 103 | 1849 |
| **Standard Deviation** | 4.0 | 61 | 0.04 | 12.3 | 3.5 | 33 | 0.14 | 1 | 0.3 | 37 | 0.4 | 27 | 0.1189 | 17 | 0.8 | 9 | 102 |

| Membrane; FilmTec BW30FR | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Date** | **NPDOC** | **TDS** | **Ba** | **Ca** | **Mg** | **Na** | **T. Fe** | **SiO2** | **Sr** | **Cl** | **Br** | **SO4** | **UV-254** | **color** | **pH** | **Alkalinity** | **Conductivity** |
| | **mg/L** | **mg/L** | **µg/L** | **mg/L** | **mg/L** | **mg/L** | **mg/L** | **mg/L** | **µg/L** | **mg/L** | **mg/L** | **mg/L** | **1/cm** | **cpu** | | **mg/LCaCO3** | **µmhos/cm** |
| 04/12/2002 | 10.3 | 3190 | 0.40 | 245.6 | 88.3 | 686 | 0.05 | < 1 | 4.6 | 1323 | 0.6 | 775 | 0.1720 | 4 | 7.1 | 50 | 4826 |
| 04/19/2002 | 15.2 | 2833 | 0.27 | 211.7 | 86.2 | 622 | 0.08 | < 1 | 4.2 | 1138 | 0.3 | 700 | 0.1765 | 9 | 7.5 | 49 | 4909 |
| 04/26/2002 | 10.9 | 3014 | 0.23 | 221.1 | 82.4 | 627 | 0.02 | < 1 | 4.0 | 1138 | 1.2 | 863 | 0.1474 | 7 | 6.2 | 58 | 4972 |

**Table 7. Raw/Feed Water and Concentrate Discharge Water Quality for Phase 1B, Super P Pretreatment Chain, at the Lake Monroe Pilot Plant**

*NPDOC – Non-purgable organic carbon. TDS – Total Dissolved Solid. T = Total. UV-254 –Standard Method5910 for indication of aggregate concentration of UV-absorbing organics. Blanks indicate that the analysis was not performed.*

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05/03/2002 | 11.8 | 2992 | 0.40 | 157.1 | 74.1 | 701 | 0.08 | 8 | 5.7 | 1202 | 2.7 | 762 | 0.1487 | 7 | 7.8 | 59 | 5453 |
| 05/10/2002 | 10.7 | 3472 | 0.33 | 120.3 | 86.6 | 845 | 0.03 | 11 | 5.8 | 1411 | 1.0 | 929 | 0.1338 | 3 | 7.1 | 43 | 5693 |
| 05/17/2002 | 10.9 | 3162 | 0.34 | 121.5 | 85.2 | 757 | 0.06 | 13 | 5.7 | 1320 | 2.9 | 782 | 0.1338 | 2 | 7.4 | 53 | 6156 |
| 05/24/2002 | 5.7 | 2894 | 0.45 | 108.9 | 74.7 | 684 | 0.05 | 18 | 4.4 | 986 | 1.8 | 914 | 0.0755 | 2 | 7.3 | 77 | 5207 |
| 05/31/2002 | 9.7 | 3673 | 0.25 | 209.2 | 80.6 | 839 | 0.01 | 16 | 5.0 | 1310 | 3.2 | 1114 | 0.1422 | 7 | 7.2 | 69 | 5310 |
| 06/07/2002 | 8.3 | 3296 | 0.30 | 210.7 | 84.0 | 743 | 0.04 | 17 | 4.9 | 1207 | 3.6 | 911 | 0.1065 | 5 | 7.3 | 85 | 5592 |
| 06/14/2002 | 6.9 | 3137 | 0.31 | 147.8 | 84.4 | 813 | 0.02 | 18 | 4.2 | 1161 | 3.2 | 826 | 0.0787 | 3 | 6.5 | 57 | 5728 |
| **Average** | 10.0 | 3166 | 0.33 | 175.4 | 82.7 | 732 | 0.04 | 14 | 4.9 | 1220 | 2.1 | 858 | 0.1315 | 5 | 7.1 | 60 | 5385 |
| **Minimum** | 5.7 | 2833 | 0.23 | 108.9 | 74.1 | 622 | 0.01 | < 1 | 4.0 | 986 | 0.3 | 700 | 0.0755 | 2 | 6.2 | 43 | 4826 |
| **Maximum** | 15.2 | 3673 | 0.45 | 245.6 | 88.3 | 845 | 0.08 | 18 | 5.8 | 1411 | 3.6 | 1114 | 0.1765 | 9 | 7.8 | 85 | 6156 |
| **Standard Deviation** | 2.7 | 260 | 0.07 | 49.6 | 4.9 | 82 | 0.02 | 4 | 0.7 | 124 | 1.2 | 118 | 0.0348 | 2 | 0.5 | 13 | 422 |
| | | | | | | | | | | | | | | | | | |
| **Membrane - Hydranautics LFC1** | | | | | | | | | | | | | | | | | |
| 04/12/2002 | 10.3 | 3475 | 0.38 | 258.9 | 91.4 | 684 | 0.07 | < 1 | 5.0 | 1475 | 0.7 | 892 | 0.1707 | 5 | 7.3 | 52 | 5032 |
| 04/19/2002 | 13.4 | 3070 | 0.31 | 247.1 | 96.3 | 642 | 0.08 | < 1 | 4.9 | 1212 | 0.4 | 790 | 0.2055 | 10 | 7.6 | 56 | 5372 |
| 04/26/2002 | 11.0 | 3109 | 0.32 | 227.0 | 86.8 | 632 | 0.46 | < 1 | 4.2 | 1155 | 1.2 | 930 | 0.1366 | 7 | 6.5 | 54 | 5054 |
| 05/03/2002 | 14.6 | 3111 | 0.35 | 171.8 | 72.7 | 719 | 0.10 | 6 | 5.9 | 1178 | 3.0 | 855 | 0.2018 | 7 | 7.9 | 73 | 5411 |
| 05/10/2002 | 10.4 | 3121 | 0.30 | 110.2 | 83.0 | 739 | 0.04 | 8 | 5.7 | 1224 | 1.0 | 889 | 0.1394 | 4 | 7.1 | 42 | 5196 |
| 05/17/2002 | 11.8 | 3284 | 0.34 | 132.1 | 90.2 | 815 | 0.04 | 12 | 6.0 | 1291 | 2.8 | 858 | 0.1394 | 2 | 7.1 | 55 | 5863 |
| 05/24/2002 | 5.4 | 2708 | 0.39 | 113.9 | 75.9 | 613 | 0.07 | 15 | 4.4 | 859 | 1.5 | 914 | 0.0703 | 2 | 7.2 | 84 | 4858 |
| 05/31/2002 | 9.7 | 3130 | 0.23 | 200.1 | 79.4 | 727 | 0.02 | 14 | 4.7 | 1005 | 2.9 | 999 | 0.1241 | 6 | 6.9 | 73 | 4852 |
| 06/07/2002 | 11.6 | 3034 | 0.35 | 212.2 | 86.1 | 667 | 0.02 | 14 | 5.2 | 1041 | 3.2 | 895 | 0.1532 | 5 | 7.3 | 81 | 5084 |
| 06/14/2002 | 6.7 | 2812 | 0.37 | 170.0 | 82.1 | 708 | < 0.01 | 14 | 4.2 | 954 | 2.8 | 797 | 0.0722 | 3 | 6.8 | 60 | 5159 |
| **Average** | 10.5 | 3085 | 0.33 | 184.3 | 84.4 | 695 | 0.10 | 12 | 5.0 | 1139 | 2.0 | 882 | 0.1413 | 5 | 7.2 | 63 | 5188 |
| **Minimum** | 5.4 | 2708 | 0.23 | 110.2 | 72.7 | 613 | < 0.01 | < 1 | 4.2 | 859 | 0.4 | 790 | 0.0703 | 2 | 6.5 | 42 | 4852 |
| **Maximum** | 14.6 | 3475 | 0.39 | 258.9 | 96.3 | 815 | 0.46 | 15 | 6.0 | 1475 | 3.2 | 999 | 0.2055 | 10 | 7.9 | 84 | 5863 |
| **Standard Deviation** | 2.8 | 215 | 0.05 | 53.6 | 7.3 | 60 | 0.14 | 3 | 0.7 | 180 | 1.1 | 62 | 0.0459 | 3 | 0.4 | 14 | 301 |
| | | | | | | | | | | | | | | | | | |
| **Membrane - Osmonics SG** | | | | | | | | | | | | | | | | | |
| 04/12/2002 | 10.1 | 3236 | 0.39 | 246.4 | 88.8 | 667 | 0.09 | < 1 | 4.8 | 1352 | 0.7 | 811 | 0.1632 | 5 | 7.2 | 50 | 4877 |
| 04/19/2002 | 13.6 | 2775 | 0.27 | 216.4 | 86.1 | 603 | 0.09 | < 1 | 4.3 | 1100 | 0.4 | 694 | 0.1798 | 9 | 7.6 | 51 | 4868 |
| 04/26/2002 | 11.0 | 3298 | 0.41 | 217.6 | 86.1 | 637 | 0.11 | < 1 | 4.2 | 1159 | 1.3 | 1116 | 0.1359 | 7 | 6.2 | 58 | 5126 |
| 05/03/2002 | 14.3 | 3168 | 0.37 | 168.5 | 72.7 | 753 | 0.07 | 7 | 5.9 | 1218 | 3.2 | 842 | 0.1992 | 7 | 7.8 | 72 | 5568 |
| 05/10/2002 | 10.8 | 3308 | 0.32 | 116.4 | 86.0 | 797 | 0.02 | 9 | 5.9 | 1316 | 1.1 | 914 | 0.1405 | 3 | 7.1 | 44 | 5534 |

**Table 7. Raw/Feed Water and Concentrate Discharge Water Quality for Phase 1B, Super P Pretreatment Chain, at the Lake Monroe Pilot Plant**

*NPDOC – Non-purgable organic carbon. TDS – Total Dissolved Solid. T = Total. UV-254 –Standard Method5910 for indication of aggregate concentration of UV-absorbing organics. Blanks indicate that the analysis was not performed.*

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 05/17/2002 | 11.3 | 3386 | 0.37 | 130.7 | 88.7 | 853 | 0.06 | 12 | 6.0 | 1353 | 2.8 | 863 | 0.1405 | 2 | 7.3 | 55 | 6113 |
| 05/24/2002 | 5.3 | 2802 | 0.41 | 115.2 | 75.4 | 627 | 0.14 | 17 | 4.5 | 914 | 1.6 | 935 | 0.0717 | 2 | 7.2 | 86 | 5033 |
| 05/31/2002 | 10.0 | 3447 | 0.25 | 209.2 | 82.1 | 780 | 0.03 | 14 | 5.0 | 1156 | 3.2 | 1095 | 0.1305 | 6 | 7.1 | 75 | 5150 |
| 06/07/2002 | 11.5 | 3239 | 0.32 | 219.7 | 89.1 | 725 | 0.02 | 15 | 5.2 | 1142 | 3.4 | 927 | 0.1569 | 5 | 7.5 | 83 | 5385 |
| 06/14/2002 | 7.0 | 2953 | 0.42 | 140.8 | 82.8 | 751 | 0.02 | 14 | 4.5 | 1049 | 2.9 | 840 | 0.0807 | 9 | 6.4 | 50 | 5379 |
| **Average** | 10.5 | 3161 | 0.35 | 178.1 | 83.8 | 719 | 0.07 | 13 | 5.0 | 1176 | 2.1 | 904 | 0.1399 | 6 | 7.1 | 62 | 5303 |
| **Minimum** | 5.3 | 2775 | 0.25 | 115.2 | 72.7 | 603 | 0.02 | < 1 | 4.2 | 914 | 0.4 | 694 | 0.0717 | 2 | 6.2 | 44 | 4868 |
| **Maximum** | 14.3 | 3447 | 0.42 | 246.4 | 89.1 | 853 | 0.14 | 17 | 6.0 | 1353 | 3.4 | 1116 | 0.1992 | 9 | 7.8 | 86 | 6113 |
| **Standard Deviation** | 2.7 | 237 | 0.06 | 49.3 | 5.7 | 83 | 0.04 | 4 | 0.7 | 140 | 1.2 | 127 | 0.0397 | 3 | 0.5 | 15 | 379 |
| | | | | | | | | | | | | | | | | | |
| **Membrane - TriSep X-20** | | | | | | | | | | | | | | | | | |
| 04/12/2002 | 10.2 | 3089 | 0.37 | 229.7 | 84.3 | 635 | 0.09 | < 1 | 4.5 | 1316 | 0.5 | 751 | 0.1743 | 5 | 7.1 | 51 | 4846 |
| 04/19/2002 | 13.8 | 2788 | 0.33 | 211.7 | 86.5 | 622 | 0.07 | < 1 | 4.3 | 1105 | 0.3 | 686 | 0.1806 | 9 | 7.6 | 51 | 4960 |
| 04/26/2002 | 11.3 | 3179 | 0.36 | 230.5 | 88.1 | 681 | 0.24 | < 1 | 4.3 | 1199 | 1.3 | 898 | 0.1569 | 8 | 6.3 | 58 | 5177 |
| 05/03/2002 | 11.9 | 3112 | 0.40 | 163.6 | 70.8 | 748 | 0.11 | 8 | 5.9 | 1226 | 2.7 | 802 | 0.1521 | 6 | 8.0 | 62 | 5547 |
| 05/10/2002 | 10.7 | 3301 | 0.32 | 116.4 | 84.4 | 791 | 0.01 | 10 | 5.9 | 1316 | 1.1 | 914 | 0.1402 | 3 | 7.2 | 43 | 5460 |
| 05/17/2002 | 11.2 | 3518 | 0.36 | 112.6 | 89.9 | 906 | 0.08 | 13 | 5.9 | 1448 | 2.9 | 862 | 0.1402 | 2 | 7.1 | 55 | 6308 |
| 05/24/2002 | 5.4 | 3004 | 0.42 | 120.3 | 78.2 | 704 | 0.09 | 18 | 4.7 | 1011 | 1.8 | 951 | 0.0774 | 2 | 7.5 | 87 | 5361 |
| 05/31/2002 | 10.7 | 3832 | 0.27 | 221.9 | 85.1 | 849 | 0.08 | 17 | 4.8 | 1354 | 3.4 | 1201 | 0.1549 | 7 | 6.9 | 68 | 5439 |
| 06/07/2002 | 8.7 | 3599 | 0.32 | 218.2 | 86.3 | 741 | 0.04 | 17 | 5.2 | 1339 | 3.6 | 1068 | 0.1103 | 3 | 7.3 | 91 | 5623 |
| 06/14/2002 | 7.1 | 3156 | 0.34 | 146.4 | 84.0 | 787 | 0.05 | 18 | 4.3 | 1154 | 3.2 | 867 | 0.0805 | 4 | 6.8 | 68 | 5786 |
| **Average** | 10.1 | 3258 | 0.35 | 177.1 | 83.8 | 746 | 0.09 | 14 | 5.0 | 1247 | 2.1 | 900 | 0.1367 | 5 | 7.2 | 63 | 5451 |
| **Minimum** | 5.4 | 2788 | 0.27 | 112.6 | 70.8 | 622 | 0.01 | < 1 | 4.3 | 1011 | 0.3 | 686 | 0.0774 | 2 | 6.3 | 43 | 4846 |
| **Maximum** | 13.8 | 3832 | 0.42 | 230.5 | 89.9 | 906 | 0.24 | 18 | 5.9 | 1448 | 3.6 | 1201 | 0.1806 | 9 | 8.0 | 91 | 6308 |
| **Standard Deviation** | 2.4 | 310 | 0.04 | 50.2 | 5.5 | 90 | 0.06 | 4 | 0.7 | 132 | 1.2 | 150 | 0.0361 | 3 | 0.5 | 16 | 418 |

The rules and regulations governing the management of demineralization concentrate in Florida are primarily associated with FDEP, with additional requirements from a broad base of local, state, and federal agencies. Although FDEP grants approval for any and all concentrate projects, the involvement of other agencies may be dependent on project-specific factors such as the selected concentrate management alternative or the location of the project.

The agencies potentially requiring permits, approvals, or authorization for demineralization concentrate management projects are listed as follows:

**Responsible Agency**

**Federal**

EPA, Region IV
U.S. Army Corps of Engineers
Occupational Safety and Health Administration
USGS
U.S. Fish and Wildlife Service
National Marine Fisheries Service

**State**

FDEP (Primary Agency)
FFWCC

**Regional**

SJRWMD

**Local**

Health department

Local pollution control

County Environmental Resource Management Department or Natural Resource Management Department

City/county building and/or zoning departments

Federal acts that affect demineralization concentrate management include the CWA, the Safe Drinking Water Act (SDWA), and the Resource Conservation and Recovery Act (RCRA). Under federal regulations, demineralization concentrate is a category of industrial wastewater. FDEP regulations have incorporated the federal requirements and, in some cases, have developed more stringent requirements consistent with the unique characteristics of Florida's natural environment. The State of Florida has enacted legislation and is developing regulations specific to demineralization concentrate. State law classifies concentrate as a drinking water treatment by-product, which is permitted as an industrial wastewater through the Industrial Wastewater Permitting Section of FDEP.

The complexity of FDEP's regulations are such that the acceptability of a demineralization concentrate management alternative to FDEP is difficult to determine prior to the detailed development of the permit application. In addition, the specifics of individual demineralization water treatment projects render each concentrate permitting effort unique.

Only surface water discharge permitting is discussed below, because it has been determined by the FDEP and District to be the most practical method of concentrate disposal for this type of facility. FDEP regulations that affect surface water discharge demineralization concentrate permitting are listed in Table 8.

**Table 8. State Regulations from the *Florida Administrative Code***

| Reference | Description | Keyword |
|---|---|---|
| 62-4 | Permits | Surface water discharge, ocean outfall, underground injection control, non-surface water discharge, mixing zones |
| 62-160 | Quality Assurance | Sampling, analyses, laboratories, surface water, ground water, wastewater |
| 62-301 | Surface Waters of the State | Surface water, ocean outfall |
| 62-302 | Surface Water Quality Standards | Toxicity, Outstanding Florida Waters |
| 62-330 62-343 | Environmental Resource Permitting | Dredge and fill, pipelines |
| 62-620 | Wastewater Facility and Activities Permitting | Industrial wastewater, permit applications |
| 62-650 | Water Quality Based Effluent Limitations | Surface water discharge |
| 62-660 | Industrial Wastewater Facilities | Industrial wastewater, effluent limitations |

# SURFACE WATER DISCHARGE PERMITTING

The discharge of concentrate to surface water requires a national Pollutant Discharge Elimination system (NPDES) permit from the FDEP. The permitting process brings together numerous portions of the F.A.C. and can be complex. Surface water discharges are more likely to result in the need for discretionary decisions by FDEP permitting staff when compared to other alternatives such as underground injection.

The first and foremost factor associated with a surface water discharge is the classification of the receiving water. The definition for each class is presented below:

| | |
|---|---|
| Class I | Potable water supplies |
| Class II | Shellfish propagation or harvesting |
| Class III | Recreation, propagation and maintenance of a healthy, well-balanced population of fish and wildlife |
| Class IV | Agricultural water supplies |
| Class V | Navigation, utility, and industrial use |

The project reach of the St. Johns River is considered a Class III water body for recreation, propagation, and maintenance of a healthy, wellbalanced population of fish and wildlife.

Although each situation is unique and the regulations are complex, every surface water permit application is reviewed for compliance in five main areas:

1. Antidegradation policy and water quality based effluent limits (WQBEL) (antidegradation is only applicable to new or increased discharges)
2. Compliance with surface water criteria and mixing zone limitations
3. Impacts of tidal influence
4. Toxicity of demineralization concentrate
5. Whether the demineralization concentrate contributes to an existing impairment of the surface water/WQBEL

The antidegradation policy is defined in 62-302.300, F.A.C., and requires the abatement of water pollution and conservation and protection of Florida's natural resources and scenic beauty. The antidegradation policy was adopted by the Environmental Regulatory Commission in 1989. In addition to requiring compliance with the water quality standards developed and adopted in 1979, the policy requires that any degradation of existing background quality be found to be clearly in the public interest. Revisions to the water quality standards are considered every 3 years (triennial review) in accordance with the CWA. The water quality criteria are listed in 62-302.500–530, F.A.C.

FDEP's application of the antidegradation policy includes a variety of intentionally subjective criteria that are applied uniquely to each specific permit scenario. There is a "weighing" of various public interest criteria, including economic and social concerns, against the potential for degradation of the state's valuable water resources. An excerpt from 62- 302.300, F.A.C., best explains the purpose behind the flexibility:

– 62-302.300.10.b.1 - The Department's rules that were adopted on March 1, 1979, regarding water quality standards are based upon the best scientific knowledge related to the protection of the various designated uses of waters of the state.

– 62-302.300.10.b.2 - The mixing zone, zone of discharge, site-specific alternative criteria, exemption, and equitable allocation provisions are designed to provide an opportunity for the future consideration of factors relating to localized situations which could not adequately be addressed in this proceeding, including economic and social consequences, attainability, irretrievable conditions, natural background, and detectability.

– 62-302.300.10.d - Without the moderating provisions described in b.2 above, the Commission would not have adopted the revisions described in b.1 above nor determined that they are attainable as generally applicable water quality standards.

Although some latitude may exist depending on site-specific conditions, it is important to compare the expected concentrate quality with the water quality standards as soon as possible. Projects that meet all water quality criteria, although rare, greatly simplify the permitting process.

In addition, the anti-degradation policy requires that the Department consider and balance four factors, paraphrased below (see 62-4.242, F.A.C.):

1. Whether the proposed project is important to and is beneficial to the public health, safety, or welfare
2. Whether the proposed discharge will adversely affect conservation of fish and wildlife, including endangered or threatened species, or their habitats
3. Whether the proposed discharge will adversely affect the fishing or water-based recreational values or marine productivity in the vicinity of the proposed discharge
4. Whether the proposed discharge is consistent with any applicable Surface Water Improvement and Management Plan that has been adopted by a water management district and approved by the Department

Each permit application is evaluated on an individual basis to ensure that the Department has reasonable assurance that the proposed facility will meet the applicable water quality standards. Staff members and the Department must make discretionary decisions, balancing these factors with each surface water permit application. Because the majority of membrane concentrate discharges are related to public water supply facilities, they are considered to be beneficial to the public health, safety, and welfare in most, but not all, cases. However, the economic analysis requirements may often point to other alternatives for disposal (e.g., underground injection control) that, although more costly, can be implemented and will avoid any degradation of surface waters.

Mixing zones may be granted for dilution of concentrate, if no pre-dilution takes place at the treatment facility. The applicant must demonstrate a current and continuing need for the mixing zone. Mixing zones are commonly needed for concentrate projects because of exceedances of numeric or narrative water quality criteria and acute or chronic toxicity. Criteria for mixing zones are complex and are dependent on the type of receiving water body. Three categories of water bodies are defined and addressed differently:

1. Canals, rivers, streams, and other similar water bodies

2. Lakes, estuaries, bays, lagoons, bayous, sounds, and coastal waters
3. Open ocean waters

For additional information about mixing zones, 62-4.244, F.A.C., should be referenced. In addition, the passage in June 2001 of Senate Bill 536 allows for approval of mixing zones for toxicity due to ionic imbalance in Outstanding Florida Waters, if certain criteria are met. This regulation expands the classes of surface waters eligible for consideration.

Biotoxicity requirements are identified in 62-302, F.A.C. - Surface Water Quality Standards for acute and chronic toxicity. In many cases, demineralization concentrate has been found to fail biotoxicity tests because of naturally occurring constituents such as calcium, potassium, and sodium. In many cases, the relative ratio of these constituents is different than that of the proposed receiving water body, even though the concentration of total dissolved solids may be equal. This difference in the ratio of constituents has been found to cause mortality in test organisms that can be corrected by an adjustment of the ratio of these ions, such as naturally occurs in free flowing surface water bodies via dilution effects. Due to the source of and solution to this toxicity, Senate Bill 536 has dictated that failure of toxicity tests due to naturally occurring constituents cannot be the cause for the rejection of a permit application. Therefore, demineralization concentrate streams that fail biotoxicity tests should be evaluated to determine if naturally occurring constituents are the cause. In 1995, FDEP published a methodology for testing sewater membrane demineralization concentrate to determine whether and to what degree observed toxicity is the result of naturally occurring constituents (FDEP 1995).

The amendments to Section 403.0882, *F*S, pursuant to the passage of Senate Bill 536, will result in rule making by FDEP that will, at a minimum, result in permit applications specific to demineralization concentrate and clarification of options and requirements for demineralization concentrate disposal. However, the federal industrial wastewater requirements that form the base of FDEP's regulations have not changed. Therefore, technical criteria may remain as stringent, but the level of effort to determine permit viability and the intentions of FDEP should be reduced.

In summary, permitting of concentrate discharge to surface waters involves balancing numerous factors and considerations. The viability of a permit application is highly dependent on site-specific conditions and the interpretation of regulations.

# PLAN OF STUDY FOR CONCENTRATE MANAGEMENT

Many issues must be considered when planning and permitting concentrate disposal. The following strategies are suggested to further develop the Concentrate Management Plan for the proposed St. Johns River water supply facility. The following strategies are based on the literature review findings and regulatory requirements.

### Strategy for Water Quality Characterization

- As more data become available from Phase 2 pilot testing, further evaluate seasonal variations of the raw water quality from the river in comparison to the concentrate discharge water quality.
- Compare the Phase 2 concentrate discharge water quality to the water quality standards established for the classification of the water body (Class III). Surface water discharges must meet all of the water quality criteria (Chapter 62-302.530) established for the classification of waters or be granted a mixing zone or other administrative relief. Identify any elevated concentrate discharge water quality parameters that may be of concern regarding biotoxicity.
- Test the pilot plant raw and finished water quality for algal toxins during Phase 2 pilot testing.
- Perform additional raw water quality testing at the suitable locations for water intake and concentrate disposal. Compare any quality variations/anomalies with other river monitoring station data.
- A risk assessment for discharge of the concentrate will be conducted under Project Task J. The risk assessment will identify whether ecological risks are likely at potential discharge sites.

**Strategy for Fish and Wildlife Characterization**

- Once suitable sites for concentrate discharge have been identified site-specific field surveys should be conducted to evaluate the presence or absence of rare, threatened, or endangered species and natural communities habitat.
- Once suitable sites for concentrate discharge have been identified site-specific field surveys should be considered to collect baseline macroinvertebrate data.

**Strategy for Concentrate Disposal Permitting**

- Become familiar with all federal, state, and local rules that apply to concentrate disposal and any recent or pending rule changes. A more detailed comparison of regulations with project-specific factors is necessary to more accurately determine viable options for concentrate management.
- Coordinate with the District's Concentrate Management Consultant regarding knowledge and experience with surface water concentrate disposal permitting.
- Perform mixing zone analysis and determine the requirements for mixing zones, including dilution ratios, water quality, and toxicity requirements. FDEP may allow the water quality to be degraded to the extent that only the minimum conditions described in Section 62-3.051(1) F.A.C. applies within this limited defined zone. River discharge of concentrate will be evaluated using a desktop mass balance approach in Project Task J.
- Compare the suitable locations of concentrate disposal with regard to Outstanding Florida Waters/Aquatic Preserves and Impaired Water Bodies 303(b) segments/TMDL regulations.
- Identify agencies that would likely be involved with the concentrate disposal permitting review for the proposed facility and meet to discuss any specific issues. Identify the lead contact staff for each agency.

**Strategy for Coordination with Other Ongoing Projects**

- Coordinate with District Staff and others in regard to the proposed concentrate discharge plan, being consistent with the

Middle St. Johns River SWIM Plan. Identify any planned water quality improvement projects that would affect this project.

- Coordinate with District staff and others in regard to the proposed quantity of water supply needed and the results of the MFL program. It is necessary to quantify the supply source and concentrate disposal amounts for the development of the Concentrate Management Plan.
- Coordinate the data collection efforts and analysis with the District's SWQMP as related to establishing background conditions, determining temporal trends, and identifying areas of poor or affected water quality.
- Coordinate with District staff and HDR, Inc., with regard to siting the potential surface water treatment plant and demineralized concentrate disposal area. This step will be necessary for any modeling or mixing zone analyses.

# FIELD EVALUATION OF ENVIRONMENTAL RESOURCES

## INTRODUCTION

Field evaluation of the Middle St. Johns River verified the environmental conditions of the river ecosystem described in the literature review. The information developed in the site visits will be used to consider how the different sites could be used to best manage the potential risks associated with discharge of an RO concentrate in this section of the river. The purpose of this section is to summarize the findings of the field surveys and to identify the characteristics of each area that may be considered when siting a discharge pipe for a river water derived concentrate.

Field surveys for each of the three sections within the Middle St. Johns River are summarized. The methods that were used are first described. An evaluation of the three river reaches is then presented. A summary section provides a short discussion of the advantages and disadvantages of using each reach as a concentrate discharge area. To denote direction the terms left and right are used when necessary rather than east and west because the river meanders and compass points may confuse, rather than enlighten.

## METHODS

The field investigation was preceded by a review of existing information. This information was used to select the sites to be visited in the field. The field investigation to document the physical environment, water quality, vegetation community and animal community characteristics was then conducted.

The following background materials were reviewed:

- Aerial photographs
- USGS topographic maps of the river
- Available documents, including various technical publications from the SJRWMD pertaining to the area
- Draft Report: Literature review of physical and biological conditions on the St. Johns River

On the basis of the review of this information and discussions with District staff and other investigators on the Surface Water Treatability Project, the project area was divided into three reaches (Figure 11):

- **Government Cut** – Lemon Bluff to the origin of Monroe Canal
- **Lake Monroe** –Southern/Western shoreline
- **St. Johns River** - SR 17/92 Bridge to confluence with Wekiva River

The Government Cut area was identified by Ed Copeland of HDR, Inc., another investigator for the Surface Water Treatability Study, as a high potential area for siting a plant, considering real estate issues. The southern/western shoreline of Lake Monroe (on the left side going downstream) is the location of the Pilot Plant for the larger project and represents the area with the least likely environmental impact. A seawall has been constructed along a large portion of the shore and minimal vegetation remains in those areas. The St. Johns River downstream of Lake Monroe to the Wekiva confluence is a single channel with considerable upland access to the main river channel.

Within each of the reaches, one to three locations were selected as representative field sampling points, for a total of six sampling points (Figure 11).

Two CH2M HILL biologists and a hydrologist with Barnes, Ferland and Associates evaluated the project area by water using a boat piloted by a local fishing guide. The area investigated ranged from Leman Bluff several miles upstream of the boat launch at the State Road 46 bridge and the St. Johns River at the mouth of Lake Jesup in Sanford to the confluence of the St. Johns and Wekiva rivers. Information concerning physical environment, local environmental resources, and observations of recreational use were documented.

**Physical Environment**

Observations at each site selected included a description of the physical environment, simple water chemistry measures, and observations about the biological system. Physical observations included general cross section shape, depth finder and/or sounding information, surface sediment conditions and approximate water depth at each sampling point. Conductivity, pH, and dissolved oxygen (DO) were measured at each sampling location using a portable YSI meters calibrated prior to the field work, and immediately before and after the field day.

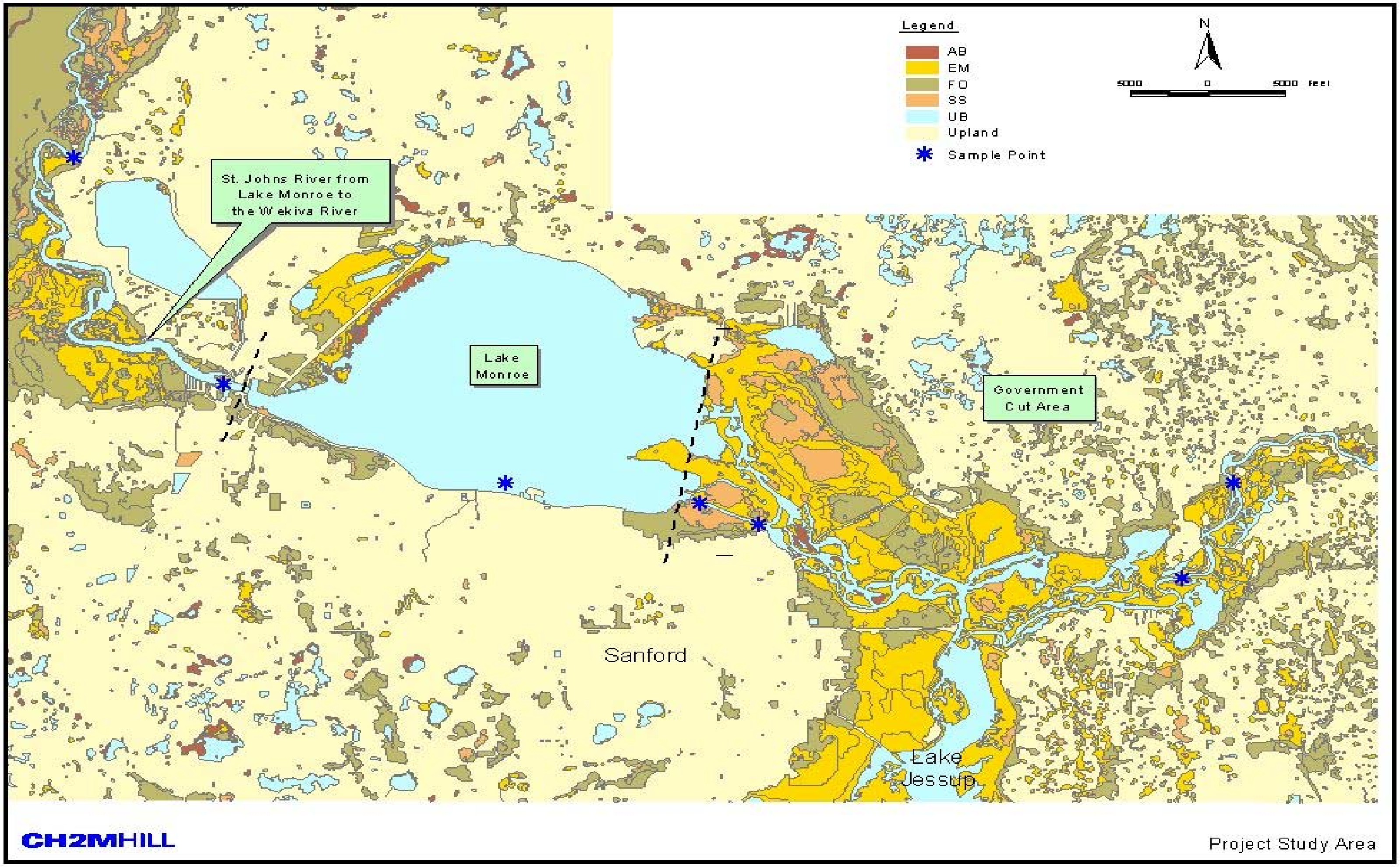



**Figure 11. Three Reaches of Middle St. Johns' River Study Area.**
**Blue asterisks indicate sampling locations.** *AB-aquatic Bed EM Emergent Marsh; FO Forested; SS Shrub Scrub; UB Unconsolidated Bottom*

A second field day was used to search for a salt wedge condition in the bottom of the river. More intensive physical sampling of the river along three transects was performed. Portable meters were used to measure temperature and conductivity at several points across transects in the government cut area.

### Environmental Resources

- Vegetative Communities. Plant species within the project area were documented. Floating aquatics, emergent macrophytes, and riverbank vegetative species were identified and recorded.
- Benthic Macroinvertebrates. Bottom samples collected with a petit ponar were sieved through a 0.5-millimeter (mm) -brass screen. Animals were hand picked without the use of magnification and orders of animals present were recorded. Floating and emergent plants and snags were collected by hand and also examined for invertebrates.
- Wildlife – Habitat observations were made along the project area, and signs of wildlife use were recorded.

## RESULTS

During both field days, river stage had been generally falling from the summer high stage conditions. In the several weeks prior to the field sump, the climate had shifted to cooler, drier mid-Florida winter conditions The air temperature on both days was cool (high in the mid-60s) and clear, with only scattered clouds. A steady northeast wind on one of the sample days provided considerable wave energy in areas not sheltered by trees or adjacent to high bluffs. The cooler weather may have influenced the benthic sampling results, because macroinvertebrate emergence to adulthood and breeding are triggered by the onset of cooler weather and many of the easily recognizable, late-instar organisms may have already completed their life cycles at the time of the survey. The river water was highly colored and clear (not turbid), even in the open lake area.

### Government Cut

Three sampling points were selected within the Government Cut reach:

- Upstream of Lemon Bluff where the river is contained in a single channel
- Lemon Bluff
- Origin of Monroe Canal at the St. Johns River Channel

## Physical Environment

### Upstream of Lemon Bluff

Upstream of Lemon Bluff is contained in a single channel with natural levees on both sides. Approaching Lemon Bluff from upstream, the river breaks into a number of channels and lakes that are more or less connected, depending on river stage. This complex braided condition continues to Lake Monroe. Extensive marshes and open water areas extend landward between the river channel and the upland. There is little relief in the landscape. Vegetation, rather than obvious increases in land elevation, marks upland borders.

The river littoral zone was narrow (about 20 feet wide) and the channel bottom sloped sharply from the littoral shelf to the channel bottom. The littoral shelves contained silty sand and fine detritus including fresh plant material and decomposed vegetation, and coarse recalcitrant organic matter such as seeds and bark. The rest of the bottom was packed fine sand with relatively little surface detrital matter. The main part of the river cross section was approximately 10 to 12 feet deep.

### Lemon Bluff

Lemon Bluff, as the name indicates, is a bluff about 10 feet or less in height on the left side of the river (facing downstream) that contains a small number of houses. The other side of the river is extensive marsh and open water. The river channel begins to split into a braided system here, including lakes that are part of the river during higher water and numerous river channels and islands.

### Monroe Canal

Monroe Canal intersects with the St. Johns River upstream of Lake Monroe, at a point where the river is running in multiple channels. The canal intersects with the river at the downstream end Indian Mound Slough, one of the river channels, at the western edge of the left (facing downstream) floodplain. It is downstream of the confluence of Lake Jessup and the river. Indian Mound slough is bordered on the left /west by a bluff 4 to 5 feet in height that has its downstream terminus at the canal origin. The bluff is armored with concrete and large residences have been constructed on the top. The channel was cut in the early 1960s as a barge canal. Between 150 and 200 feet in width, the bottom profile is rectangular and the canal is relatively deep (12 feet) compared to the adjacent river channels (less than 10 feet deep). The canal terminates in Lake Monroe south of the main channel and is separated from it by emergent marshes.

#### Water Quality

The river water was deeply colored, clear (not turbid) and well mixed. Measured water quality parameters were relatively uniform within this section of river (Table 9). The greatest change was seen in and downstream of Lake Monroe. Conductivity was about 100 µohms centimeter $(cm)^{-1}$ higher upstream of Lake Monroe.

### Ecological Resources

#### Vegetative Community

The Government Cut area of the river is generally characterized by a poorly defined channel interspersed with numerous wetland and upland islands and natural levees. The islands and levees are vegetated by maidencane flag marsh species and, on higher ground, cabbage palm and oak hammock communities. Cypress stands are common in the area. Dominant emergent species include fireflag (*Thalia geniculata*), pickerelweed (*Pontedaria cordata*), maidencane (*Panicum hemitomon),* and cattail (*Typha latifolia*). The littoral zone is absent or narrow, vegetated with scattered floating aquatics such as the invasive exotic water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistea stratiotes*). Much of the floodplain, including the emergent wetlands, are used for cattle grazing.

#### Benthic Macroinvertebrates

Benthic macroinvertebrates found in this reach include those expected to be seen in a relatively high quality bottom. The littoral zones contained a greater abundance of animals than the main channel bottom. Small freshwater sponges were common on hard substrates such as snags. On the relatively rare small freshwater sponges, beetles and mayflies were found.

**Table 9. Water Quality Characteristics of Sampling Sites in the Middle St. Johns River**

| Reach | Sample Point | Depth (feet) | pH | Conductivity $\mu$ohms cm$^{-1}$ | DO (mg/L) |
|---|---|---|---|---|---|
| Upstream of Lemon Bluff | East bank | 3 | 7.36 | 753 | 7.00 |
| | Center | 7 | 7.37 | 760 | NA |
| | West bank | 3 | 7.43 | 749 | 6.35 |
| Lemon Bluff area | East bank | 3 | 7.48 | 760 | 6.00 |
| | Center | 6 | 7.43 | 749 | 6.35 |
| | West bank | 3 | 7.43 | 749 | 6.35 |
| Origin of Monroe Canal | East bank | 3 | 7.47 | 743 | 6.10 |
| | Center | 12 | 7.40 | 734 | 5.88 |
| | West bank | 3 | 7.33 | 744 | 5.83 |
| Lake Monroe Open Water | NA | 2 | 776 | 670 | 7.40 |
| Downstream of I-4 Bridge | East bank | 6 | 7.66 | 654 | NA |
| | Center | 12 | 7.64 | 665 | 6.60 |
| | West bank | 4 | 7.66 | 670 | NA |
| Downstream of Wekiva R. | East bank | 3 | 7.45 | 571 | 6.95 |
| | Center | 18 | 7.54 | 659 | 6.36 |
| | West bank | 3 | 7.50 | 678 | 6.00 |

Notes:
Data collected on 14 November 2002.
NA indicates that no data were collected.

typically associated with small stands of baldcypress. Chironomidae (midges) of at least two families (Orthocladiinae and Chironominae), Coleoptera (beetle) larvae, mussels and Corbicula (Asiatic clam) were common and abundant in the littoral zone areas. The scoured and armored (hard compact bottom) nature of the main channel area offers habitat only to small midges and bivalves that are swept into the channel from more suitable habitats. The cooler weather probably had affected the likelihood of finding other insect larvae, because the late instar organisms would already have emerged. A few mayflies were found on live stems. Minnows and other small, unidentified fishes were seen in the water. Grass shrimp and amphipods were found in and on roots and submerged vegetation masses. Small worms (oligochaetes) and dragonfly larvae occasionally were found in vegetation and in bottom samples with abundant silt.

The samples collected from the bottom of Monroe Canal more closely resembled littoral zone samples than center channel river samples. They contained more silt and organic matter, and contained clams, mussels, snails, beetle larvae, and grass shrimp. The materials and animals found there suggested that there was less current in this channel than through the adjacent main river channels.

**Wildlife**

Abundant wading birds were observed foraging in the project area, including wood storks, great blue herons, little blue herons, great egrets, snowy egrets, cattle egrets, and white ibis. Each of these species, with the exception of cattle egret, is under federal and/or state protection as endangered (wood stork), or species of special concern.

Mullet and Tilapia were seen at several of the sampling sites, and several alligators were seen sunning or in the littoral zone while sampling was being conducted. The largest number of fishermen was seen in this area; fishermen were common during the field sampling, both in boats and on the banks. Deer and raccoon tracks also were observed on the banks, although no animals were seen. The guide indicated that fishing for mullet was a common activity in this area.

**Search for a High Salinity Zone**

Saline groundwater underlies the entire Middle St. Johns River area and contributes salinity to the river water. Highly saline surface water (on the order of seawater) is found in the St. Johns River floodplain upstream of the area surveyed for this study (GB Hall, Personal Communication, 2002). Placement of a mineral concentrate discharge in a wedge or region of highly saline water within the river channel cross section would have a lesser water quality impact than would dilution in a water of lower salinity. However, the salinity conditions probably would have to be persistent to be useful in this fashion.

Two areas within the Government Cut reach of the river were searched – Monroe Canal and the River channel just upstream of Lake Monroe (Figure 12). Monroe Canal was cut deeper than the existing river channel, and thus exposure of saline groundwater seemed more likely than in the main river channel. The river immediately upstream of Lake Monroe flows in a single channel. A more saline condition at this point would signal a relatively stable water quality condition upstream of this point.

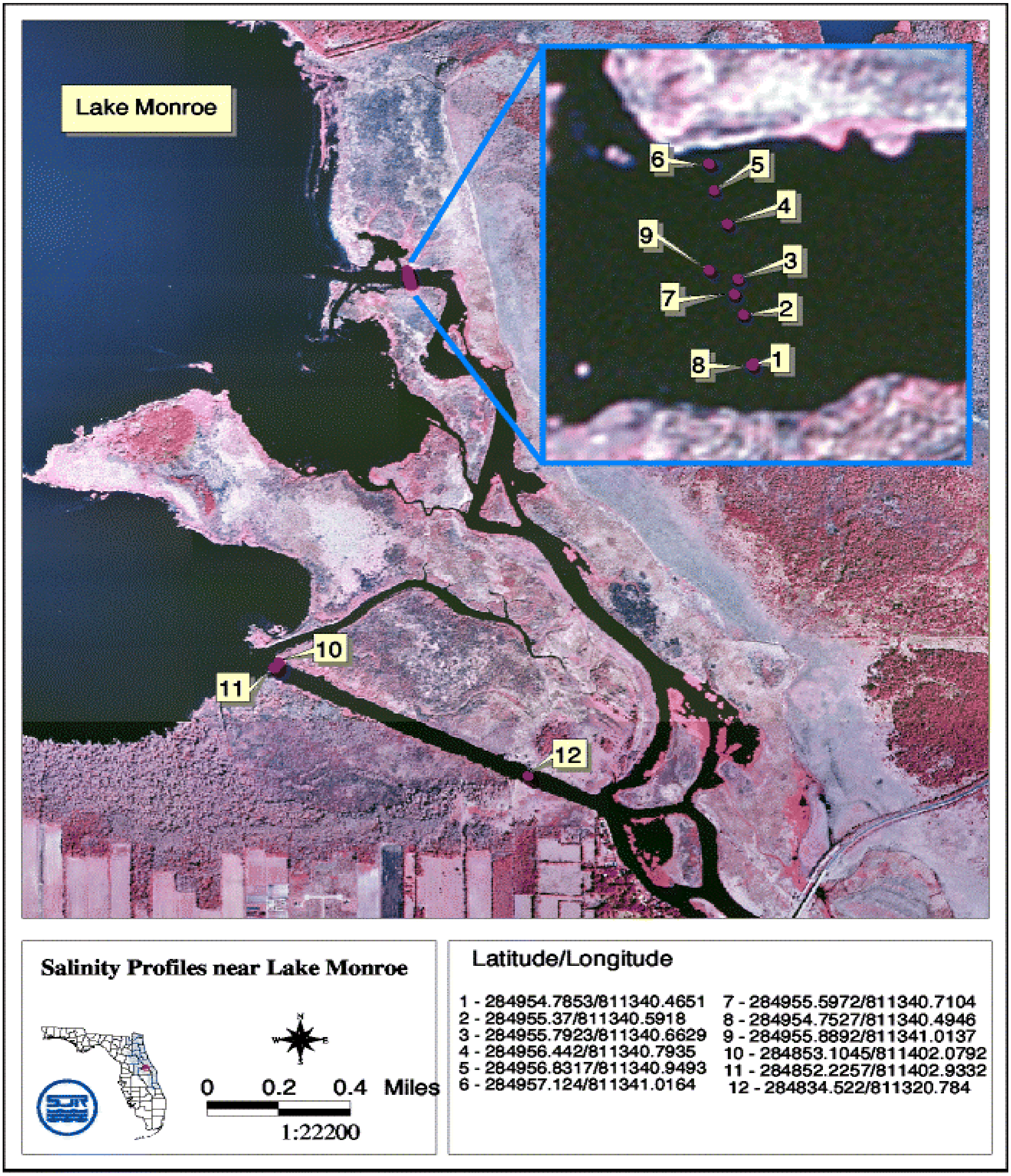
The conductivity at the bottom of the water column was tested at several points along a cross section with a conductivity meter to look for increases in conductivity over the surface water values. Conductivity was measured at the surface. The probe was then lowered to the river bottom and withdrawn about one foot up. The conductivity was then also measured there. The river and Monroe Canal were sampled in this fashion near the intersection of each with Lake Monroe. An additional point on Monroe Canal was also measured (Figure 12).

No difference in conductivity was found at any point sampled. The canal and the river were uniform with respect to water quality, and temperature at all points. Thus, it seems likely that such conditions are seasonal or dependent on specific low-flow periods to appear, if they develop in this area of the river.

### Lake Monroe

One sampling point was selected to characterize the southern shore area of Lake Monroe, where a concrete seawall is the primary shoreline condition. The site selected was adjacent to a small stand of soft-stem bulrush (*Scirpus validus)* a few hundred feet from the seawall. There are a few such stands of bullrush along this section of the lake shore area.

## Figure 12. Salinity Profiles Near Lake Monroe



### Physical Environment

The south/west shore of Lake Monroe is a shallow (3 to 4 feet deep) fully exposed, high-energy open water environment with occasional small clumps of bulrush. Because of a steady northeast wind during the field survey, the lake had waves from approximately 1/2 to 2 feet in height.

The sampling site was extremely choppy due to the reflection of wave energy off the concrete seawall that defines much of the southern shoreline. Extending beyond either end of the seawall at the upstream and downstream ends of the lake is a more natural community. The bottom was 3 to 4 feet deep in this area and appeared to be the same depth to a point near the seawall. The bottom was hard packed. It was composed of clean, medium- and fine-grained sand with some coarse detrital material mixed in. Mussel and Asiatic clam shells were a large component of the sediment surface.

### Ecological Resources

#### Vegetation Communities

A seawall bounds the south-central bank of Lake Monroe, where urban development associated with the City of Sanford has replaced the natural vegetation communities. A small patch of soft-stem bulrush (*Scirpus validus)* comprised the only emergent vegetation observed within the south-central portion of Lake Monroe. Mature cypress swamps extend along the southwestern and southeastern borders of Lake Monroe. Dominant species in these communities include bald cypress, swamp tupelo (*Nyssa sylvatica*), red maple (*Acer rubrum*), and buttonbush (*Cephalanthus occidentalis*).

#### Benthic Macroinvertebrates

Chironomids, mussels, and Asiatic clams comprised almost all of the invertebrates found in benthic samples. One small (1- to 2-inch) blue crab was collected in the ponar sample. The relatively small types and numbers of animals were not surprising because of the hard bottom conditions and wave energy present at the site.

#### Wildlife

No wildlife was seen in the immediate sample area. The bordering cypress swamps upstream and downstream of the seawall area are expected, however, to provide forage and nursery habitat for aquatic species, including crustaceans such as blue crab; mollusks such as clams and mussels; and finfish such as striped bass, crappie, and striped mullet.

Numerous wading birds including great egrets, great blue herons, and little blue herons were observed in these areas. There were few boats on the lake, probably because of the high winds and rough conditions. The guide said that during the winter, there was a significant recreational fishery in this area of the lake as well as in less disturbed areas.

## St. Johns River to Wekiva River

Two sampling points were evaluated in this downstream reach: one located just downstream of the Interstate 4 (I-4) adjacent to the Sanford Power Plant, and another located just downstream of the confluence with the Wekiva River.

### Physical Environment

The St. Johns River downstream of Lake Monroe is contained within a single channel at least to the confluence of the Wekiva River. Immediately south of the lake the floodplain is narrow, but expands on the west into the Wekiva river floodplain wetlands well north of the confluence of that tributary with the St. Johns River. On the east, a relatively narrow fringe swamp typically separates the river from upland. The river channel appears to be placed somewhat lower in the landscape in this area and the upland is closer and higher. The channel cross section appeared similar in shape to that of the Government Cut area. A narrow littoral shelf on each border of the channel sloped steeply to the main channel bottom, which accounted for the large majority of the cross section. The main channel was, however, deeper (more than 18 feet deep) than that upstream (Table 9), possibly as a result of the relatively restricted single channel configuration combined with a somewhat larger drainage area.

### Ecological Resources

#### Vegetation Communities

The St. Johns River to Wekiva reach is largely characterized by extensive mixed cypress and tupelo swamp with cabbage palms along the south side (left side facing downstream) and cabbage palm and on the north (right) banks of the river, as well as live oak hammocks interspersed with emergent marshes. Dominant vegetative species in the hammocks include cabbage palm, American elm (*Ulmus americana*), live oak, and water hickory (*Carya aquatica*), while the emergent marshes are dominated by fireflag, common reed (*Phragmites australis*), pickerelweed, and maidencane. Much of the north bank area is used for cattle grazing.

#### Benthic Macroinvertebrates

Benthic macroinvertebrates found in this effort included those expected to be seen in a relatively high quality bottom. The littoral zones contained emergent macrophytes and abundant snags at the edges of the cypress tupelo swamps. Small freshwater sponges, mayflies, beetle larvae, and a variety of cased and uncased chironomids were found on the snags. Chironomids, beetles, and mayflies were found on emergent plant stems. Asiatic clams and mussels were common in benthic samples. A small blue crab was collected in one of the littoral zone ponar samples.

The east littoral zone included a large mussel bed. The main channel bottom contained as lesser abundance, as expected. The scoured and armored (hard compact bottom) nature of the main channel area offer habitat only to small midges and bivalves that are swept into the channel from more suitable habitats. Minnows and other small, unidentified fishes were seen in the water. Grass shrimp and amphipods were found in connection with root and submerged vegetation masses.

#### Wildlife

The study area downstream of Lake Monroe appears to support a robust aquatic and avian wildlife communities. In particular, the cypress and tupelo swamps appear to be relatively undisturbed and are likely to support a diversity of wildlife, including wading birds, alligators, and mammals such as river otter and bobcat.

People fishing and passing in boats were common in this stretch of the river. The guide was not thoroughly familiar with fishing spots in this area, but said this reach of the river was well used. Evidence of camping on the shoreline supported this statement.

# SUMMARY

The field survey of the middle St. Johns River provided additional understanding of ecosystem conditions there. The physical conditions of the bottom were appropriate to riverine conditions, and the water was clear, although highly colored. The area of lake bottom sampled also was indicative of relatively healthy conditions. The Lake Monroe sites and the sites in the river downstream of Lake Monroe had lower conductivity than that at sites upstream of the lake. All sections appeared to contain both native and exotic vegetation, but the Government Cut area appeared to have a larger exotic community than below Lake Monroe. All sections appeared to contain appropriate benthic communities, although the evaluation was cursory. Wildlife was common at all sites except Lake Monroe.

Estuarine/marine animal life was present throughout the river length examined, although conductivity (and presumably total dissolved solids) was toward the lower end of the long-term record for that parameter. Conductivity fell approximately 100 units downstream of the Government Cut area. Mullet are considered part of the recreational fishery in this area, which suggests that they are common in the area. Whether they are known to be fished downstream of Lake Monroe was not discussed.

In the river floodplain, upstream of Lake Monroe showed the most evidence of disturbance, particularly from grazing animals and community development. The seawall along the shore of Lake Monroe has eliminated the littoral zone there, but the lake at the site examined did not appear to be greatly physically affected otherwise, and is apparently a popular area to fish for some species. The entire middle St. Johns River is clearly popular for recreation, although there were few people seen in Lake Monroe during the field visits. This may have been due to the weather at that time.

Ecosystem conditions suggest that fewer environmental impact concerns might be associated with a concentrate discharge upstream of Lake Monroe. However, the braided channel in this area provides a more difficult environment in which to dilute a concentrate. Monroe Canal does not appear to carry as much current as the adjacent river channels, and thus, dilution may be more difficult there than in the main channel areas. There were no areas of higher salt concentration identified in the Government Cut area. It seems likely that if such conditions exist, they are seasonal or ephemeral, and depend on specific low-flow conditions in order to develop.

Lake Monroe appears to present a good opportunity for discharge on the basis of its size and visibly affected area. However, much of the lake is shallow and dilution is based on an area in a lake situation.

Downstream of Lake Monroe the single, deep channel appears to provide a good physical setting for diluting a mineral concentrate. However, as the least disturbed area of the river, its relatively high habitat values and recreational benefits must be considered, along with its suitability as a discharge location.

# SUMMARY AND CONCLUSIONS

1. As part of the St. Johns River Water Supply Project, CH2M HILL was commissioned to conduct the Surface Water Treatability and Demineralization Concentrate Management Study, which primarily determines how to treat the surface water to drinking quality standards and how to manage the demineralization process.

2. The study area for this project is considered the St. Johns River reach between the outlet of Lake Poinsett to the inlet of Lake George (Figure 2). Lake Monroe in Sanford is the focus for a potential surface water supply source because of strong local interest by Seminole and Volusia counties. A pilot membrane treatment plant is operating at the Sanford Wastewater Treatment Facility to determine the treatment requirements of the St. Johns River.

3. Task I involves conducting a literature review to summarize recent technical information related to the impacts and management of low salinity waste concentrate and the hydrologic and biologic characteristics of the project reach of the St. Johns River. Data and references are available from the District and the USGS, and also by searching various agency web-sites. Many GIS coverages were identified that are available from various government agencies. These coverages may be useful primarily to evaluate potential environmental constraints. Essentially, Task I provides information for the development of a Concentrate Management Plan for a proposed facility of this type.

4. A bibliography database was developed using MS Access software that allows a search of the documents through various topic listings and tables. The bibliography includes a total of 200 entries, with 50 of these considered most relevant.

5. Several ongoing SJRWMD projects are directly related to this Surface Water Treatability and Demineralization Concentrate Management Study. Project coordination and sharing of data between these projects will mutually benefit their development.

6. Primarily on the basis of the river water quality and on the expected concentrate water quantity and quality, SJRWMD

and FDEP have identified surface water discharge to the St. Johns River as the most favorable concentrate disposal option to consider. Currently, there are no facilities in Florida that are similar to the proposed facility with regard to size, source water quality, and concentrate disposal type. Most existing facilities use groundwater as a source and injection wells or ocean discharge for concentrate disposal.

7. Surface water sources can be highly variable in terms of both flow magnitude and water quality. The USGS monitors historical flow and quality data at five established stations along the project reach of the St. Johns River (Figure 2). In summary, the water has a low turbidity, high TOC, high hardness, and high TDS. Surface water quality along the project reach of the St. Johns River is seasonally variable and concentrations generally are related to the flow magnitude. The project reach of the St. Johns River is a slightly brackish surface water.

8. This project reach of the St. Johns River is considered a Class III water body for recreation, propagation, and maintenance of a healthy, wellbalanced population of fish and wildlife. Impaired segments (303b) along the project reach include Lakes Monroe and Harney and most of the St. Johns River along eastern Orange County (Figures 7 and 8). The projected year of TMDL development for Lake Monroe is 2008. The resulting actions of the Middle Basin SWIM Plan may provide measures to attain the necessary reduction in pollutant loading. Fish need DO levels of about 5 ppm and fish mortality begins when DO levels reach 1 or 2 ppm.

9. Many wildlife species exist within the project reach of the St. Johns River that depend on the river for survival. The concentrate discharge location has not yet been determined by HDR, Inc.; however, this evaluation should include a site-specific survey at potential locations to determine the current presence or absence of rare, threatened, or endangered species and natural communities.

10. A field evaluation of the environmental resources in the study reach identified three different areas of the river, and evaluated general environmental quality in each area.

11. The pilot testing program began in September 2001 and water quality analyses are being conducted both in the field and in analytical laboratories. Phase 1B testing was completed in June 2002. Average concentrate TDS values ranged from 3,085 mg/L to 3,258 mg/L for membrane concentrate. Average concentrate chloride values ranged from 1,139 mg/L to 1,247 mg/L for membrane concentrate. As expected, these values are approximately three to four times higher than the feed concentrations. This relationship of the salts concentration increase with respect to the raw and feed water is important for the risk evaluation (Task J).

12. Phase 2 pilot testing should further evaluate seasonal variations of the raw water quality from the river in comparison to the concentrate discharge water quality. Surface water discharges must meet all of the water quality criteria (Chapter 62-302.530) established for the classification of waters or be granted a mixing zone or other administrative relief.

13. The rules and regulations governing the management of demineralizationconcentrate in Florida are primarily associated with FDEP, with additional requirements from a broad base of local, state, and federal agencies. Although FDEP must grant approval for any and all concentrate projects, the involvement of other agencies may be dependent on project-specific factors such as the selected concentrate management alternative or the location of the project. The specifics of individual demineralization water treatment projects render each concentrate permitting effort unique.

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# Appendix A

Table A-1 Summary of Raw Water Quality Data from USGS Monitoring Station Near Cocoa, FL

| DATES | Color (cu) | Turbidity (NTU) | Oxygen, Dissolved (mg/L) | pH | Specific Conductance (uS/cm) | Water Temperature (Deg C) | Total Hardness (mg/L as CaO3) | Alkalinity (mg/L as CaCO3) | Bromide (mg/L) | Chloride (mg/L) | Silica (mg/L) | Sulfate (mg/L) | Sulfide (mg/L as S) | Total Dissolved Solids (mg/L) | Ammonia (mg/L as N) | NO2 + NO3, Dissolved (mg/L as N) | NO2 + NO3, Total (mg/L as N) | Nitrite (mg/L as N) | Orthophosphorus, Total (mg/L as P) | Phosphorus, Total (mg/L as P) | Organic Carbon, Dissolved (mg/L) | Chlorophyll A (ug/L) | Barium (ug/L) | Iron,Dissolved (ug/L) | Iron,Total (ug/L) | Strontium (ug/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/06/2000 | 200 | 1.3 | 8.4 | 7.6 | 441 | 18.2 | | 57 | 0.3 | 83 | 5.8 | 24 | | | 0.05 | 0.18 | 0.2 | 0.01 | 0.06 | 0.07 | 20 | 13 | 21 | 180 | 260 | 870 |
| 01/19/2000 | 160 | 2.6 | 7.7 | 7.6 | 482 | 17.2 | | 58 | 0.3 | 89 | 6 | 27 | | | 0.03 | 0.14 | 0.1 | 0.01 | 0.02 | 0.03 | 26 | 4.7 | 22 | 170 | 310 | 910 |
| 02/01/2000 | 200 | 4.4 | 9.4 | 7.8 | 534 | 14.9 | | 59 | 0.3 | 104 | 5.5 | 32 | | | 0.05 | 0.23 | 0.2 | 0.01 | 0.03 | 0.03 | 26 | 11 | 24 | 140 | 270 | 1000 |
| 02/16/2000 | 160 | 5 | 8.5 | 7.5 | 606 | 20.2 | | 62 | 0.4 | 113 | 5.2 | 41 | | | 0.17 | 0.11 | 0.1 | 0.01 | 0.02 | 0.04 | 20 | 7.3 | 28 | 130 | 260 | 1200 |
| 02/29/2000 | 160 | 8.1 | 6.6 | 7.5 | 639 | 21.3 | | 63 | 0.4 | 127 | 4.2 | 55 | | | 0.07 | 0.21 | 0.2 | 0.01 | 0.01 | 0.03 | 25 | 8.2 | 33 | 100 | 360 | 1400 |
| 03/15/2000 | 120 | 8.4 | 6.7 | 7.6 | 759 | 20.9 | | 66 | 0.5 | 147 | 0.2 | 64 | | | 0.06 | 0.02 | 0.02 | 0.01 | 0.03 | 0.07 | 26 | 17 | 34 | 80 | 340 | 1600 |
| 03/29/2000 | 100 | 3.9 | 5.6 | 7.7 | 995 | 23.9 | 230 | 67 | 0.6 | 211 | 0.7 | 84 | | | 0.07 | 0.02 | 0.02 | 0.01 | 0.01 | 0.04 | 24 | 5.7 | 42 | 70 | 190 | 1900 |
| 04/11/2000 | 100 | 5.7 | 6.6 | 7.9 | 1160 | 22.2 | 260 | 73 | 0.8 | 245 | 0.2 | 102 | | | 0.13 | 0.02 | 0.02 | 0.01 | 0.02 | 0.07 | 24 | 9.4 | 48 | 50 | 270 | 2400 |
| 04/26/2000 | 80 | 5.4 | 5.7 | 7.6 | 1340 | 23.1 | 300 | 76 | 0.9 | 290 | 0.5 | 117 | | | 0.12 | 0.02 | 0.02 | 0.01 | 0.03 | 0.05 | 24 | 5.1 | 57 | 50 | 220 | 2800 |
| 05/09/2000 | 80 | 12 | 5.7 | 6.9 | 1660 | 27 | 350 | 86 | 1.2 | 382 | 0.7 | 143 | | | 0.11 | 0.02 | 0.02 | 0.01 | 0.02 | 0.09 | 25 | 11 | 70 | 70 | 500 | 3400 |
| 05/23/2000 | 80 | 3.3 | 5.4 | 7.8 | 1940 | 28.3 | 410 | 95 | 1.4 | 422 | 1.6 | 147 | | | 0.34 | 0.04 | | 0.01 | 0.03 | 0.11 | 29 | 31 | 77 | 60 | 230 | 4100 |
| 06/06/2000 | 80 | 7.6 | 8.4 | 8.6 | 2240 | 30.1 | 460 | 94 | 1.7 | 546 | 2.5 | 177 | | 1210 | 0.05 | 0.02 | 0.02 | 0.01 | 0.03 | 0.18 | 29 | 55 | 91 | 20 | 250 | 4600 |
| 06/23/2000 | 80 | 20 | 10.7 | 9.1 | 2590 | 32.1 | 490 | 78 | 2.1 | 647 | 7.4 | 189 | | 1390 | 0.12 | 0.02 | 0.02 | 0.01 | 0.06 | 0.25 | 37 | 58 | 86 | 20 | 450 | 5200 |
| 07/06/2000 | 80 | 8.6 | 6 | 8.5 | 2180 | 30.9 | 410 | 54 | 2 | 538 | 12 | 163 | | 1150 | 0.06 | 0.02 | 0.02 | 0.01 | 0.02 | 0.16 | 29 | 85 | 82 | 20 | 230 | 4300 |
| 07/19/2000 | 80 | 10 | 4.7 | 8.1 | 2390 | 30.2 | 450 | 62 | 1.9 | 587 | 15 | 174 | | 1270 | 0.04 | 0.02 | 0.02 | 0.01 | 0.03 | 0.12 | 31 | 12 | 94 | 20 | 190 | 4800 |
| 08/02/2000 | 80 | 11 | 7.9 | 9 | 2180 | 30.9 | 420 | 57 | 1.7 | 533 | 12 | 174 | | 1170 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.09 | 26 | 58 | 87 | 20 | 150 | 4500 |
| 08/15/2000 | 80 | 15 | 8.7 | 8.7 | 1930 | 29.4 | 380 | 68 | 1.4 | 460 | 8.9 | 153 | | 1030 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.13 | 25 | 110 | 80 | 30 | 240 | 4200 |
| 08/30/2000 | 70 | 5.8 | 7.6 | 8.6 | 1540 | 29.5 | 350 | 95 | 1 | 317 | 11 | 135 | | 811 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.08 | 23 | 55 | 74 | 20 | 120 | 3700 |
| 09/12/2000 | 80 | 4 | 8.9 | 7.8 | 1040 | 29.4 | 250 | 78 | 0.6 | 205 | 9.7 | 111 | | 566 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.07 | 22 | 67 | 54 | 40 | 180 | 2600 |
| 09/27/2000 | 100 | 2.4 | 6.4 | 8.2 | 953 | 29.7 | 240 | 79 | 0.4 | 178 | 10 | 98 | | 511 | 0.07 | 0.02 | 0.02 | 0.01 | 0.01 | 0.05 | 24 | 21 | 48 | 40 | 120 | 2300 |
| 10/10/2000 | 200 | 2.6 | 6.7 | 7.5 | 610 | 21.6 | 140 | 42 | 0.3 | 99 | 7.9 | 65 | | 313 | 0.35 | 0.1 | 0.1 | 0.02 | 0.2 | 0.2 | 24 | 8 | 28 | 270 | 450 | 1300 |
| 10/25/2000 | 240 | 3.6 | 4.8 | 7.4 | 530 | 23.2 | 140 | 48 | 0.3 | 98 | 9.6 | 49 | | 294 | 0.22 | 0.19 | 0.2 | 0.06 | 0.22 | 0.23 | 27 | 0.1 | 25 | 430 | 660 | 1100 |
| 11/07/2000 | 240 | 2.5 | 6 | 7.6 | 454 | 24.2 | 150 | 54 | 0.4 | 112 | 11 | 47 | | 321 | 0.18 | 0.23 | 0.2 | 0.02 | 0.17 | 0.18 | 29 | 4.9 | 27 | 430 | 600 | 1300 |
| 11/21/2000 | 240 | 4 | 7.6 | 7.6 | 691 | 17.2 | 180 | 63 | 0.56 | 130 | 11 | 55 | 1 | 370 | 0.12 | 0.3 | 0.3 | 0.02 | 0.12 | 0.16 | 31 | 0.1 | 31 | 440 | 630 | 1400 |
| 12/06/2000 | 240 | 5.7 | 9.5 | 7.5 | 792 | 14.6 | 210 | 64 | 0.61 | 150 | 11 | 82 | 1 | 439 | 0.05 | 0.41 | 0.4 | 0.01 | 0.08 | 0.1 | 27 | 7.3 | 36 | 360 | 620 | 1700 |
| 12/19/2000 | 140 | 4.4 | 8.1 | 7.8 | 938 | 16.5 | 240 | 63 | 0.66 | 170 | 8.6 | 110 | 1 | 506 | 0.1 | 0.35 | 0.4 | 0.01 | 0.06 | 0.07 | 26 | 11 | 41 | 240 | 470 | 2100 |
| 01/04/2001 | 140 | 12 | 9.7 | 7.9 | 1120 | 9.9 | 300 | 66 | 0.93 | 210 | 4.8 | 160 | 1 | 629 | 0.12 | 0.27 | 0.3 | 0.01 | 0.04 | 0.09 | 27 | 10 | 49 | 160 | 600 | 2600 |
| 01/18/2001 | 140 | 6.5 | 7.2 | 7.8 | 1240 | 21.4 | 330 | 68 | 0.84 | 231 | 0.7 | 181 | 1 | 697 | 0.09 | 0.02 | 0.02 | 0.01 | 0.01 | 0.06 | 27 | 5.2 | 56 | 90 | 420 | 2940 |
| 02/28/2001 | 80 | 6.3 | 7.2 | 7.9 | 1710 | 27.9 | 440 | 75 | 2.6 | 320 | 0.4 | 260 | 1 | 961 | 0.14 | 0.02 | 0.02 | 0.01 | 0.03 | 0.03 | 25 | 12 | 76 | 50 | 260 | 4200 |
| 03/15/2001 | 100 | 10 | 6.4 | 7.9 | 1840 | 22.1 | 470 | 75 | 17 | 370 | 0.3 | 280 | 1 | 1050 | 0.11 | 0.02 | 0.02 | 0.01 | 0.03 | 0.08 | 24 | 11 | 84 | 40 | 320 | 4400 |
| 03/28/2001 | 70 | 4.5 | 8 | 8 | 1950 | 20 | 510 | 77 | 12 | 390 | 0.2 | 300 | 1 | 1140 | 0.07 | 0.02 | 0.02 | 0.01 | 0.01 | 0.04 | 21 | 8.9 | 92 | 30 | 160 | 4900 |
| 04/11/2001 | 60 | 5.3 | 6.6 | 7.6 | 1900 | 26.9 | 500 | 65 | 6.1 | 370 | 0.3 | 310 | 1 | 1100 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 | 0.05 | 23 | 11 | 88 | 30 | 230 | 4800 |
| 04/25/2001 | 70 | 4.2 | 7.3 | 7.8 | 2210 | 26.5 | 580 | 72 | 5 | 440 | 0.3 | 350 | 1 | 1270 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.07 | 24 | 24 | 100 | 30 | 180 | 5900 |
| 05/09/2001 | 60 | 7.5 | 7.9 | 8.7 | 2310 | 24.6 | 590 | 72 | 1.6 | 470 | 0.4 | 360 | 1 | 1320 | 0.05 | 0.02 | 0.02 | 0.01 | 0.01 | 0.09 | 25 | 42 | 99 | 20 | 210 | 5900 |
| 05/23/2001 | 60 | 9 | 5 | 8.4 | 2490 | 28.1 | 630 | 71 | 1.9 | 520 | 1 | 370 | 1 | 1430 | 0.07 | 0.02 | 0.02 | 0.01 | 0.02 | 0.13 | 27 | 84 | 120 | 20 | 220 | 6500 |
| 06/06/2001 | 60 | 7 | 6.1 | 8.8 | 2580 | 29.9 | 620 | 60 | 1.8 | 550 | 1.9 | 380 | 1 | 1480 | 0.04 | 0.02 | 0.02 | 0.01 | 0.02 | 0.07 | 9.7 | 62 | 110 | 20 | 180 | 6300 |
| 06/20/2001 | 50 | 6 | 5 | 8.6 | 2620 | 28.9 | 580 | 54 | 1.7 | 530 | 5.1 | 340 | 1 | 1390 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.08 | 27 | 37 | 110 | 20 | 120 | 5900 |
| 07/03/2001 | 50 | 7.6 | 6.1 | 8.9 | 2200 | 30.4 | 510 | 59 | 1.8 | 470 | 8.7 | 270 | 1 | 1210 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.09 | 25 | 54 | 93 | 10 | 140 | 5300 |
| 08/01/2001 | 120 | 4.5 | 6.5 | 7.2 | 1060 | 29.5 | 250 | 60 | 0.66 | 207 | 5.9 | 113 | 1 | 556 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.06 | 20 | 38 | 47 | 140 | 330 | 2480 |
| 08/16/2001 | 280 | 0.5 | 2.4 | 7 | 588 | 30.9 | 150 | 65 | 0.49 | 113 | 11 | 31 | 2 | 308 | 0.4 | 0.02 | 0.02 | 0.01 | 0.34 | 0.39 | 23 | 13 | 30 | 510 | 710 | 1250 |
| 08/28/2001 | 400 | 0.5 | 10.2 | 6.9 | 525 | 29.5 | 140 | 68 | 0.51 | 96 | 13 | 24 | 4 | 277 | 0.33 | 0.02 | 0.02 | 0.01 | 0.26 | 0.32 | 26 | 25 | 28 | 540 | 690 | 1140 |
| 09/13/2001 | 240 | 0.6 | 5 | 7.2 | 361 | 26.5 | 99 | 59 | 0.34 | 64 | 10 | 12 | 2 | | 0.3 | 0.02 | 0.02 | 0.01 | 0.13 | 0.12 | 29 | 0.1 | 21 | 500 | 600 | 760 |
| 09/26/2001 | 240 | 1.7 | 3.2 | 7 | 381 | 28.1 | 100 | 54 | 0.37 | 68 | 9.3 | 15 | 3 | 200 | 0.23 | 0.02 | | 0.01 | 0.11 | 0.14 | 30 | 5.6 | 20 | 440 | 580 | 780 |
| 10/10/2001 | 320 | 1.7 | 6.7 | 7.2 | 351 | 24 | 99 | 56 | 0.33 | 61 | 8.2 | 15 | 3 | | 0.11 | 0.02 | | 0.01 | 0.05 | 0.06 | 42 | 7.2 | 20 | 340 | 500 | 750 |
| 10/24/2001 | 240 | 0.3 | 4.5 | 6.9 | 364 | 25.4 | 100 | 54 | 0.35 | 63 | 7.6 | 16 | 2 | | 0.16 | 0.03 | | 0.01 | 0.05 | 0.06 | 30 | 0.1 | 20 | 360 | 440 | 760 |
| 11/05/2001 | 200 | 0.3 | 6.9 | 7.4 | 403 | 22.7 | 100 | 56 | 0.4 | 70 | 7.6 | 19 | 1 | | 0.11 | 0.06 | | 0.01 | 0.04 | 0.05 | 33 | 0.1 | 20 | 330 | 400 | 830 |
| 11/20/2001 | 240 | 1.6 | 7.7 | 7.6 | 394 | 21.5 | 110 | 56 | 0.43 | 73 | 7 | 19 | 2 | | 0.06 | 0.08 | | 0.01 | 0.03 | 0.04 | 29 | 0.1 | 20 | 280 | 370 | 840 |
| 12/05/2001 | 200 | 0.9 | 6.9 | 7.3 | 459 | 22.4 | 120 | 60 | 0.36 | 88 | 6.2 | 21 | 2 | | 0.1 | 0.06 | | 0.01 | 0.04 | 0.06 | 28 | 4.3 | 21 | 300 | 360 | 940 |
| 12/18/2001 | 200 | 0.9 | 7.5 | 7.8 | 512 | 23.2 | 130 | 63 | 0.39 | 97 | 6.6 | 24 | 2 | 265 | 0.11 | 0.15 | | 0.01 | 0.04 | 0.06 | 29 | 5.2 | 25 | 270 | 370 | 1050 |
| 01/03/2002 | 240 | 2.6 | 8.7 | 7.3 | 558 | 14.9 | 140 | 65 | 0.44 | 109 | 6.9 | 30 | 2 | 294 | 0.09 | 0.24 | | 0.01 | 0.02 | 0.04 | 30 | 3.1 | 27 | 260 | 340 | 1150 |
| 01/15/2002 | 140 | 2.2 | 9.3 | 7.7 | 620 | 16.5 | 160 | 64 | 0.61 | 124 | 6.3 | 44 | 1 | 333 | 0.05 | 0.2 | | 0.01 | 0.01 | 0.05 | 31 | 0.1 | 27 | 250 | 330 | 1330 |
| 01/29/2002 | 160 | 5.5 | 7.4 | 7.6 | 791 | 23.6 | 200 | 70 | 0.77 | 156 | 2 | 64 | 1 | 409 | 0.03 | 0.02 | | 0.01 | 0.01 | 0.03 | 28 | 16 | 35 | 220 | 360 | 1700 |
| 02/12/2002 | 120 | 5 | 8.8 | 7.5 | 920 | 19.3 | 220 | 71 | 0.74 | 183 | 0.1 | 85 | 2 | 486 | 0.06 | 0.02 | | 0.01 | 0.01 | 0.04 | 2.2 | 0.1 | 40 | 160 | 390 | 2070 |
| 02/27/2002 | 120 | 4.5 | 9 | 7.8 | 948 | 18.8 | 230 | 66 | 0.73 | 187 | 1.1 | 103 | 1 | 511 | 0.12 | 0.03 | | 0.01 | 0.02 | 0.06 | 25 | 13 | 43 | 130 | 320 | 2100 |
| 03/13/2002 | 100 | 9.8 | 7.7 | 7.7 | 1020 | 23.5 | 250 | 64 | 0.81 | 199 | 0.5 | 117 | 1 | 549 | 0.06 | 0.02 | | 0.01 | 0.01 | 0.06 | 24 | 19 | 45 | 110 | 540 | 2370 |
| 03/27/2002 | 100 | 6.1 | 6.5 | 7.5 | 1000 | 24.6 | 240 | 66 | 0.82 | 193 | 0.3 | 111 | 1 | 530 | 0.04 | 0.02 | | 0.01 | 0.01 | 0.03 | 24 | 15 | 45 | 100 | 280 | 2310 |
| 04/10/2002 | 100 | 6.6 | 7.7 | 7.5 | 1050 | 24.2 | 260 | 72 | 0.8 | 212 | 0.4 | 111 | 2 | 567 | 0.03 | 0.02 | | 0.01 | 0.01 | 0.05 | 25 | 7.7 | 47 | 60 | 290 | 2470 |
| 04/24/2002 | 100 | 5.7 | 5.8 | 7.4 | 1090 | 26.4 | 260 | 71 | 0.86 | 220 | 0.5 | 118 | 1 | 591 | 0.09 | 0.02 | | 0.01 | 0.01 | 0.04 | 24 | 12 | 51 | 60 | 250 | 2570 |
| 05/07/2002 | 100 | 5.2 | 6.3 | 7.9 | 1250 | 29 | 300 | 81 | 1.1 | 258 | 0.4 | 128 | 3 | 679 | 0.04 | 0.02 | | 0.01 | 0.01 | 0.05 | 29 | 13 | 58 | 40 | 180 | 2930 |
| 05/22/2002 | 80 | 11 | 7.5 | 7.3 | 1450 | 22.7 | 330 | 90 | 1.2 | 315 | 0.9 | 135 | 1 | 783 | 0.18 | 0.03 | | 0.01 | 0.02 | 0.08 | 29 | 38 | 64 | 40 | 350 | 3280 |
| 07/18/2002 | 70 | 13 | 8.6 | 8.6 | 1300 | 31.8 | 300 | 50 | 0.84 | 263 | 6.2 | 159 | 1 | 700 | 0.08 | 0.02 | 0.7 | 0.01 | 0.02 | 0.11 | 16 | 42 | 56 | 70 | 560 | 3030 |
| | **139.7** | **5.6** | **7.1** | **7.8** | **1199.7** | **24.3** | **298.3** | **66.5** | **1.5** | **250.4** | **5.3** | **126.1** | **1.5** | **751.5** | **0.1** | **0.1** | **0.1** | **0.0** | **0.0** | **0.1** | **25.7** | **21.6** | **52.9** | **156.2** | **346.7** | **2708.4** |
| | **50** | **0.3** | **2.4** | **6.9** | **351** | **9.9** | **99** | **42** | **0.30** | **61** | **0.1** | **12** | **1** | **200** | **0.01** | **0.02** | **0.02** | **0.01** | **0.01** | **0.03** | **2.2** | **0.1** | **20** | **10** | **120** | **750** |
| | **400** | **20.0** | **10.7** | **9.1** | **2620** | **32.1** | **630** | **95** | **17.00** | **647** | **15.0** | **380** | **4** | **1480** | **0.40** | **0.41** | **0.70** | **0.06** | **0.34** | **0.39** | **42** | **110** | **120** | **540** | **710** | **6500** |
| | **76.7** | **3.9** | **1.6** | **0.5** | **706** | **5.1** | **155** | **11** | **2.66** | **165** | **4.3** | **102** | **1** | **395** | **0.09** | **0.10** | **0.14** | **0.01** | **0.07** | **0.07** | **5.5** | **24.5** | **28.4** | **151.9** | **159.9** | **1680.2** |

Table A-2 Summary of Raw Water Quality Data from USGS Monitoring Station Near Christmas, FL

| | Color (cu) | Turbidity (NTU) | Oxygen, Dissolved (mg/L) | pH | Specific Conductance (uS/cm) | Water Temperature (Deg C) | Total Hardness (mg/L as CaO3) | Alkalinity (mg/L as CaCO3) | Bromide (mg/L) | Chloride (mg/L) | Silica (mg/L) | Sulfate (mg/L) | Sulfide (mg/L as S) | Total Dissolved Solids (mg/L) | Ammonia (mg/L as N) | NO2 + NO3, Dissolved (mg/L as N) | NO2 + NO3, Total (mg/L as N) | Nitrite (mg/L as N) | Orthophosphorus, Total (mg/L as P) | Phosphorus, Total (mg/L as P) | Organic Carbon, Dissolved (mg/L) | Chlorophyll A (ug/L) | Barium (ug/L) | Iron,Dissolved (ug/L) | Iron,Total (ug/L) | Strontium (ug/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/06/2000 | 200 | 3.2 | 5.9 | 7.2 | 597 | 18.4 | | 59 | 0.4 | 122 | 3.3 | 33 | | | 0.07 | 0.14 | 0.1 | 0.01 | 0.06 | 0.07 | 22 | 4.2 | 23 | 240 | 410 | 980 |
| 01/19/2000 | 200 | 3.8 | 8.1 | 7.4 | 690 | 17.1 | | 62 | 0.4 | 141 | 4.7 | 41 | | | 0.09 | 0.14 | 0.1 | 0.01 | 0.04 | 0.04 | 25 | 2 | 25 | 200 | 370 | 1100 |
| 02/01/2000 | 140 | 4.2 | 8.3 | 7.5 | 802 | 14.4 | | 62 | 0.5 | 164 | 4.8 | 54 | | | 0.16 | 0.27 | 0.3 | 0.01 | 0.02 | 0.03 | 25 | 2.4 | 26 | 160 | 380 | 1200 |
| 02/16/2000 | 160 | 6.8 | 7.2 | 7.2 | 884 | 19 | | 64 | 0.6 | 182 | 4.4 | 63 | | | 0.24 | 0.18 | 0.2 | 0.02 | 0.03 | 0.04 | 25 | 1.4 | 32 | 180 | 400 | 1400 |
| 02/29/2000 | 140 | 13 | 5.5 | 7.2 | 967 | 21.2 | | 66 | 0.6 | 198 | 3.9 | 76 | | | 0.24 | 0.25 | 0.2 | 0.02 | 0.03 | 0.04 | 24 | 1.6 | 37 | 150 | 570 | 1600 |
| 03/15/2000 | 140 | 12 | 5.9 | 7.8 | 1120 | 20.4 | | 70 | 0.8 | 238 | 0.4 | 88 | | | 0.2 | 0.14 | 0.1 | 0.02 | 0.03 | 0.08 | 25 | 15 | 38 | 120 | 540 | 1800 |
| 03/29/2000 | 120 | 12 | 5.7 | 7.8 | 1390 | 22.8 | 270 | 74 | 1 | 319 | 0.9 | 113 | | | 0.21 | 0.18 | 0.2 | 0.02 | 0.03 | 0.06 | 22 | 6.7 | 46 | 100 | 470 | 2200 |
| 04/11/2000 | 100 | 6.5 | 6.8 | 7.5 | 1580 | 20.7 | 300 | 81 | 1.2 | 358 | 1 | 128 | | | 0.24 | 0.18 | 0.2 | 0.01 | 0.04 | 0.08 | 22 | 8.3 | 51 | 90 | 420 | 2600 |
| 04/26/2000 | 80 | 12 | 6.7 | 7.1 | 1680 | 24 | 330 | 82 | 1.2 | 381 | 1.1 | 136 | | | 0.24 | 0.17 | 0.2 | 0.02 | 0.05 | 0.06 | 23 | 3.4 | 60 | 70 | 450 | 2900 |
| 05/09/2000 | 80 | 6.2 | 6.2 | 7.5 | 1860 | 26 | 360 | 85 | 1.4 | 434 | 0.8 | 151 | | | 0.19 | 0.16 | 0.2 | 0.02 | 0.01 | 0.06 | 24 | 7.8 | 67 | 50 | 300 | 3300 |
| 05/23/2000 | 60 | 6.5 | 5.8 | 7.3 | 2380 | 27.7 | 440 | 89 | 1.8 | 552 | 1.7 | 185 | | | 0.25 | 0.22 | 0.2 | 0.02 | 0.03 | 0.06 | 24 | 6 | 80 | 60 | 250 | 3900 |
| 06/06/2000 | 70 | 8.9 | 4.9 | 7.5 | 2620 | 29 | 490 | 84 | 2.3 | 668 | 1.4 | 211 | | 1440 | 0.14 | 0.02 | 0.02 | 0.01 | 0.05 | 0.09 | 25 | 24 | 89 | 30 | 320 | 4300 |
| 06/23/2000 | 70 | 5.9 | 4.9 | 7.8 | 3220 | 30.1 | 550 | 103 | 2.6 | 822 | 1.6 | 244 | | 1740 | 0.28 | 0.07 | 0.1 | 0.02 | 0.05 | 0.08 | 27 | 7.3 | 100 | 30 | 220 | 5100 |
| 07/06/2000 | 40 | 9 | 5.6 | 7 | 3900 | 29.4 | 830 | 38 | 3.3 | 1150 | 7.5 | 534 | | 2640 | 1.7 | 0.14 | 0.1 | 0.06 | 0.06 | 0.13 | 20 | 22 | 120 | 130 | 830 | 6400 |
| 07/19/2000 | 60 | 9 | 6.5 | 7.7 | 3340 | 30 | 670 | 59 | 3.3 | 991 | 8.9 | 383 | | 2190 | 0.37 | 0.03 | | 0.01 | 0.06 | 0.1 | 25 | 71 | 96 | 70 | 410 | 5600 |
| 08/02/2000 | 120 | 7.5 | 5.7 | 7.2 | 2660 | 29.5 | 490 | 33 | 1.8 | 605 | 9.5 | 316 | | 1460 | 0.31 | 0.03 | | 0.01 | 0.02 | 0.06 | 23 | 28 | 74 | 480 | 890 | 4100 |
| 08/15/2000 | 160 | 9.7 | 4.8 | 7.1 | 1350 | 29.1 | 250 | 43 | 0.9 | 319 | 6 | 120 | | 713 | 0.05 | 0.02 | 0.02 | 0.01 | 0.01 | 0.09 | 27 | 28 | 46 | 370 | 740 | 2200 |
| 08/30/2000 | 80 | 7.6 | 7.2 | 7.8 | 1810 | 30.2 | 380 | 84 | 1.2 | 394 | 9.5 | 171 | | 958 | 0.03 | 0.02 | 0.02 | 0.01 | 0.03 | 0.09 | 23 | 51 | 73 | 100 | 450 | 3900 |
| 09/12/2000 | 140 | 5.6 | 4.6 | 7.1 | 1620 | 28.6 | 340 | 57 | 1 | 335 | 9.5 | 201 | | 877 | 0.13 | 0.04 | | 0.01 | 0.01 | 0.06 | 25 | 27 | 58 | 380 | 740 | 3000 |
| 09/27/2000 | 160 | 3.1 | 2 | 7 | 1400 | 29.1 | 290 | 45 | 0.8 | 287 | 8.9 | 179 | | 761 | 0.2 | 0.03 | | 0.01 | 0.04 | 0.06 | 24 | 4.9 | 43 | 520 | 880 | 2300 |
| 10/10/2000 | 280 | 0.6 | 2.8 | 7.5 | 779 | 19.3 | 170 | 46 | 0.4 | 157 | 9.5 | 77 | | 419 | 0.21 | 0.02 | 0.02 | 0.01 | 0.11 | 0.11 | 28 | 0.1 | 30 | 720 | 940 | 1400 |
| 10/25/2000 | 200 | 2.6 | 2.8 | 7 | 691 | 22.5 | 160 | 44 | 0.4 | 137 | 4.8 | 69 | | 369 | 0.09 | 0.04 | | 0.01 | 0.12 | 0.13 | 26 | 0.1 | 26 | 420 | 600 | 1300 |
| 11/07/2000 | 200 | 4.3 | 3.3 | 7.3 | 763 | 22.5 | 180 | 56 | 0.6 | 151 | 6 | 65 | | 404 | 0.11 | 0.08 | 0.1 | 0.01 | 0.12 | 0.14 | 28 | 0.1 | 28 | 470 | 690 | 1400 |
| 11/21/2000 | 240 | 7.1 | 6.5 | 7.4 | 946 | 17.2 | 210 | 63 | 0.71 | 190 | 8.4 | 85 | 1 | 504 | 0.13 | 0.32 | 0.3 | 0.03 | 0.09 | 0.14 | 29 | 0.1 | 34 | 590 | 890 | 1700 |
| 12/06/2000 | 200 | 8 | 8.4 | 7.4 | 1210 | 14.8 | 270 | 66 | 1.1 | 260 | 9.1 | 130 | 1 | 676 | 0.19 | 0.4 | 0.4 | 0.02 | 0.07 | 0.08 | 26 | 0.1 | 41 | 560 | 890 | 2200 |
| 12/19/2000 | 160 | 9.4 | 6.9 | 7.8 | 1380 | 17.9 | 300 | 64 | 1 | 290 | 7.7 | 160 | 1 | 762 | 0.25 | 0.35 | 0.4 | 0.02 | 0.06 | 0.07 | 25 | 0.1 | 47 | 380 | 750 | 2500 |
| 01/04/2001 | 140 | 7.4 | 9.7 | 7.7 | 1720 | 9.3 | 370 | 72 | 1.3 | 370 | 5.2 | 200 | 1 | 950 | 0.33 | 0.28 | 0.3 | 0.01 | 0.04 | 0.06 | 25 | 0.1 | 52 | 290 | 560 | 3100 |
| 01/18/2001 | 100 | 4.3 | 5.4 | 7.4 | 1750 | 20.5 | 380 | 72 | 1.5 | 370 | 2.8 | 220 | 1 | 991 | 0.28 | 0.19 | 0.2 | 0.01 | 0.02 | 0.05 | 25 | 4.7 | 58 | 160 | 410 | 3200 |
| 01/31/2001 | 80 | 0.6 | 8.6 | 8.8 | 2000 | 18.7 | 430 | 74 | 1.3 | 430 | 0.9 | 260 | 1 | 1130 | 0.22 | 0.1 | 0.1 | 0.01 | 0.03 | 0.04 | 23 | 3.6 | 64 | 140 | 370 | 3800 |
| 02/13/2001 | 80 | 1 | 6.4 | 7.5 | 2020 | 22 | 450 | 76 | 2.2 | 410 | 0.9 | 250 | 1 | 1100 | 0.22 | 0.08 | 0.1 | 0.01 | 0.04 | 0.03 | 27 | 0.1 | 71 | 90 | 290 | 3900 |
| 02/28/2001 | 80 | 5.3 | 6.4 | 7.4 | 1580 | 24.9 | 490 | 81 | 3.8 | 460 | 1.1 | 270 | 1 | 1210 | 0.28 | 0.11 | 0.1 | 0.02 | 0.05 | 0.02 | 24 | 6.6 | 74 | 60 | 260 | 4300 |
| 03/15/2001 | 100 | 8 | 6.5 | 7.8 | 2400 | 23.3 | 540 | 79 | 6 | 520 | 0.6 | 300 | 1 | 1340 | 0.26 | 0.12 | 0.1 | 0.02 | 0.04 | 0.07 | 23 | 9.7 | 81 | 40 | 250 | 4500 |
| 03/28/2001 | 60 | 3.2 | 7.5 | 8.1 | 3310 | 19.6 | 720 | 72 | 6.6 | 930 | 1.5 | 460 | 1 | 2200 | 0.34 | 0.2 | 0.2 | 0.03 | 0.02 | 0.05 | 21 | 8.6 | 96 | 50 | 190 | 5700 |
| 04/11/2001 | 60 | 4 | 6 | 7.2 | 2530 | 25.8 | 540 | 65 | 3.6 | 540 | 0.7 | 340 | 1 | 1410 | 0.13 | 0.07 | 0.1 | 0.01 | 0.04 | 0.04 | 21 | 8.6 | 79 | 60 | 260 | 4700 |
| 04/25/2001 | 60 | 8.4 | 5.1 | 7.4 | 2450 | 24.3 | 570 | 76 | 5 | 530 | 0.4 | 320 | 1 | 1390 | 0.1 | 0.04 | 0.1 | 0.01 | 0.02 | 0.06 | 22 | 9.6 | 90 | 40 | 300 | 5200 |
| 05/09/2001 | 60 | 6.2 | 6.4 | 7.5 | 3360 | 24.1 | 670 | 41 | 2.4 | 758 | 1.6 | 434 | 1 | 1880 | 0.24 | 0.09 | 0.1 | 0.02 | 0.02 | 0.05 | 18 | 4.1 | 74 | 180 | 520 | 4910 |
| 05/23/2001 | 60 | 6.5 | 5.1 | 7.4 | 3180 | 27.9 | 650 | 72 | 2.4 | 760 | 1.6 | 410 | 1 | 1850 | 0.03 | 0.02 | 0.02 | 0.01 | 0.03 | 0.09 | 24 | 17 | 93 | 60 | 380 | 5900 |
| 06/06/2001 | 60 | 4.1 | 6.6 | 7.9 | 3420 | 29.8 | 650 | 63 | 2.5 | 780 | 1.8 | 410 | 1 | 1900 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 | 0.07 | 24 | 17 | 95 | 40 | 310 | 6000 |
| 06/20/2001 | 70 | 3.7 | 4.4 | 7.5 | 3690 | 28.5 | 690 | 43 | 3.2 | 890 | 3.9 | 430 | 1 | 2090 | 0.33 | 0.13 | 0.1 | 0.01 | 0.04 | 0.07 | 18 | 12 | 85 | 230 | 540 | 5600 |
| 07/03/2001 | 60 | 8.6 | 5.2 | 7.5 | 3070 | 30.1 | 600 | 62 | 2.7 | 690 | 6.7 | 340 | 1 | 1670 | 0.04 | 0.02 | 0.02 | 0.01 | 0.02 | 0.12 | 23 | 49 | 86 | 60 | 550 | 5500 |
| 07/18/2002 | 160 | 4.3 | 1.1 | 6.3 | 1150 | 27.6 | 230 | 23 | 0.78 | 240 | 5.8 | 150 | 1.8 | 630 | 0.22 | 0.23 | 0.2 | 0.01 | 0.02 | 0.08 | 22 | 63 | 30 | 400 | 930 | 1800 |
| 08/01/2001 | 240 | 3 | 0.1 | 6.6 | 1140 | 29 | 250 | 58 | 0.86 | 237 | 7.4 | 119 | 2 | 614 | 0.09 | 0.02 | 0.02 | 0.01 | 0.13 | 0.19 | 23 | 0.1 | 44 | 920 | 1410 | 2270 |
| 08/16/2001 | 280 | 0.5 | 0.1 | 6.7 | 749 | 30.1 | 170 | 64 | 0.66 | 154 | 11 | 44 | 3 | 388 | 0.08 | 0.02 | 0.02 | 0.01 | 0.22 | 0.28 | 26 | 0.1 | 33 | 760 | 1070 | 1400 |
| 08/28/2001 | 320 | 0.7 | 2.1 | 6.7 | 587 | 30.2 | 140 | 70 | 0.53 | 116 | 14 | 23 | 4 | 309 | 0.05 | 0.02 | 0.02 | 0.01 | 0.21 | 0.27 | 26 | 19 | 28 | 460 | 760 | 1140 |
| 09/13/2001 | 240 | 0.9 | 1.1 | 6.8 | 404 | 26.4 | 100 | 55 | 0.36 | 75 | 11 | 14 | 2 | | 0.13 | 0.02 | 0.02 | 0.01 | 0.11 | 0.09 | 31 | 0.1 | 21 | 420 | 560 | 780 |
| 09/26/2001 | 240 | 1.2 | 0.1 | 6.6 | 442 | 27.6 | 100 | 54 | 0.44 | 82 | 9.8 | 17 | 2 | 225 | 0.09 | 0.02 | | 0.01 | 0.08 | 0.1 | 30 | 0.1 | 20 | 340 | 600 | 790 |
| 10/10/2001 | 240 | 1.2 | 3.4 | 6.7 | 402 | 23.4 | 100 | 54 | 0.49 | 75 | 8.4 | 17 | 2 | | 0.09 | 0.02 | | 0.01 | 0.05 | 0.06 | 28 | 0.1 | 20 | 300 | 400 | 790 |
| 10/24/2001 | 200 | 0.2 | 1 | 6.7 | 442 | 25.9 | 100 | 53 | 0.38 | 82 | 7.7 | 19 | 2 | 224 | 0.13 | 0.02 | | 0.01 | 0.06 | 0.08 | 31 | 0.1 | 21 | 380 | 570 | 790 |
| 11/05/2001 | 200 | 0.8 | 2.8 | 6.7 | 430 | 22.5 | 100 | 52 | 0.49 | 83 | 6.7 | 21 | 1 | | 0.08 | 0.04 | | 0.01 | 0.04 | 0.07 | 34 | 0.1 | 20 | 400 | 560 | 800 |
| 11/20/2001 | 200 | 1.1 | 2.2 | 6.9 | 547 | 21.2 | 120 | 58 | 0.59 | 109 | 6.5 | 28 | 2 | | 0.06 | 0.08 | | 0.01 | 0.05 | 0.05 | 29 | 0.1 | 22 | 370 | 560 | 940 |
| 12/05/2001 | 200 | 1.5 | 3.7 | 7 | 574 | 22.1 | 130 | 60 | 0.47 | 118 | 6 | 30 | 2 | | 0.09 | 0.11 | | 0.01 | 0.06 | 0.07 | 28 | 0.1 | 23 | 340 | 580 | 990 |
| 12/18/2001 | 200 | 4 | 4.6 | 7.2 | 677 | 22.3 | 160 | 67 | 0.55 | 140 | 6.6 | 34 | 2 | 349 | 0.13 | 0.16 | | 0.01 | 0.06 | 0.08 | 29 | 0.1 | 27 | 380 | 610 | 1130 |
| 01/03/2002 | 200 | 6.8 | 8.1 | 7.2 | 822 | 14.6 | 180 | 137 | 0.98 | 172 | 6.3 | 52 | 2 | 466 | 0.16 | 0.26 | | 0.01 | 0.01 | 0.05 | 30 | 0.1 | 28 | 310 | 620 | 1360 |
| 01/15/2002 | 140 | 7.7 | 8.8 | 7.5 | 962 | 17.1 | 200 | 66 | 1.4 | 210 | 5.6 | 73 | 1 | 517 | 0.12 | 0.25 | | 0.01 | 0.03 | 0.05 | 28 | 18 | 32 | 320 | 660 | 1580 |
| 01/29/2002 | 160 | 13 | 6.6 | 7.4 | 1130 | 22.4 | 240 | 72 | 1.3 | 245 | 2.8 | 90 | 2 | 591 | 0.09 | 0.09 | | 0.01 | 0.02 | 0.04 | 27 | 20 | 39 | 280 | 860 | 1890 |
| 02/12/2002 | 140 | 12 | 8.4 | 7.4 | 1340 | 19.8 | 280 | 73 | 1.1 | 294 | 0.7 | 121 | 3 | 713 | 0.13 | 0.07 | | 0.01 | 0.01 | 0.05 | 2.1 | 14 | 45 | 240 | 890 | 2360 |
| 02/27/2002 | 160 | 5.5 | 8.2 | 7 | 1120 | 18.2 | 210 | 30 | 0.92 | 247 | 3.1 | 121 | 1 | 599 | 0.08 | 0.07 | | 0.01 | 0.02 | 0.07 | 26 | 11 | 34 | 310 | 740 | 1570 |
| 03/13/2002 | 100 | 6 | 7.5 | 7.5 | 1300 | 22.7 | 280 | 68 | 1 | 276 | 0.6 | 134 | 1 | 697 | 0.09 | 0.03 | | 0.01 | 0.01 | 0.05 | 24 | 23 | 45 | 190 | 610 | 2450 |
| 03/27/2002 | 100 | 9.5 | 6.8 | 7.4 | 1420 | 25.7 | 290 | 70 | 1.2 | 296 | 1 | 141 | 1 | 740 | 0.04 | 0.06 | | 0.01 | 0.02 | 0.06 | 24 | 24 | 49 | 160 | 590 | 2620 |
| 04/10/2002 | 100 | 9.2 | 7.5 | 7.5 | 1360 | 23.8 | 280 | 76 | 1.2 | 297 | 0.9 | 135 | 1 | 733 | 0.07 | 0.07 | | 0.01 | 0.01 | 0.05 | 25 | 17 | 46 | 100 | 510 | 2520 |
| 04/24/2002 | 100 | 9.1 | 7 | 7.4 | 1450 | 28.3 | 300 | 76 | 1.3 | 321 | 1 | 132 | 2 | 774 | 0.02 | 0.02 | | 0.01 | 0.02 | 0.04 | 23 | 28 | 53 | 80 | 440 | 2760 |
| 05/07/2002 | 100 | 9.4 | 6 | 7.6 | 1600 | 27.9 | 330 | 84 | 1.4 | 351 | 0.9 | 150 | 1 | 858 | 0.25 | 0.03 | | 0.01 | 0.01 | 0.05 | 28 | 19 | 59 | 70 | 440 | 3140 |
| 05/22/2002 | 80 | 15 | 8 | 7.7 | 1950 | 23.7 | 420 | 85 | 1.5 | 443 | 0.9 | 196 | 1 | 1070 | 0.07 | 0.05 | | 0.01 | 0.02 | 0.07 | 27 | 53 | 66 | 30 | 480 | 3620 |
| | **139.2** | **6.0** | **5.5** | **7.3** | **1589.2** | **23.7** | **346.3** | **65.6** | **1.5** | **364.2** | **4.6** | **167.0** | **1.5** | **1011.1** | **0.2** | **0.1** | **0.1** | **0.0** | **0.0** | **0.1** | **24.8** | **12.4** | **52.3** | **249.7** | **562.5** | **2796.5** |
| | **40** | **0.2** | **0.1** | **6.3** | **402** | **9.3** | **100** | **23** | **0.36** | **75** | **0.4** | **14** | **1** | **224** | **0.02** | **0.02** | **0.02** | **0.01** | **0.01** | **0.02** | **2.1** | **0.1** | **20** | **30** | **190** | **780** |
| | **320** | **15** | **9.7** | **8.8** | **3900** | **30.2** | **830** | **137** | **6.6** | **1150** | **14** | **534** | **4** | **2640** | **1.7** | **0.4** | **0.4** | **0.06** | **0.22** | **0.28** | **34** | **71** | **120** | **920** | **1410** | **6400** |
| | **67.8** | **3.7** | **2.4** | **0.4** | **944.7** | **4.9** | **188.2** | **17.8** | **1.3** | **252.7** | **3.5** | **130.0** | **0.7** | **600.7** | **0.2** | **0.1** | **0.1** | **0.0** | **0.0** | **0.0** | **4.2** | **16.1** | **25.6** | **199.6** | **236.9** | **1618.5** |

Table A-3 Summary of Raw Water Quality Data from USGS Monitoring Station Near Sanford, FL

| | Color (cu) | Turbidity (NTU) | Oxygen, Dissolved (mg/L) | pH | Specific Conductance (uS/cm) | Water Temperature (Deg C) | Total Hardness (mg/L as CaO3) | Alkalinity (mg/L as CaCO3) | Bromide (mg/L) | Chloride (mg/L) | Silica (mg/L) | Sulfate (mg/L) | Sulfide (mg/L as S) | Total Dissolved Solids (mg/L) | Ammonia (mg/L as N) | NO2 + NO3, Dissolved (mg/L as N) | NO2 + NO3, Total (mg/L as N) | Nitrite (mg/L as N) | Orthophosphorus, Total (mg/L as P) | Phosphorus, Total (mg/L as P) | Organic Carbon, Dissolved (mg/L) | Chlorophyll A (ug/L) | Barium (ug/L) | Iron,Dissolved (ug/L) | Iron,Total (ug/L) | Strontium (ug/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/05/2000 | 200 | 1.4 | | 7.7 | | | | 58 | 0.5 | 139 | 4.5 | 28 | | | 0.07 | 0.16 | 0.2 | 0.01 | 0.06 | 0.06 | 25 | 7.6 | 18 | 270 | 420 | 700 |
| 01/18/2000 | 200 | 3.4 | 8.4 | 7.7 | 728 | 16.1 | | 60 | 0.5 | 163 | 3.7 | 33 | | | 0.04 | 0.18 | 0.2 | 0.01 | 0.04 | 0.04 | 24 | 5.9 | 19 | 240 | 390 | 730 |
| 01/31/2000 | 200 | 3.9 | 8.3 | 7.8 | 799 | 13.5 | | 61 | 0.6 | 174 | 3.1 | 38 | | | 0.06 | 0.23 | 0.2 | 0.01 | 0.03 | 0.04 | 23 | 5.6 | 20 | 220 | 360 | 800 |
| 02/15/2000 | 160 | 2.8 | 8.4 | 7.2 | 891 | 18.8 | | 64 | 0.7 | 197 | 1.9 | 44 | | | 0.08 | 0.13 | 0.1 | 0.01 | 0.02 | 0.04 | 23 | 11 | 22 | 200 | 310 | 870 |
| 03/01/2000 | 120 | 4.9 | 7.2 | 7.5 | 1020 | 21.6 | | 67 | 0.7 | 226 | 0.1 | 54 | | | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.03 | 22 | 13 | 25 | 140 | 290 | 1000 |
| 03/14/2000 | 120 | 4.2 | 7.1 | 7.9 | 1110 | 21.9 | | 68 | 0.8 | 255 | 0.3 | 61 | | | 0.07 | 0.02 | 0.02 | 0.01 | 0.03 | 0.07 | 22 | 15 | 26 | 120 | 230 | 1100 |
| 03/28/2000 | 100 | 3.8 | 7.8 | 7.7 | 1160 | 23.3 | 210 | 76 | 0.8 | 263 | 1 | 68 | | | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.06 | 19 | 23 | 26 | 60 | 150 | 1100 |
| 04/12/2000 | 80 | 3.4 | 9.6 | 8.7 | 1210 | 24.4 | 200 | 76 | 0.9 | 278 | 0.3 | 71 | | | 0.04 | 0.02 | 0.02 | 0.01 | 0.01 | 0.07 | 18 | 21 | 26 | 40 | 130 | 1100 |
| 04/25/2000 | 70 | 6 | 10.3 | 9.2 | 1280 | 27 | 210 | 78 | 1 | 295 | 0.6 | 77 | | | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.09 | 20 | 44 | 28 | 20 | 130 | 1200 |
| 05/08/2000 | 70 | 9.1 | 13.8 | 9.6 | 1340 | 28 | 230 | 78 | 1 | 318 | 2.6 | 79 | | | 0.05 | 0.02 | 0.02 | 0.01 | 0.06 | 0.13 | 19 | 48 | 29 | | 160 | 1200 |
| 05/22/2000 | 50 | 2.1 | 5.2 | 8.1 | 1260 | 29.1 | 230 | 90 | 0.9 | 287 | 6 | 82 | | | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.09 | 15 | 30 | 31 | 10 | 70 | 1200 |
| 06/05/2000 | 20 | 2 | 7.4 | 7.8 | 1130 | 32 | 230 | 107 | 0.8 | 238 | 4 | 77 | | 588 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 | 0.08 | 5.5 | 36 | 21 | | 60 | 970 |
| 06/20/2000 | 50 | 2.6 | 5.5 | 8.2 | 1470 | 29.8 | 260 | 91 | 1.1 | 345 | 8 | 95 | | 778 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.08 | 16 | 42 | 36 | | 160 | 1400 |
| 07/05/2000 | 10 | 4.7 | 10.5 | 8.2 | 1190 | 32.1 | 240 | 101 | 0.8 | 244 | 7.5 | 95 | | 627 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 | 0.08 | 8.2 | 35 | 24 | | 120 | 1100 |
| 07/18/2000 | 30 | 11 | 10.1 | 8.2 | 1470 | 32.3 | 250 | 80 | 1.3 | 348 | 8.2 | 96 | | 782 | 0.04 | 0.02 | 0.02 | 0.01 | 0.02 | 0.09 | 13 | 15 | 34 | | 240 | 1400 |
| 08/01/2000 | 30 | 5.6 | 9.7 | 8.9 | 1460 | 30.8 | 240 | 68 | 1.2 | 346 | 6.6 | 91 | | 762 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.07 | 14 | 40 | 34 | | 120 | 1300 |
| 08/14/2000 | 20 | 5.7 | 7 | 8 | 1650 | 30.6 | 240 | 56 | 1.2 | 401 | 6.8 | 101 | | 853 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.06 | 17 | 32 | 36 | | 90 | 1400 |
| 08/29/2000 | 30 | 3.7 | 6.2 | 7.9 | 1620 | 30.2 | 240 | 50 | 1.3 | 394 | 5.1 | 104 | | 832 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.04 | 14 | 5.2 | 34 | | 70 | 1400 |
| 09/11/2000 | 30 | 3 | 5.4 | 7.7 | 1240 | 29.4 | 240 | 97 | 0.9 | 253 | 6.1 | 97 | | 644 | 0.05 | 0.1 | 0.1 | 0.01 | 0.04 | 0.38 | 7.5 | 19 | 21 | 20 | 90 | 1000 |
| 09/26/2000 | 30 | 2.8 | 6.8 | 8 | 1750 | 30.1 | 250 | 45 | 1.2 | 418 | 3.6 | 117 | | 888 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.03 | 14 | 9.6 | 35 | 10 | 70 | 1500 |
| 10/11/2000 | 50 | 4 | 9 | 8.1 | 1880 | 21.5 | 280 | 51 | 1.4 | 455 | 4.7 | 133 | | 979 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.04 | 16 | 38 | 42 | 10 | 100 | 1800 |
| 10/24/2000 | 80 | 6.8 | 6.7 | 7.8 | 1820 | 23.4 | 310 | 48 | 1.2 | 435 | 6 | 157 | | 971 | 0.04 | 0.02 | 0.02 | 0.01 | 0.01 | 0.07 | 19 | 41 | 41 | 70 | 240 | 2000 |
| 11/06/2000 | 120 | 2.9 | 8 | 8 | 1580 | 24.5 | 270 | 48 | 1.2 | 370 | 6.6 | 150 | | 869 | 0.15 | 0.04 | 0.1 | 0.01 | 0.02 | 0.05 | 22 | 30 | 38 | 130 | 230 | 1900 |
| 11/20/2000 | 140 | 2.1 | 7 | 7.8 | 1460 | 20.8 | 260 | 51 | 1.2 | 330 | 7.4 | 130 | 1 | 778 | 0.23 | 0.14 | 0.1 | 0.02 | 0.01 | 0.06 | 25 | 22 | 35 | 150 | 240 | 1800 |
| 12/05/2000 | 120 | 2.8 | 7.3 | 7.7 | 1240 | 16.1 | 250 | 71 | 1.2 | 270 | 7.1 | 110 | 1 | 664 | 0.1 | 0.28 | 0.3 | 0.01 | 0.04 | 0.04 | 17 | 8.9 | 26 | 110 | 170 | 1500 |
| 12/20/2000 | 140 | 2.9 | 7.6 | 8 | 1430 | 15.1 | 250 | 60 | 1.3 | 320 | 6.5 | 120 | 1 | 758 | 0.25 | 0.22 | 0.2 | 0.01 | 0.03 | 0.04 | 24 | 25 | 33 | 140 | 230 | 1700 |
| 01/05/2001 | 140 | 4.9 | 10.8 | 8.2 | 1490 | 10.1 | 270 | 65 | 1.1 | 350 | 5.4 | 120 | 1 | 796 | 0.18 | 0.26 | 0.3 | 0.01 | 0.01 | 0.06 | 22 | 28 | 33 | 110 | 180 | 1700 |
| 01/18/2001 | 80 | 3.5 | 13.2 | 8.2 | 1340 | 20 | 260 | 76 | 1 | 300 | 3.3 | 120 | 1 | 737 | 0.29 | 0.14 | 0.1 | 0.01 | 0.01 | 0.09 | 19 | 39 | 29 | 70 | 130 | 1500 |
| 01/31/2001 | 80 | 1.1 | 9.3 | 8.3 | 1760 | 23.3 | 310 | 73 | 1.7 | 407 | 0.1 | 140 | 1 | 926 | 0.25 | 0.02 | 0.02 | 0.01 | 0.01 | 0.04 | 23 | 36 | 39 | 40 | 150 | 1900 |
| 02/15/2001 | 80 | 4.5 | 10.6 | 7.5 | 1700 | 26.1 | 300 | 80 | 3 | 380 | 0.6 | 140 | 1 | 904 | 0.12 | 0.02 | 0.02 | 0.01 | 0.01 | 0.08 | 19 | 79 | 37 | 20 | 120 | 1900 |
| 03/15/2001 | 30 | 5.0 | 6.6 | 7.7 | 1330 | 20.0 | 260 | 105 | 3.7 | 200 | 4.3 | 100 | 1 | 690 | 0.12 | 0.21 | 0.2 | 0.01 | 0.06 | 0.00 | 9.9 | 21 | 22 | 10 | 120 | 1300 |
| 03/28/2001 | 60 | 6.3 | 10.9 | 8.8 | 1700 | 21.9 | 280 | 78 | 8 | 390 | 0.4 | 140 | 1 | 901 | 0.06 | 0.02 | 0.02 | 0.01 | 0.01 | 0.08 | 16 | 64 | 34 | | 120 | 1700 |
| 04/11/2001 | 60 | 6.9 | 8 | 8.7 | 1780 | 27.7 | 310 | 77 | 8.3 | 410 | 1.1 | 140 | 1 | 939 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 | 0.07 | 18 | 9.2 | 39 | 10 | 120 | 1800 |
| 04/25/2001 | 60 | 7.8 | 5.4 | 7.8 | 1920 | 27.3 | 340 | 76 | 5 | 460 | 2.8 | 160 | 1 | 1030 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.09 | 19 | | 44 | 10 | 190 | 2000 |
| 05/09/2001 | 20 | 5.9 | 8.4 | 8.1 | 1070 | 24.5 | 240 | 108 | 0.68 | 207 | 5.4 | 94 | 1 | 569 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.07 | 5.3 | 33 | 18 | | 90 | 1020 |
| 05/23/2001 | 50 | 10 | 8.1 | 8.7 | 1970 | 29.1 | 350 | 84 | 1.6 | 460 | 3.1 | 170 | 1 | 1050 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.1 | 16 | 59 | 42 | | 210 | 2000 |
| 06/06/2001 | 40 | 15 | 10.4 | 9.2 | 2220 | 31.1 | 360 | 79 | 1.7 | 510 | 3.5 | 180 | 1 | 1180 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.15 | 18 | 120 | 45 | | 780 | 2200 |
| 06/20/2001 | 40 | 8.2 | 5 | 8.8 | 2290 | 32.3 | 380 | 72 | 1.8 | 540 | 5.8 | 190 | 1 | 1210 | 0.02 | 0.02 | 0.02 | 0.01 | 0.04 | 0.13 | 18 | 120 | 44 | | 260 | 2300 |
| 07/03/2001 | 40 | 8.1 | 8.3 | 9.3 | 2380 | 31.7 | 390 | 75 | 2 | 560 | 8.7 | 200 | 1 | 1260 | 0.04 | 0.02 | 0.02 | 0.01 | 0.03 | 0.07 | 18 | 77 | 43 | | 90 | 2400 |
| 07/18/2002 | 20 | 45 | 6.2 | 8.2 | 1810 | 29.5 | 360 | 68 | 1.6 | 440 | 9.3 | 190 | 1 | 1050 | 0.81 | 0.03 | 0.1 | 0.01 | 0.01 | 0.24 | 8.5 | 60 | 31 | 10 | 1200 | 2000 |
| 08/01/2001 | 40 | 7.2 | 8.1 | 8.8 | 2160 | 29.8 | 350 | 49 | 2 | 517 | 8.7 | 200 | 1 | 1180 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 | 0.09 | 13 | 93 | 39 | | 190 | 2260 |
| 08/16/2001 | 140 | 0.9 | 3 | 7.1 | 1390 | 30 | 230 | 46 | 1.2 | 316 | 7.9 | 116 | 1 | 727 | 0.26 | 0.05 | 0.1 | 0.04 | 0.02 | 0.09 | 18 | 68 | 27 | 170 | 320 | 1470 |
| 08/28/2001 | 280 | 2.8 | 3 | 7 | 1010 | 30.6 | 180 | 53 | 1 | 229 | 9.6 | 64 | 3 | 525 | 0.31 | 0.21 | 0.2 | 0.2 | 0.18 | 0.22 | 23 | 21 | 22 | 390 | 510 | 1160 |
| 09/13/2001 | 240 | 3.2 | 4.7 | 7.3 | 808 | 27.8 | 160 | 61 | 0.88 | 177 | 12 | 37 | 2 | 416 | 0.32 | 0.25 | 0.3 | 0.19 | 0.22 | 0.24 | 31 | 0.1 | 23 | 430 | 600 | 990 |
| 09/26/2001 | 320 | 2.4 | 1.7 | 6.8 | 462 | 27.3 | 93 | 42 | 0.5 | 97 | 9.3 | 19 | 1 | 239 | 0.15 | 0.14 | | 0.04 | 0.16 | 0.18 | 32 | 0.1 | 16 | 430 | 610 | 600 |
| 10/10/2001 | 280 | 7 | 6.4 | 7 | 452 | 24 | 92 | 45 | 0.53 | 92 | 9.3 | 17 | 2 | | 0.15 | 0.16 | | 0.07 | 0.14 | 0.17 | 30 | 6.1 | 17 | 490 | 780 | 580 |
| 10/24/2001 | 280 | 1.2 | 4 | 6.7 | 546 | 24.9 | 110 | 51 | 0.63 | 113 | 9.5 | 21 | 2 | 276 | 0.1 | 0.14 | | 0.04 | 0.07 | 0.07 | 32 | 3.4 | 19 | 400 | 490 | 700 |
| 11/05/2001 | 240 | 1.4 | 6.4 | 7.5 | 521 | 21.1 | 110 | 52 | 0.59 | 111 | 8.4 | 21 | 2 | | 0.06 | 0.16 | | 0.02 | 0.06 | 0.09 | 33 | 0.1 | 18 | 360 | 480 | 700 |
| 11/20/2001 | 240 | 1.3 | 7.1 | 7.5 | 533 | 20.9 | 110 | 50 | 0.61 | 111 | 7 | 22 | 2 | | 0.07 | 0.17 | | 0.02 | 0.05 | 0.06 | 29 | 0.1 | 17 | 350 | 470 | 660 |
| 12/05/2001 | 240 | 1.6 | 5.7 | 7.2 | 571 | 22.9 | | 51 | 0.5 | 123 | 6.1 | 7.9 | 2 | | 0.23 | 0.12 | | 0.02 | 0.07 | 0.07 | 30 | 0.1 | 18 | 370 | 490 | 680 |
| 12/18/2001 | 240 | 3.2 | 6.7 | 7.5 | 671 | 23.6 | 140 | 59 | 0.57 | 148 | 6.3 | 30 | 1 | 346 | 0.1 | 0.2 | | 0.05 | 0.07 | 0.09 | 28 | 0.1 | 21 | 360 | 480 | 800 |
| 01/04/2002 | 200 | 2.9 | 9.7 | 7.8 | 776 | 11.8 | 150 | 66 | 0.66 | 168 | 6.3 | 36 | 2 | 395 | 0.09 | 0.23 | | 0.01 | 0.05 | 0.06 | 30 | 0.1 | 23 | 290 | 400 | 870 |
| 01/14/2002 | 160 | 2.7 | 10 | 7.8 | 823 | 14.1 | 160 | 67 | 1.5 | 183 | 5.9 | 38 | 1 | 424 | 0.04 | 0.24 | | 0.01 | 0.04 | 0.07 | 28 | 11 | 21 | 280 | 350 | 880 |
| 01/30/2002 | 140 | 3.6 | 7.4 | 7.5 | 947 | 22.9 | 180 | 71 | 1 | 210 | 4.2 | 50 | 1 | 486 | 0.12 | 0.15 | | 0.01 | 0.03 | 0.05 | 25 | 8.1 | 25 | 210 | 320 | 970 |
| 02/14/2002 | 120 | 3.4 | 9.2 | 7.6 | 1060 | 16.8 | 190 | 70 | 0.9 | 244 | 0.7 | 62 | 2 | 553 | 0.03 | 0.11 | | 0.01 | 0.02 | 0.04 | 3.6 | 0.1 | 27 | 190 | 280 | 1120 |
| 02/26/2002 | 120 | 4.5 | 9.6 | 7.8 | 1120 | 18.3 | 200 | 70 | 0.86 | 258 | 0.2 | 68 | 1 | 575 | 0.04 | 0.03 | | 0.01 | 0.03 | 0.06 | 22 | 13 | 28 | 150 | 250 | 1150 |
| 03/12/2002 | 120 | 4.9 | 9.2 | 8.1 | 1300 | 22.2 | 230 | 68 | 1.3 | 302 | 0.1 | 88 | 1 | 667 | 0.04 | 0.02 | | 0.01 | 0.01 | 0.05 | 22 | 18 | 30 | 120 | 240 | 1380 |
| 03/28/2002 | 100 | 5.8 | 7.8 | 8 | 1420 | 24.9 | 250 | 61 | 1.3 | 323 | 0.2 | 114 | 1 | 736 | 0.02 | 0.02 | | 0.01 | 0.01 | 0.04 | 20 | 27 | 34 | 80 | 160 | 1500 |
| 04/09/2002 | 80 | 6.6 | 8.8 | 8.3 | 1460 | 22.2 | 250 | 64 | 1.3 | 336 | 0.4 | 114 | 1 | 754 | 0.02 | 0.02 | | 0.01 | 0.01 | 0.07 | 20 | 50 | 33 | 40 | 150 | 1540 |
| 04/25/2002 | 100 | 7.5 | 5.9 | 8.4 | 1520 | 28.8 | 250 | 64 | 1.4 | 360 | 1.2 | 120 | 1 | 805 | 0.01 | 0.02 | | 0.01 | 0.02 | 0.07 | 19 | 92 | 33 | 20 | 110 | 1540 |
| 05/08/2002 | 80 | 12 | 2.6 | 8 | 1520 | 30.9 | 270 | 70 | 1.4 | 358 | 3 | 121 | 1 | 814 | 0.04 | 0.02 | | 0.01 | 0.02 | 0.08 | 21 | 46 | 34 | 20 | 220 | 1620 |
| 05/21/2002 | 40 | 8 | 9.8 | 7.7 | 1280 | 25.1 | 250 | 105 | 1 | 273 | 6.3 | 88 | 1 | 684 | 0.01 | 0.03 | | 0.01 | 0.02 | 0.06 | 9.6 | 35 | 23 | 10 | 110 | 1170 |
| | **110.8** | **5.4** | **7.7** | **8.0** | **1316.4** | **24.6** | **241.0** | **68.6** | **1.4** | **298.5** | **4.8** | **94.3** | **1.3** | **758.0** | **0.1** | **0.1** | **0.1** | **0.0** | **0.0** | **0.1** | **19.5** | **30.5** | **29.2** | **157.4** | **268.4** | **1342.4** |
| | **10** | **0.9** | **1.7** | **6.7** | **452** | **10.1** | **92** | **42** | **0.5** | **92** | **0.1** | **7.9** | **1** | **239** | **0.01** | **0.02** | **0.02** | **0.01** | **0.01** | **0.03** | **3.6** | **0.1** | **16** | **10** | **60** | **580** |
| | **320** | **45** | **13.8** | **9.6** | **2380** | **32.3** | **390** | **108** | **8.3** | **560** | **12** | **200** | **3** | **1260** | **0.81** | **0.28** | **0.3** | **0.2** | **0.22** | **0.38** | **33** | **120** | **45** | **490** | **1200** | **2400** |
| | **80.5** | **5.8** | **2.4** | **0.6** | **468.0** | **5.6** | **71.0** | **16.5** | **1.4** | **117.0** | **3.1** | **50.3** | **0.5** | **240.7** | **0.1** | **0.1** | **0.1** | **0.0** | **0.0** | **0.1** | **6.9** | **28.8** | **8.2** | **143.5** | **208.8** | **473.2** |

Table A-4 Summary of Raw Water Quality Data from USGS Monitoring Station Near Sanford, FL

| | Color (cu) | Turbidity (NTU) | Oxygen, Dissolved (mg/L) | pH | Specific Conductance (uS/cm) | Water Temperature (Deg C) | Total Hardness (mg/L as CaO3) | Alkalinity (mg/L as CaCO3) | Bromide (mg/L) | Chloride (mg/L) | Silica (mg/L) | Sulfate (mg/L) | Sulfide (mg/L as S) | Total Dissolved Solids (mg/L) | Ammonia (mg/L as N) | NO2 + NO3, Dissolved (mg/L as N) | NO2 + NO3, Total (mg/L as N) | Nitrite (mg/L as N) | Orthophosphorus, Total (mg/L as P) | Phosphorus, Total (mg/L as P) | Organic Carbon, Dissolved (mg/L) | Chlorophyll A (ug/L) | Barium (ug/L) | Iron,Dissolved (ug/L) | Iron,Total (ug/L) | Strontium (ug/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/05/2000 | 200 | 2.2 | | 7.2 | 681 | 18 | | 65 | 0.5 | 145 | 5 | 33 | | | 0.08 | 0.16 | 0.2 | 0.01 | 0.06 | 0.07 | 22 | 4 | 18 | 240 | 380 | 720 |
| 01/18/2000 | 200 | 4.2 | 7.2 | 7.3 | 781 | 16.2 | | 69 | 0.5 | 168 | 4.9 | 39 | | | 0.08 | 0.23 | 0.2 | 0.01 | 0.05 | 0.08 | 21 | 3.6 | 18 | 190 | 360 | 750 |
| 01/31/2000 | 120 | 2.8 | 7.7 | 7.4 | 865 | 14.2 | | 73 | 0.6 | 180 | 4.5 | 47 | | | 0.08 | 0.29 | 0.3 | 0.01 | 0.05 | 0.05 | 20 | 2.3 | 19 | 170 | 270 | 800 |
| 02/15/2000 | 140 | 2.6 | 7.2 | 7 | 929 | 17.9 | | 76 | 0.6 | 197 | 3.4 | 52 | | | 0.14 | 0.23 | 0.2 | 0.01 | 0.04 | 0.05 | 19 | 3.3 | 20 | 150 | 250 | 870 |
| 03/01/2000 | 100 | 2.1 | 5.7 | 7.3 | 1020 | 22.1 | | 85 | 0.7 | 217 | 2.9 | 61 | | | 0.1 | 0.19 | 0.2 | 0.01 | 0.06 | 0.04 | 15 | 5.9 | 22 | 90 | 160 | 950 |
| 03/14/2000 | 160 | 2.2 | 4.6 | 7.4 | 1130 | 22 | | 89 | 0.8 | 250 | 3 | 64 | | | 0.14 | 0.16 | 0.2 | 0.01 | 0.06 | 0.04 | 15 | 4.6 | 22 | 70 | 130 | 970 |
| 03/28/2000 | 50 | 2.8 | 5 | 7.3 | 1230 | 23.2 | 230 | 99 | 0.9 | 275 | 3.2 | 64 | | | 0.07 | 0.12 | 0.1 | 0.01 | 0.03 | 0.06 | 10 | 7 | 21 | 30 | 100 | 970 |
| 04/12/2000 | 50 | 3.1 | 7.2 | 7.9 | 1090 | 22.5 | 210 | 95 | 0.8 | 230 | 3.3 | 71 | | | 0.06 | 0.13 | 0.1 | 0.01 | 0.03 | 0.08 | 11 | 15 | 20 | 30 | 100 | 970 |
| 04/25/2000 | 20 | 2.7 | 6.8 | 7.2 | 1110 | 24.9 | 220 | 108 | 0.8 | 230 | 3.8 | 71 | | | 0.02 | 0.08 | 0.1 | 0.01 | 0.02 | 0.06 | 6.5 | 23 | 19 | 20 | 80 | 900 |
| 05/08/2000 | 20 | 3 | 6.9 | 7.7 | 1190 | 25.5 | 230 | 114 | 0.8 | 262 | 1.8 | 71 | | | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.06 | 5.6 | 26 | 19 | | 60 | 950 |
| 05/22/2000 | 10 | 1.4 | 5.8 | 7.9 | 1080 | 27.9 | 220 | 111 | 0.7 | 215 | 4.6 | 74 | | | 0.02 | 0.09 | 0.1 | 0.01 | 0.01 | 0.07 | 5.6 | 31 | 19 | | 60 | 930 |
| 06/05/2000 | 40 | 4.3 | 5.6 | 8.2 | 1260 | 29.3 | 220 | 86 | 1 | 289 | 3.1 | 80 | | 657 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.09 | 12 | 34 | 20 | 10 | 70 | 1100 |
| 06/20/2000 | 20 | 4.5 | 5.9 | 8.1 | 1320 | 30 | 240 | 103 | 1 | 297 | 7.5 | 85 | | 693 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.09 | 11 | 58 | 28 | | 100 | 1200 |
| 07/05/2000 | 10 | 3.7 | 5.6 | 7.8 | 1170 | 28.8 | 230 | 105 | 0.8 | 246 | 6.4 | 80 | | 610 | 0.01 | 0.02 | 0.02 | 0.01 | 0.03 | 0.07 | 6.2 | 28 | 97 | | 70 | 1000 |
| 07/18/2000 | 10 | 3.4 | 8.1 | 8.1 | 1080 | 29.7 | 230 | 109 | 0.7 | 212 | 5.5 | 84 | | 561 | 0.05 | 0.02 | 0.02 | 0.01 | 0.01 | 0.06 | 3.9 | 39 | 19 | | 50 | 950 |
| 08/01/2000 | 20 | 4.6 | 5.6 | 7.7 | 1300 | 29.5 | 280 | 85 | 0.8 | 250 | 8 | 143 | | 697 | 0.04 | 0.03 | | 0.01 | 0.02 | 0.06 | 9.8 | 27 | 26 | 20 | 80 | 1300 |
| 08/14/2000 | 20 | 5.5 | 6 | 7.8 | 1380 | 29 | 250 | 91 | 0.9 | 298 | 7.2 | 105 | | 718 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.07 | 11 | 27 | 27 | | 80 | 1200 |
| 08/29/2000 | 20 | 3.5 | 5.6 | 8 | 1190 | 29.7 | 240 | 101 | 0.8 | 244 | 6.1 | 93 | | 624 | 0.04 | 0.02 | 0.02 | 0.01 | 0.02 | 0.06 | 6.9 | 23 | 21 | | 60 | 1000 |
| 09/11/2000 | 30 | 4.8 | 5.4 | 7.8 | 1280 | 28.3 | 220 | 74 | 1 | 284 | 3.5 | 93 | | 656 | 0.03 | 0.02 | 0.02 | 0.01 | 0.01 | 0.07 | 10 | 46 | 21 | 30 | 150 | 1100 |
| 09/26/2000 | 60 | 4.8 | 4 | 7.3 | 1420 | 29.3 | 240 | 61 | 1 | 321 | 5 | 112 | | 732 | 0.05 | 0.04 | | 0.01 | 0.05 | 0.07 | 15 | 10 | 27 | 70 | 200 | 1200 |
| 10/11/2000 | 50 | 2.9 | 5.7 | 7.5 | 1580 | 22.9 | 260 | 67 | 1 | 328 | 5.1 | 105 | | 774 | 0.04 | 0.03 | | 0.01 | 0.03 | 0.04 | 13 | 20 | 32 | 20 | 100 | 1400 |
| 10/24/2000 | 70 | 3.2 | 5 | 7.2 | 1740 | 23.5 | 300 | 62 | 1.1 | 421 | 6.1 | 143 | | 939 | 0.09 | 0.05 | 0.1 | 0.01 | 0.01 | 0.06 | 16 | 20 | 37 | 60 | 140 | 1800 |
| 11/06/2000 | 100 | 2 | 4.6 | 7.9 | 1580 | 23 | 280 | 61 | 1.2 | 358 | 7.4 | 135 | | 842 | 0.18 | 0.09 | 0.1 | 0.01 | 0.03 | 0.06 | 19 | 7.8 | 35 | 110 | 210 | 1700 |
| 11/20/2000 | 120 | 2 | 5.3 | 7.6 | 1380 | 20.4 | 250 | 68 | 1 | 310 | 8.2 | 120 | 1 | 735 | 0.26 | 0.24 | 0.2 | 0.03 | 0.03 | 0.07 | 20 | 5.2 | 30 | 120 | 190 | 1500 |
| 12/05/2000 | 120 | 2.5 | 6.1 | 7.5 | 1360 | 15.9 | 250 | 68 | 0.96 | 310 | 7.4 | 110 | 1 | 723 | 0.1 | 0.26 | 0.2 | 0.01 | 0.03 | 0.05 | 18 | 0.1 | 28 | 110 | 150 | 1500 |
| 12/20/2000 | 100 | 2 | 6.7 | 7.6 | 1320 | 17 | 250 | 79 | 0.97 | 290 | 7.1 | 110 | 1 | 709 | 0.18 | 0.22 | 0.2 | 0.01 | 0.04 | 0.04 | 17 | 11 | 27 | 80 | 140 | 1400 |
| 01/05/2001 | 50 | 3 | 7.1 | 7.5 | 1150 | 11.9 | 250 | 98 | 0.82 | 240 | 7.6 | 100 | | 622 | 0.13 | 0.44 | 0.4 | 0.01 | 0.05 | 0.08 | 8.9 | 0.1 | 20 | 40 | 80 | 1200 |
| 01/18/2001 | | 0.3 | | | | | | 2 | 0.05 | 0.1 | | 0.1 | 1 | | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.02 | | 16 | 0.5 | 2 | 2 | 0.5 |
| 01/17/2001 | 80 | 3 | 7.8 | 7.8 | 1440 | 15.5 | 270 | 85 | 1.3 | 330 | 4.4 | 110 | 1 | 789 | 0.19 | 0.25 | 0.2 | 0.02 | 0.02 | 0.05 | 16 | 21 | 28 | 60 | 110 | 1500 |
| 02/12/2001 | 60 | 2.8 | 7 | 7.8 | 1410 | 19.9 | 270 | 93 | 1.4 | 304 | 2.7 | 117 | 1 | 743 | 0.29 | 0.27 | 0.3 | 0.06 | 0.06 | 0.06 | 16 | 23 | 27 | 30 | 90 | 1440 |
| 02/27/2001 | 30 | 2.5 | 9.3 | 7.2 | 1440 | 23.7 | 280 | 110 | 2.5 | 310 | 3.9 | 100 | 1 | 765 | 0.26 | 0.15 | 0.2 | 0.02 | 0.07 | 0.1 | 9 | 23 | 24 | 10 | 60 | 1300 |
| 03/14/2001 | 20 | 3.7 | 7.2 | 7.8 | 1230 | 20.6 | 240 | 105 | 3.2 | 260 | 4.3 | 91 | 1 | 651 | 0.16 | 0.15 | 0.1 | 0.04 | 0.06 | 0.08 | 7.1 | 16 | 18 | | 60 | 1100 |
| 03/28/2001 | 40 | 2.8 | 7.4 | 7.2 | 1320 | 20.5 | 280 | 97 | 8.7 | 270 | 4.9 | 130 | 1 | 727 | 0.07 | 0.2 | 0.2 | 0.01 | 0.05 | 0.06 | 7.8 | 11 | 23 | 20 | 70 | 1300 |
| 04/10/2001 | 50 | 6.3 | 5.7 | 7.6 | 1540 | 25 | 290 | 88 | 8.2 | 330 | 2.8 | 130 | 1 | 812 | 0.04 | 0.05 | 0.1 | 0.01 | 0.03 | 0.09 | 14 | 49 | 31 | 10 | 110 | 1500 |
| 04/26/2001 | 40 | 5.8 | 5.5 | 7.5 | 1500 | 24.4 | 290 | 97 | 5.8 | 330 | 4.5 | 120 | 1 | 805 | 0.04 | 0.03 | | 0.01 | 0.01 | 0.09 | 13 | 40 | 30 | 10 | 110 | 1500 |
| 05/08/2001 | 40 | 4.9 | 5.8 | 7.7 | 1460 | 24.5 | 280 | 99 | 1 | 320 | 3.8 | 120 | 1 | 775 | 0.04 | 0.02 | 0.02 | 0.01 | 0.03 | 0.08 | 11 | 25 | 27 | | 70 | 1400 |
| 05/22/2001 | 20 | 6 | 6.3 | 7.8 | 1610 | 27.4 | 290 | 118 | 1.3 | 360 | 5.5 | 97 | 1 | 832 | 0.02 | 0.02 | 0.02 | 0.01 | 0.03 | 0.1 | 6.2 | 33 | 27 | | 90 | 1300 |
| 06/05/2001 | 30 | 4.5 | 6.6 | 8 | 1580 | 29.4 | 290 | 98 | 1.1 | 340 | 5.2 | 130 | 1 | 831 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.07 | 11 | 56 | 27 | 20 | 100 | 1400 |
| 06/19/2001 | 30 | 4.1 | 4.5 | 7.9 | 1640 | 29.3 | 300 | 97 | 1.2 | 360 | 6 | 130 | 1 | 864 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.08 | 11 | 66 | 15 | | 80 | 1500 |
| 07/02/2001 | 30 | 6.7 | 6.6 | 8.1 | 1720 | 28.6 | 300 | 103 | 1.5 | 390 | 7.8 | 120 | 1 | 902 | 0.02 | 0.02 | 0.02 | 0.01 | 0.01 | 0.06 | 9.7 | 48 | 20 | | 50 | 1400 |
| 07/17/2001 | 60 | 4.1 | 4.3 | 7.5 | 1800 | 28.2 | 330 | 75 | 1.5 | 400 | 8.7 | 160 | 1 | 957 | 0.5 | 0.06 | 0.1 | 0.01 | 0.04 | 0.1 | 9.9 | 0.1 | 21 | 50 | 130 | 1700 |
| 07/31/2001 | 50 | 8.7 | 5.2 | 7.8 | 2010 | 30.6 | 350 | 60 | 1.6 | 459 | 9.5 | 187 | 1 | 1080 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.09 | 15 | 150 | 39 | 30 | 220 | 2070 |
| 08/14/2001 | 120 | 0.5 | 3.1 | 7 | 1450 | 30.5 | 250 | 52 | 1.2 | 322 | 8.5 | 128 | 1 | 755 | 0.15 | 0.02 | | 0.01 | 0.01 | 0.08 | 16 | 57 | 26 | 130 | 340 | 1490 |
| 08/30/2001 | 280 | 1.3 | 1.1 | 6.9 | 1050 | 29.7 | 190 | 59 | 1 | 234 | 9.9 | 69 | 1 | 553 | 0.33 | 0.22 | 0.2 | 0.16 | 0.16 | 0.2 | 22 | 3.9 | 22 | 360 | 500 | 1150 |
| 09/11/2001 | 240 | 1.9 | 1.9 | 7 | 896 | 28.1 | 170 | 64 | 0.97 | 193 | 11 | 49 | 2 | 461 | 0.26 | 0.27 | 0.3 | 0.16 | 0.21 | 0.22 | 29 | 0.1 | 23 | 380 | 560 | 1020 |
| 09/25/2001 | 280 | 2.2 | 0.5 | 6.6 | 550 | 26.7 | 120 | 48 | 0.5 | 114 | 10 | 35 | 3 | 296 | 0.07 | 0.07 | | 0.02 | 0.14 | 0.16 | 34 | 0.1 | 16 | 350 | 570 | 690 |
| 10/09/2001 | 320 | 2 | 1.7 | 6.6 | 456 | 24 | 99 | 48 | 0.54 | 92 | 9.3 | 20 | 2 | | 0.13 | 0.02 | | 0.01 | 0.13 | 0.14 | 30 | 0.1 | 15 | 410 | 540 | 570 |
| 10/23/2001 | 320 | 0.7 | 2.3 | 6.7 | 547 | 24.2 | 110 | 54 | 0.66 | 114 | 10 | 22 | 2 | 283 | 0.05 | 0.02 | | 0.02 | 0.1 | 0.09 | 35 | 0.1 | 18 | 380 | 500 | 680 |
| 11/06/2001 | 240 | 1.3 | 3.2 | 6.8 | 553 | 21.1 | 110 | 57 | 0.65 | 116 | 9 | 23 | 2 | | 0.04 | 0.12 | | 0.01 | 0.07 | 0.09 | 33 | 0.1 | 17 | 350 | 450 | 690 |
| 11/21/2001 | 240 | 0.9 | 3.7 | 7 | 559 | 20.7 | 120 | 56 | 0.64 | 118 | 7.4 | 25 | 2 | | 0.05 | 0.1 | | 0.01 | 0.05 | 0.07 | 28 | 0.1 | 17 | 320 | 410 | 680 |
| 12/04/2001 | 240 | 0.9 | 3.3 | 6.9 | 589 | 22.4 | 120 | 56 | 0.49 | 125 | 6.2 | 7.9 | 4 | | 0.06 | 0.11 | | 0.01 | 0.06 | 0.07 | 28 | 0.1 | 17 | 330 | 440 | 690 |
| 12/17/2001 | 200 | 2.3 | 3.9 | 7.1 | 685 | 23.5 | 140 | 66 | 0.58 | 148 | 6.5 | 32 | 1 | 359 | 0.09 | 0.17 | | 0.02 | 0.06 | 0.06 | 26 | 0.1 | 20 | 320 | 420 | 790 |
| 01/04/2002 | 140 | 2.2 | 7.5 | 7.4 | 802 | 13.7 | 160 | 73 | 0.64 | 168 | 6.8 | 42 | 2 | 410 | 0.1 | 0.32 | | 0.01 | 0.06 | 0.07 | 26 | 0.1 | 21 | 240 | 330 | 850 |
| 01/14/2002 | 160 | 3.5 | 8.6 | 7.4 | 846 | 14.2 | 170 | 75 | 0.88 | 181 | 6.6 | 46 | 1 | 439 | 0.06 | 0.31 | | 0.01 | 0.07 | 0.08 | 24 | 4.2 | 20 | 240 | 340 | 880 |
| 01/30/2002 | 120 | 3.2 | 5.6 | 7.3 | 944 | 22.1 | 200 | 84 | 0.91 | 196 | 6.1 | 60 | 1 | 487 | 0.09 | 0.27 | | 0.01 | 0.06 | 0.06 | 20 | 3.6 | 21 | 160 | 240 | 930 |
| 02/13/2002 | 100 | 2.8 | 7 | 7.4 | 1020 | 19.2 | 200 | 87 | 0.86 | 217 | 3.6 | 65 | 2 | 535 | 0.06 | 0.23 | | 0.01 | 0.04 | 0.05 | 1.6 | 0.1 | 22 | 130 | 200 | 990 |
| 02/26/2002 | 80 | 2.8 | 6.7 | 7.3 | 1050 | 18.7 | 220 | 88 | 0.87 | 219 | 4.9 | 83 | 1 | 553 | 0.07 | 0.27 | | 0.01 | 0.05 | 0.08 | 16 | 0.1 | 20 | 110 | 180 | 1030 |
| 03/12/2002 | 100 | 5.2 | 7.3 | 7.4 | 1220 | 21.6 | 230 | 76 | 1.1 | 273 | 1.8 | 87 | 1 | 632 | 0.03 | 0.06 | | 0.01 | 0.02 | 0.05 | 19 | 18 | 26 | 110 | 200 | 1250 |
| 03/28/2002 | 80 | 2.5 | 5.1 | 7.1 | 1240 | 24.3 | 230 | 81 | 1 | 267 | 3.3 | 96 | 1 | 643 | 0.14 | 0.15 | | 0.01 | 0.04 | 0.05 | 16 | 9.8 | 26 | 80 | 140 | 1250 |
| 04/09/2002 | 50 | 3.5 | 6.4 | 7.4 | 1300 | 23.1 | 240 | 107 | 1.2 | 291 | 4.8 | 78 | 1 | 679 | 0.04 | 0.16 | | 0.01 | 0.03 | 0.06 | 9 | 15 | 24 | 30 | 80 | 1060 |
| 04/25/2002 | 100 | 5.4 | 4.4 | 7.3 | 1340 | 27.7 | 250 | 83 | 1.2 | 300 | 3 | 103 | 1 | 708 | 0.11 | 0.02 | | 0.01 | 0.02 | 0.09 | 15 | 62 | 29 | 20 | 100 | 1320 |
| 05/08/2002 | 70 | 3.6 | 2.8 | 7.3 | 1350 | 29.1 | 260 | 86 | 1.2 | 298 | 4 | 101 | 2 | 710 | 0.36 | 0.02 | | 0.01 | 0.04 | 0.07 | 16 | 36 | 27 | 20 | 90 | 1340 |
| 05/21/2002 | 40 | 5.6 | 8.4 | 7.2 | 1250 | 25.5 | 240 | 93 | 0.97 | 269 | 6 | 89 | 1 | 659 | 0.03 | 0.02 | | 0.01 | 0.03 | 0.03 | 10 | 19 | 24 | 10 | 80 | 1150 |
| | **96.9** | **3.3** | **5.6** | **7.5** | **1193.8** | **23.7** | **231.9** | **81.3** | **1.3** | **255.3** | **5.7** | **84.9** | **1.3** | **680.6** | **0.1** | **0.1** | **0.1** | **0.0** | **0.0** | **0.1** | **15.5** | **20.5** | **24.1** | **125.1** | **188.6** | **1130.8** |
| | **10** | **0.3** | **0.5** | **6.6** | **456** | **11.9** | **99** | **2** | **0.05** | **0.1** | **1.8** | **0.1** | **1** | **283** | **0.01** | **0.02** | **0.02** | **0.01** | **0.01** | **0.02** | **1.6** | **0.1** | **0.5** | **2** | **2** | **0.5** |
| | **320** | **8.7** | **9.3** | **8.2** | **2010** | **30.6** | **350** | **118** | **8.7** | **459** | **11** | **187** | **4** | **1080** | **0.5** | **0.44** | **0.4** | **0.16** | **0.21** | **0.22** | **35** | **150** | **97** | **410** | **570** | **2070** |
| | **83.5** | **1.6** | **1.9** | **0.4** | **344.4** | **4.9** | **57.4** | **21.0** | **1.5** | **86.6** | **2.3** | **39.3** | **0.7** | **165.6** | **0.1** | **0.1** | **0.1** | **0.0** | **0.0** | **0.0** | **7.8** | **24.7** | **11.1** | **124.9** | **149.7** | **344.3** |

# Appendix F
# Detailed Construction Costs Tables

## All Volusia-Intermittent Source with ASR

Demand Location: Volusia

ADF: 34
MDF: 45
Site: Site E

| Unit Process | Flow | Plant Cost ($)** | Annual O&M Cost ($/yr) |
|---|---|---|---|
| Raw Water Screening and Pump Station | 60 | $ 2,158,018 | $ 1,514,064 |
| Pretreatment | | | |
| Rapid Mixing | 60 | $ 536,257 | $ 35,527 |
| Flow Splitting Structure | 60 | $ 170,641 | $ 9,151 |
| Actiflo Clarification | 60 | $ 4,891,513 | $ 329,162 |
| Memcor CMF-S Microfiltration | 57 | $ 19,505,622 | $ 3,568,177 |
| Desalting | | | |
| Reverse Osmosis | 53 | $ 29,915,070 | $ 9,170,476 |
| Disinfection | | | |
| UV Disinfection | 53 | $ 2,895,330 | $ 533,761 |
| On-Site Sodium Hypochlorite Generation | Var | $ 2,129,547 | $ 464,674 |
| Chemical Feed and Storage* | Var | $ 10,120,938 | $ 7,449,704 |
| Solids Handling | | | |
| Gravity Thickener | NA | $ 4,494,476 | $ 241,442 |
| Centrifuge Solids Dewatering | NA | $ 4,447,714 | $ 1,395,312 |
| Ground Storage and Clearwell | 53 | $ 12,602,550 | $ 675,842 |
| High Service Pump Station | 53 | $ 1,789,751 | $ 2,680,430 |
| Additional Standard O&M Costs | | | $ 641,232 |
| Subtotal - Project Cost | | $ 95,657,428 | |
| **Additional Project Costs** | | | |
| Demolition | 0% | $ - | |
| Overall Sitework | 3% | $ 2,869,723 | |
| Plant Computer System | 4% | $ 3,826,297 | |
| Yard Electrical | 3% | $ 2,391,436 | |
| Yard Piping | 6% | $ 5,739,446 | |
| Subtotal - Additional Project Costs | | $ 110,484,329 | |
| **Constuction Markups** | | | |
| Overhead | 10% | $ 121,532,762 | |
| Profit | 5% | $ 127,609,400 | |
| Mob/Bonds/Insurance | 3% | $ 131,437,682 | |
| Contingency | 30% | $ 33,145,299 | |
| **Total Construction Cost** | | $ 164,582,981 | |
| **Capital Markups** | | | |
| Permitting | 3% | 4,937,489 | |
| Engineering | 8% | 13,166,638 | |
| SDC | 8% | 13,166,638 | |
| Commissioning and Startup | 2% | 3,291,660 | |
| Land ROW | 0% | - | |
| Legal/Admin | 3% | 4,937,489 | |
| **Total Cost** | | $ 204,082,896 | $ 28,708,952 |

*Includes feed and storage for ferric sulfate, powdered activated carbon, liquid polymer, sodium hydroxide, chlorine, ammonia, sulfuric acid, antiscalant

**Cost does not include pipelines or ASR

## All Volusia - Reliable Source with ASR

Demand Location: Volusia

ADF: 34
MDF: 39
Site: Site E

| Unit Process | Flow | Plant Cost ($)** | Annual O&M Cost ($/yr) |
|---|---|---|---|
| Raw Water Screening and Pump Station | 53 | $ 1,878,901 | $ 1,252,824 |
| Pretreatment | | | |
| Rapid Mixing | 53 | $ 510,681 | $ 32,247 |
| Flow Splitting Structure | 53 | $ 298,758 | $ 16,022 |
| Actiflo Clarification | 53 | $ 4,610,814 | $ 314,497 |
| Memcor CMF-S Microfiltration | 50 | $ 17,411,859 | $ 3,151,816 |
| Desalting | | | |
| Reverse Osmosis | 46 | $ 25,949,258 | $ 7,741,109 |
| Disinfection | | | |
| UV Disinfection | 46 | $ 2,724,291 | $ 521,959 |
| On-Site Sodium Hypochlorite Generation | Var | $ 2,100,762 | $ 468,080 |
| Chemical Feed and Storage* | Var | $ 9,603,074 | $ 8,441,888 |
| Solids Handling | | | |
| Gravity Thickener | NA | $ 4,068,102 | $ 218,639 |
| Centrifuge Solids Dewatering | NA | $ 4,441,443 | $ 1,437,655 |
| Ground Storage and Clearwell | 46 | $ 11,051,047 | $ 592,639 |
| High Service Pump Station | 46 | $ 1,317,915 | $ 2,070,405 |
| Additional Standard O&M Costs | | | $ 576,273 |
| Subtotal - Project Cost | | $ 85,966,906 | |
| **Additional Project Costs** | | | |
| Demolition | 0% | $ - | |
| Overall Sitework | 3% | $ 2,579,007 | |
| Plant Computer System | 4% | $ 3,438,676 | |
| Yard Electrical | 3% | $ 2,149,173 | |
| Yard Piping | 6% | $ 5,158,014 | |
| Subtotal - Additional Project Costs | | $ 99,291,776 | |
| **Constuction Markups** | | | |
| Overhead | 10% | $ 109,220,954 | |
| Profit | 5% | $ 114,682,002 | |
| Mob/Bonds/Insurance | 3% | $ 118,122,462 | |
| Contingency | 30% | $ 29,787,533 | |
| **Total Construction Cost** | | $ 147,909,995 | |
| **Capital Markups** | | | |
| Permitting | 3% | 4,437,300 | |
| Engineering | 8% | 11,832,800 | |
| SDC | 8% | 11,832,800 | |
| Commissioning and Startup | 2% | 2,958,200 | |
| Land ROW | 0% | - | |
| Legal/Admin | 3% | 4,437,300 | |
| **Total Cost** | | $ 183,408,393 | $ 26,836,052 |

*Includes feed and storage for ferric sulfate, powdered activated carbon, liquid polymer, sodium hydroxide, chlorine, ammonia, sulfuric acid, antiscalant

**Cost does not include pipelines or ASR

## All Volusia - Reliable Source without ASR

Demand Location: Volusia

ADF: 34
MDF: 51
Site: Site E

| Unit Process | Flow | Plant Cost ($)** | Annual O&M Cost ($/yr) |
|---|---|---|---|
| Raw Water Screening and Pump Station | 69 | $ 2,581,038 | $ 1,995,828 |
| Pretreatment | | | |
| Rapid Mixing | 69 | $ 615,590 | $ 39,509 |
| Flow Splitting Structure | 69 | $ 226,884 | $ 12,167 |
| Actiflo Clarification | 69 | $ 5,315,988 | $ 358,476 |
| Memcor CMF-S Microfiltration | 65 | $ 21,637,862 | $ 3,987,852 |
| Desalting | | | |
| Reverse Osmosis | 60 | $ 33,990,250 | $ 10,331,380 |
| Disinfection | | | |
| UV Disinfection | 60 | $ 3,224,670 | $ 524,838 |
| On-Site Sodium Hypochlorite Generation | Var | $ 2,165,464 | $ 471,082 |
| Chemical Feed and Storage* | Var | $ 9,634,228 | $ 6,604,970 |
| Solids Handling | | | |
| Gravity Thickener | NA | $ 5,038,814 | $ 270,584 |
| Centrifuge Solids Dewatering | NA | $ 4,445,371 | $ 1,417,709 |
| Ground Storage and Clearwell | 60 | $ 14,157,774 | $ 759,245 |
| High Service Pump Station | 60 | $ 2,338,706 | $ 3,364,125 |
| Additional Standard O&M Costs | | | $ 706,358 |
| Subtotal - Project Cost | | $ 105,372,639 | |
| **Additional Project Costs** | | | |
| Demolition | 0% | $ - | |
| Overall Sitework | 3% | $ 3,161,179 | |
| Plant Computer System | 4% | $ 4,214,906 | |
| Yard Electrical | 3% | $ 2,634,316 | |
| Yard Piping | 6% | $ 6,322,358 | |
| Subtotal - Additional Project Costs | | $ 121,705,398 | |
| **Constuction Markups** | | | |
| Overhead | 10% | $ 133,875,938 | |
| Profit | 5% | $ 140,569,735 | |
| Mob/Bonds/Insurance | 3% | $ 144,786,827 | |
| Contingency | 30% | $ 36,511,620 | |
| **Total Construction Cost** | | $ 181,298,447 | |
| **Capital Markups** | | | |
| Permitting | 3% | 5,438,953 | |
| Engineering | 8% | 14,503,876 | |
| SDC | 8% | 14,503,876 | |
| Commissioning and Startup | 2% | 3,625,969 | |
| Land ROW | 0% | - | |
| Legal/Admin | 3% | 5,438,953 | |
| **Total Cost** | | $ 224,810,074 | $ 30,844,123 |

*Includes feed and storage for ferric sulfate, powdered activated carbon, liquid polymer, sodium hydroxide, chlorine, ammonia, sulfuric acid, antiscalant

**Cost does not include pipelines or ASR

## All Seminole - Intermittent Source with ASR

Demand Location: Seminole

ADF: 25
MDF: 33
Site: Site K

| Unit Process | Flow | Plant Cost ($)** | Annual O&M Cost ($/yr) |
|---|---|---|---|
| Raw Water Screening and Pump Station | 44 | $ 1,382,319 | $298,655 |
| Pretreatment | | | |
| Rapid Mixing | 44 | $ 438,345 | $28,246 |
| Flow Splitting Structure | 44 | $ 160,797 | $8,623 |
| Actiflo Clarification | 44 | $ 4,019,789 | $270,266 |
| Memcor CMF-S Microfiltration | 42 | $ 14,966,320 | $2,647,161 |
| Desalting | | | |
| Reverse Osmosis | 39 | $ 21,882,405 | $5,853,150 |
| Disinfection | | | |
| UV Disinfection | 39 | $ 2,234,613 | $382,637 |
| On-Site Sodium Hypochlorite Generation | Var | $ 2,007,274 | $365,415 |
| Chemical Feed and Storage* | Var | $ 7,487,205 | $5,484,391 |
| Solids Handling | | | |
| Gravity Thickener | NA | $ 3,514,373 | $188,882 |
| Centrifuge Solids Dewatering | NA | $ 4,447,874 | $1,087,249 |
| Ground Storage and Clearwell | 39 | $ 9,495,806 | $509,235 |
| High Service Pump Station | 39 | $ 872,809 | $988,178 |
| Additional Standard O&M Costs | | | $488,746 |
| Subtotal - Project Cost | | $ 72,909,930 | |
| **Additional Project Costs** | | | |
| Demolition | 0% | $ - | |
| Overall Sitework | 3% | $ 2,187,298 | |
| Plant Computer System | 4% | $ 2,916,397 | |
| Yard Electrical | 3% | $ 1,822,748 | |
| Yard Piping | 6% | $ 4,374,596 | |
| Subtotal - Additional Project Costs | | $ 84,210,969 | |
| **Constuction Markups** | | | |
| Overhead | 10% | $ 92,632,066 | |
| Profit | 5% | $ 97,263,669 | |
| Mob/Bonds/Insurance | 3% | $ 100,181,579 | |
| Contingency | 30% | $ 25,263,291 | |
| **Total Construction Cost** | | $ 125,444,870 | |
| **Capital Markups** | | | |
| Permitting | 3% | 3,763,346 | |
| Engineering | 8% | 10,035,590 | |
| SDC | 8% | 10,035,590 | |
| Commissioning and Startup | 2% | 2,508,897 | |
| Land ROW | 0% | - | |
| Legal/Admin | 3% | 3,763,346 | |
| **Total Cost** | | $ 155,551,638 | $ 18,600,835 |

*Includes feed and storage for ferric sulfate, powdered activated carbon, liquid polymer, sodium hydroxide, chlorine, ammonia, sulfuric acid, antiscalant

**Cost does not include pipelines or ASR

## All Seminole - Reliable Source with ASR

Demand Location: Seminole

ADF: 25
MDF: 29
Site: Site K

| Unit Process | Flow | Plant Cost ($)** | Annual O&M Cost ($/yr) |
|---|---|---|---|
| Raw Water Screening and Pump Station | 39 | $ 1,327,355 | $264,856 |
| Pretreatment | | | |
| Rapid Mixing | 39 | $ 365,946 | $23,020 |
| Flow Splitting Structure | 39 | $ 158,091 | $8,478 |
| Actiflo Clarification | 39 | $ 3,775,792 | $260,586 |
| Memcor CMF-S Microfiltration | 37 | $ 13,513,826 | $2,387,997 |
| Desalting | | | |
| Reverse Osmosis | 34 | $ 19,286,139 | $5,147,936 |
| Disinfection | | | |
| UV Disinfection | 34 | $ 1,992,457 | $397,662 |
| On-Site Sodium Hypochlorite Generation | Var | $ 1,185,028 | $324,703 |
| Chemical Feed and Storage* | Var | $ 7,477,484 | $6,232,648 |
| Solids Handling | | | |
| Gravity Thickener | NA | $ 3,203,062 | $172,249 |
| Centrifuge Solids Dewatering | NA | $ 4,445,665 | $1,107,156 |
| Ground Storage and Clearwell | 34 | $ 8,387,574 | $449,804 |
| High Service Pump Station | 34 | $ 673,495 | $747,375 |
| Additional Standard O&M Costs | | | $441,031 |
| Subtotal - Project Cost | | $ 65,791,914 | |
| **Additional Project Costs** | | | |
| Demolition | 0% | $ - | |
| Overall Sitework | 3% | $ 1,973,757 | |
| Plant Computer System | 4% | $ 2,631,677 | |
| Yard Electrical | 3% | $ 1,644,798 | |
| Yard Piping | 6% | $ 3,947,515 | |
| Subtotal - Additional Project Costs | | $ 75,989,660 | |
| **Constuction Markups** | | | |
| Overhead | 10% | 7,598,966.02 | |
| Profit | 5% | 3,799,483.01 | |
| Mob/Bonds/Insurance | 3% | 2,279,689.81 | |
| Contingency | 30% | 22,796,898.07 | |
| **Total Construction Cost** | | 112,464,697.16 | |
| **Capital Markups** | | | |
| Permitting | 3% | 3,373,941 | |
| Engineering | 8% | 8,997,176 | |
| SDC | 8% | 8,997,176 | |
| Commissioning and Startup | 2% | 2,249,294 | |
| Land ROW | 0% | - | |
| Legal/Admin | 3% | 3,373,941 | |
| **Total Cost** | | $ 139,456,224 | $ 17,965,501 |

*Includes feed and storage for ferric sulfate, powdered activated carbon, liquid polymer, sodium hydroxide, chlorine, ammonia, sulfuric acid, antiscalant

**Cost does not include pipelines or ASR

## All Seminole - Reliable Source without ASR

Demand Location: Seminole

ADF: 25
MDF: 38
Site: Site K

| Unit Process | Flow | Plant Cost ($)** | Annual O&M Cost ($/yr) |
|---|---|---|---|
| Raw Water Screening and Pump Station | 50 | $ 1,495,466 | $ 367,658 |
| Pretreatment | | | |
| Rapid Mixing | 50 | $ 442,383 | $ 28,114 |
| Flow Splitting Structure | 50 | $ 163,486 | $ 8,767 |
| Actiflo Clarification | 50 | $ 4,309,589 | $ 283,018 |
| Memcor CMF-S Microfiltration | 48 | $ 16,839,388 | $ 2,994,489 |
| Desalting | | | |
| Reverse Osmosis | 44 | $ 24,915,916 | $ 6,664,055 |
| Disinfection | | | |
| UV Disinfection | 44 | $ 2,576,789 | $ 404,164 |
| On-Site Sodium Hypochlorite Generation | Var | $ 2,033,055 | $ 366,619 |
| Chemical Feed and Storage* | Var | $ 7,498,249 | $ 4,880,059 |
| Solids Handling | | | |
| Gravity Thickener | NA | $ 3,884,322 | $ 208,672 |
| Centrifuge Solids Dewatering | NA | $ 4,446,107 | $ 1,090,809 |
| Ground Storage and Clearwell | 44 | $ 10,607,759 | $ 568,867 |
| High Service Pump Station | 44 | $ 1,079,662 | $ 1,198,277 |
| Additional Standard O&M Costs | | | $ 538,233 |
| Subtotal - Project Cost | | $ 80,292,171 | |
| **Additional Project Costs** | | | |
| Demolition | 0% | $ - | |
| Overall Sitework | 3% | $ 2,408,765 | |
| Plant Computer System | 4% | $ 3,211,687 | |
| Yard Electrical | 3% | $ 2,007,304 | |
| Yard Piping | 6% | $ 4,817,530 | |
| Subtotal - Additional Project Costs | | $ 92,737,457 | |
| **Constuction Markups** | | | |
| Overhead | 10% | $ 102,011,203 | |
| Profit | 5% | $ 107,111,763 | |
| Mob/Bonds/Insurance | 3% | $ 110,325,116 | |
| Contingency | 30% | $ 27,821,237 | |
| **Total Construction Cost** | | $ 138,146,353 | |
| **Capital Markups** | | | |
| Permitting | 3% | 4,144,391 | |
| Engineering | 8% | 11,051,708 | |
| SDC | 8% | 11,051,708 | |
| Commissioning and Startup | 2% | 2,762,927 | |
| Land ROW | 0% | - | |
| Legal/Admin | 3% | 4,144,391 | |
| **Total Cost** | | $ 171,301,478 | $ 19,601,801 |

*Includes feed and storage for ferric sulfate, powdered activated carbon, liquid polymer, sodium hydroxide, chlorine, ammonia, sulfuric acid, antiscalant

**Cost does not include pipelines or ASR

**Seminole and South Volusia - Intermittent Source with ASR**

Demand Location: Seminole/Volusia

ADF: 43
MDF: 57
Site: Site E

| Unit Process | Flow | Plant Cost ($)** | Annual O&M Cost ($/yr) |
|---|---|---|---|
| Raw Water Screening and Pump Station | 76 | $ 2,960,556 | $ 2,930,428 |
| Pretreatment | | | |
| Rapid Mixing | 76 | $ 621,648 | $ 40,432 |
| Flow Splitting Structure | 76 | $ 227,639 | $ 12,208 |
| Actiflo Clarification | 76 | $ 5,619,673 | $ 391,504 |
| Memcor CMF-S Microfiltration | 67 | $ 23,904,955 | $ 4,455,505 |
| Desalting | | | |
| Reverse Osmosis | 65 | $ 37,566,393 | $ 12,968,474 |
| Disinfection | | | |
| UV Disinfection | 65 | $ 4,391,869 | $ 905,137 |
| On-Site Sodium Hypochlorite Generation | Var | $ 2,192,693 | $ 566,071 |
| Chemical Feed and Storage* | Var | $ 11,550,792 | $ 9,446,325 |
| Solids Handling | | | |
| Gravity Thickener | NA | $ 5,460,027 | $ 293,227 |
| Centrifuge Solids Dewatering | NA | $ 4,447,622 | $ 1,721,187 |
| Ground Storage and Clearwell | 65 | $ 15,712,991 | $ 842,647 |
| High Service Pump Station | 65 | $ 1,812,662 | $ 2,233,239 |
| Additional Standard O&M Costs | | | $ 779,479 |
| Subtotal - Project Cost | | $ 116,469,518 | |
| **Additional Project Costs** | | | |
| Demolition | 0% | $ - | |
| Overall Sitework | 3% | $ 3,494,086 | |
| Plant Computer System | 4% | $ 4,658,781 | |
| Yard Electrical | 3% | $ 2,911,738 | |
| Yard Piping | 6% | $ 6,988,171 | |
| Subtotal - Additional Project Costs | | $ 134,522,293 | |
| **Constuction Markups** | | | |
| Overhead | 10% | $ 147,974,522 | |
| Profit | 5% | $ 155,373,248 | |
| Mob/Bonds/Insurance | 3% | $ 160,034,446 | |
| Contingency | 30% | $ 40,356,688 | |
| **Total Construction Cost** | | $ 200,391,134 | |
| **Capital Markups** | | | |
| Permitting | 3% | 6,011,734 | |
| Engineering | 8% | 16,031,291 | |
| SDC | 8% | 16,031,291 | |
| Commissioning and Startup | 2% | 4,007,823 | |
| Land ROW | 0% | - | |
| Legal/Admin | 3% | 6,011,734 | |
| **Total Cost** | | $ 248,485,006 | $ 37,585,862 |

*Includes feed and storage for ferric sulfate, powdered activated carbon, liquid polymer, sodium hydroxide, chlorine, ammonia, sulfuric acid, antiscalant

## Seminole and South Volusia - Reliable Source with ASR

Demand Location: Seminole/Volusia

ADF: 43
MDF: 49
Site: Site E

| Unit Process | Flow | Plant Cost ($)** | Annual O&M Cost ($/yr) |
|---|---|---|---|
| Raw Water Screening and Pump Station | 67 | $ 2,485,834 | $ 2,327,260 |
| Pretreatment | | | |
| Rapid Mixing | 67 | $ 615,590 | $ 40,728 |
| Flow Splitting Structure | 67 | $ 223,842 | $ 12,004 |
| Actiflo Clarification | 67 | $ 5,251,625 | $ 376,647 |
| Memcor CMF-S Microfiltration | 63 | $ 21,140,199 | $ 3,904,379 |
| Desalting | | | |
| Reverse Osmosis | 58 | $ 32,615,792 | $ 10,981,930 |
| Disinfection | | | |
| UV Disinfection | 58 | $ 3,224,670 | $ 642,715 |
| On-Site Sodium Hypochlorite Generation | Var | $ 2,157,577 | $ 563,890 |
| Chemical Feed and Storage* | Var | $ 11,532,109 | $ 10,622,173 |
| Solids Handling | | | |
| Gravity Thickener | NA | $ 4,918,156 | $ 264,225 |
| Centrifuge Solids Dewatering | NA | $ 4,448,169 | $ 1,719,423 |
| Ground Storage and Clearwell | 58 | $ 13,714,490 | $ 735,472 |
| High Service Pump Station | 58 | $ 1,394,039 | $ 1,465,147 |
| Additional Standard O&M Costs | | | $ 711,183 |
| Subtotal - Project Cost | | $ 103,722,092 | |
| **Additional Project Costs** | | | |
| Demolition | 0% | $ - | |
| Overall Sitework | 3% | $ 3,111,663 | |
| Plant Computer System | 4% | $ 4,148,884 | |
| Yard Electrical | 3% | $ 2,593,052 | |
| Yard Piping | 6% | $ 6,223,326 | |
| Subtotal - Additional Project Costs | | $ 119,799,016 | |
| **Constuction Markups** | | | |
| Overhead | 10% | $ 131,778,918 | |
| Profit | 5% | $ 138,367,863 | |
| Mob/Bonds/Insurance | 3% | $ 142,518,899 | |
| Contingency | 30% | $ 35,939,705 | |
| **Total Construction Cost** | | $ 178,458,604 | |
| **Capital Markups** | | | |
| Permitting | 3% | 5,353,758 | |
| Engineering | 8% | 14,276,688 | |
| SDC | 8% | 14,276,688 | |
| Commissioning and Startup | 2% | 3,569,172 | |
| Land ROW | 0% | - | |
| Legal/Admin | 3% | 5,353,758 | |
| **Total Cost** | | $ 221,288,669 | $ 34,367,175 |

*Includes feed and storage for ferric sulfate, powdered activated carbon, liquid polymer, sodium hydroxide, chlorine, ammonia, sulfuric acid, antiscalant

**Cost does not include pipelines or ASR

## Seminole and South Volusia - Reliable Source without ASR

Demand Location: Seminole/Volusia

ADF: 43
MDF: 65
Site: Site E

| Unit Process | Flow | Plant Cost ($)** | Annual O&M Cost ($/yr) |
|---|---|---|---|
| Raw Water Screening and Pump Station | 87 | $ 3,641,358 | $ 3,751,116 |
| Pretreatment | | | |
| Rapid Mixing | 87 | $ 758,769 | $ 49,916 |
| Flow Splitting Structure | 87 | $ 410,701 | $ 22,025 |
| Actiflo Clarification | 87 | $ 6,040,290 | $ 410,694 |
| Memcor CMF-S Microfiltration | 82 | $ 26,873,097 | $ 4,991,589 |
| Desalting | | | |
| Reverse Osmosis | 76 | $ 42,479,899 | $ 15,711,317 |
| Disinfection | | | |
| UV Disinfection | 76 | $ 5,555,908 | $ 934,487 |
| On-Site Sodium Hypochlorite Generation | Var | $ 3,040,676 | $ 612,135 |
| Chemical Feed and Storage* | Var | $ 11,572,306 | $ 8,339,785 |
| Solids Handling | | | |
| Gravity Thickener | NA | $ 6,119,367 | $ 328,533 |
| Centrifuge Solids Dewatering | NA | $ 4,448,402 | $ 1,718,920 |
| Ground Storage and Clearwell | 76 | $ 17,707,753 | $ 949,621 |
| High Service Pump Station | 76 | $ 2,080,209 | $ 2,638,538 |
| Additional Standard O&M Costs | | | $ 913,170 |
| Subtotal - Project Cost | | $ 130,728,735 | |
| **Additional Project Costs** | | | |
| Demolition | 0% | $ - | |
| Overall Sitework | 3% | $ 3,921,862 | |
| Plant Computer System | 4% | $ 5,229,149 | |
| Yard Electrical | 3% | $ 3,268,218 | |
| Yard Piping | 6% | $ 7,843,724 | |
| Subtotal - Additional Project Costs | | $ 150,991,689 | |
| **Constuction Markups** | | | |
| Overhead | 10% | $ 166,090,858 | |
| Profit | 5% | $ 174,395,401 | |
| Mob/Bonds/Insurance | 3% | $ 179,627,263 | |
| Contingency | 30% | $ 45,297,507 | |
| **Total Construction Cost** | | $ 224,924,770 | |
| **Capital Markups** | | | |
| Permitting | 3% | 6,747,743 | |
| Engineering | 8% | 17,993,982 | |
| SDC | 8% | 17,993,982 | |
| Commissioning and Startup | 2% | 4,498,495 | |
| Land ROW | 0% | - | |
| Legal/Admin | 3% | 6,747,743 | |
| **Total Cost** | | $ 278,906,715 | $ 41,371,847 |

*Includes feed and storage for ferric sulfate, powdered activated carbon, liquid polymer, sodium hydroxide, chlorine, ammonia, sulfuric acid, antiscalant

**Cost does not include pipelines or ASR

# Appendix G
# Reverse Osmosis Membrane Manufacturer Review of Pilot Data and Membrane Replacement Frequency

**The Dow Chemical Company**
2301 Brazosport Blvd.
Freeport, TX 77541-3257
***(979) 238-1815***
FAX ***(979) 238-5183***

September 30, 2003

Mr. Jim Lozier
CH2M Hill
1620 W Fountainhead Pkwy
Ste 550
Tempe, AZ 85282

Dear Jim:

The St. Johns Pilot Testing Report that you provided was distributed to several of my colleagues and a meeting was held 29 September to discuss the testing protocol, results, and conclusions that were reached. Below is a summary of our comments on this report.

In general, the pilot testing at the St. Johns facility was very thorough and the resulting data was presented in a thoughtful and comprehensive manner. The testing appeared to be successful in identifying a range of pretreatment options and RO system design and operational options that should prove to be successful.

In concept, we concur with the testing protocol as designed which included single element as well as multi-element testing. However, when piloting RO operation and especially cleaning efficacy on a feed water which is prone to biological fouling, it would be advantageous to use pressure vessels with a number of RO elements comparable to the anticipated full scale system design. Successfully cleaning RO systems with biological fouling is often limited by the ability to remove the bio-mass from a series of 6 or 7 elements in a pressure vessel.

There was no mention in the report of the method used to control the presence of chlorine in the feed water to the RO elements. Unless there is a slight excess of ammonia in the feed water or a fairly significant chlorine demand due to the organic constituency there will often be a residual amount of free chlorine in the feed water when using chloramine as a disinfectant. The use of the relatively large break tank between the pretreatment and the RO provided for a significant reaction time which may have minimized any free chlorine in the feed water. The final plant design should also provide for ample retention time as part of the chloramination process.

The testing results supported a conclusion that the use of chloramines to control biological fouling was necessary. An increase in normalized permeate flow (NPF) and normalized salt passage (NSP) was observed during part of the pilot testing. This was initially attributed in the report to oxidation of the membrane by chlorine or chloramine, but was later discounted by ATR/FTIR analysis. First, it is important to recognize that FilmTec is the only major membrane manufacturer that does not post-chlorinate their membrane in order to improve salt rejection. This fact will often result in confusing analytical results intended to provide evidence of oxidation on RO membranes. Evidence of chlorine oxidation on FilmTec membrane can be determined by an electron spectroscopy method, whereas post-chlorinated membranes will yield positive test results for chlorine when new.

Assuming that the full scale chloramination is controlled in a similar way as was done with the pilot system and the catalytic impact of metal oxides is not found to be more significant on the full scale system, the oxidation rate developed during the pilot testing should be valid. This would support the conclusion that a membrane life of 5 years is achievable.

The conclusion presented in the report that a combination of high pH cleaning and low pH cleaning was beneficial for this system is consistent with our experience. In RO systems which are thought to have even a small amount of metal oxide scaling in addition to biological fouling, a combination of both low and high pH cleanings is thought to further destabilize the fouling layer on the membrane resulting in improved cleaning.

There may be an opportunity for further optimization of the cleaning procedures for the full-scale plant. Recent studies in our laboratory suggest that the removal efficiency of biological fouling is greatly enhanced by increasing both the temperature and pH of the cleaning solution. Cleaning with NaOH at pH 12 in combination with a non-ionic surfactant and a chelant was shown to provide 8 times greater recovery of membrane permeability compared with cleaning with NaOH alone at pH 11. The flow rates utilized during cleaning must also be sufficiently high to maximize removal of the liberated bio-mass from the elements.

I appreciate the opportunity to review the pilot testing for this project and hope that our comments have been found useful. If you have any questions or comments, please contact me.

Sincerely,

Steven Coker
Liquid Separations TS&D

# Appendix H
# Final Letter from Peer Review Team on Pilot Project and Recommendations

McGuire
Environmental
Consultants, Inc.

*"Quality services that ensure safe drinking water"*

MEMORANDUM

TO: Mr. Jerry Salsano, PE
Taurant Consulting, Inc.

FROM: Jon Loveland, Laurie Sullivan, Ed Means, and Michael MacPhee
McGuire Environmental Consultants, Inc.

DATE: February 2, 2004

SUBJECT: Comments on Surface Water Treatability and Demineralization Study prepared by CH2M-Hill for the St. Johns River Water Management District

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MEC has conducted a final review of CH2M-Hill's report for the St. John's River Water Management District (District) titled *Surface Water Treatability and Demineralization Study*. The comments contained within this document are for the draft final report issued on December 16, 2003 and revised on January 30, 2003.

It is MEC's belief that the draft final report presents adequate information to make final recommendations to the District on candidate treatment process trains and demonstrates that the treatability of the raw water tested is feasible. Two interrelated operational and maintenance issues remain that may impact treatment plant lifecycle costs. The biofouling control regime proposed should be further optimized after implementation with site-specific future testing to determine the trade-off between lower chloramines doses that produce adequate biofouling control, and higher chloramines doses that may result in membrane damage. In addition, because the use of chloramines is new for this application and represents a tangible risk of membrane damage and shortened membrane replacement frequency, future treatment plant developers should seek membrane performance guarantees from the specified membrane manufacturer.

It has been our pleasure to assist the District and CH2M-Hill in conducting this feasibility study. Please contact us with any questions.

Ed Mean

Edward G. Means III
Sr. Vice President
McGuire Environmental Consultants, Inc.