PREPARED FOR
MIAMI-DADE COUNTY
WATER AND SEWER
DEPARTMENT

Biscayne Bay Coastal Wetlands Rehydration Pilot Project

PROCESS TECHNOLOGY ASSESSMENT | MAY 2009

TECHNICAL MEMORANDUM #2

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Executive Summary

This technical memorandum addresses advanced wastewater treatment processes and technologies capable of meeting water quality requirements for the Biscayne Bay Coastal Wetlands Rehydration Demonstration Pilot Project (BBCWRPP) for Miami-Dade Water and Sewer Department (MDWASD). The treatment processes were shown originally in a 2007 document titled "Conceptual Plan and Basis of Design" (hereinafter CPBODR). This technical memorandum updates the previous work done within CPBODR and makes recommendations on treatment processes for the BBCWRPP.

A literature review was conducted to assess the original baseline treatment process recommendation in the CPBODR. The literature review conducted showed that many of the baseline processes recommended as part of the CPBODR can be considered for future pilot studies, with some exceptions. The exceptions include proposed amendment to the treatment technologies to be tested, principally for phosphorus removal, and the inclusion of advanced oxidation process as a disinfection process. This disinfection process is a higher level of treatment than previously proposed.

The nitrification/denitrification system previously recommended in the CPBODR appears to be suitable for meeting the Wetlands Application requirements (5, 5, 3, 1). Based on the review conducted, both these processes are considered viable for pilot testing based on previous performance. Therefore, it was recommended that these technologies (BAF for nitrification followed by denitrification in biological filters with methanol addition) should be part of the pilot demonstration project.

Phosphorus is one of several key constituents that are targeted for high levels of treatment in this pilot program. In the original CPBODR baseline process train, phosphorus treatment consisted of a series of processes starting with a ballasted flocculation process followed by either ultrafiltration (UF) or microfiltration (MF) membrane filtration. Additionally, a side stream plant (SSP) was equipped with reverse osmosis (RO) and ion exchange to further reduce the total phosphorus to proposed Class III/Outstanding Florida Waters requirements. For phosphorus removal, the original CPBODR recommendation was to solely pilot test a ballasted flocculation process. The literature review conducted herein revealed that there are other technologies such as hydrous ferric oxide filtration (HFO) that merit consideration and should be pilot tested largely because of performance found in the literature in consistently reducing phosphorus to low levels desired.

Also, a study to determine the fractionation of phosphorus should be conducted at the SDWWTP as part of pilot studies. Knowledge about the distribution of phosphorus species would facilitate the selection and comparison of different filtration concepts to achieve ultra low phosphorus levels.

The CPBODR also includes UF or MF membrane filtration capabilities for phosphorus removal. Literature review indicates that membrane filtration performs relatively well for phosphorus removal. Therefore, no change is recommended from its current configuration.

The CPBODR SSP included RO, ion exchange, granular activated carbon (GAC) and advanced oxidation processes (AOP). Based on information presented in this memo, RO as a SSP processes should be tested in a pilot system. Ion exchange (IX) does not appear well suited for the application or the expected scale of the facility if considered at full scale. Although the literature shows that ion exchange (IX) can provide effective removal of nitrogen, specifically ammonia, there is scarce experience in full scale applications of the size expected, and estimated resin regeneration costs are higher than other processes. Close consideration as to its applicability would need to be considered in a case-by-case basis for other projects. Furthermore, the process treatment includes a biological nutrient removal step that is anticipated to be sufficient for this application. The incremental reduction in ammonia that may be possible with the use of IX is not anticipated to be necessary or cost efficient for the BBCWRPP project and, as such, not recommended for pilot these tests.

The use of activated carbon is not considered viable at this time because of its expected life cycle costs, and the fact that there is not enough information currently on exactly which microconstituents need to be removed and to what extent, so the use of activated carbon cannot be justified for pilot testing.

The advanced oxidation process configuration included in the SSP comprises UV disinfection with hydrogen peroxide (H_2O_2), UV with Ozone (O_3) and ozone with H_2O_2. The recommended configuration considers advanced oxidation process as part of baseline stream instead of SSP. This memorandum recommends testing UV disinfection with hydrogen peroxide (H_2O_2), and ozone with H_2O_2. Literature review indicates that ozone with H_2O_2 has the capability of reducing organics and is effective in removal of microconstituents. Literature review also indicates that this process may provide ability to produce recycled water quality effluent without filtration.

The update to the original CPBODR resulting from the work completed in this memorandum can be summarized as follows:

- Retain BAF for nitrification studies
- Retain deep bed filters for denitrification studies
- Modify chemical phosphorus removal by adding one technology to pilot test in addition to ballasted flocculation process (BFP)
- Retain use of membrane processes consisting of MF and RO
- Eliminate consideration of Ion Exchange and activated carbon in pilot studies
- Modify disinfection by using both UV and peroxide and peroxide and ozone for AOP

Three treatment trains have been proposed for pilot testing to simulate different qualities of reclaimed water. The baseline treatment train (Train A) provides nitrogen and phosphorus removal and disinfection using AOP. The baseline train is expected to produce a product that can clearly meet the nitrogen and phosphorus levels required for FDEP Wetlands application (5, 5, 3, 1) and to also provide some destruction of microconstituents using AOP. This disinfection step is higher treatment than previously anticipated.

Treatment Train B provides a similar process as the Baseline treatment train, but replaces chemical phosphorus removal with RO. This train is expected to produce a product that can clearly meet much lower levels of nitrogen and phosphorus than the Baseline Train, and to also provide some destruction of microconstituents using AOP.

Train C is very similar to Train A, as it retains chemical phosphorus removal and adds RO. This train has the potential to produce the lowest levels of N and P. This train is expected to produce a product that can meet the proposed levels of nitrogen and phosphorus targets for Class III Outstanding Florida Waters (OFW), and to also provide destruction of microconstituents using AOP.

Recommendations for treatment processes and technologies have been provided as a result of an evaluation of the original processes. It is very likely that during the period when pilot testing takes place, that there will be emerging technologies that may merit consideration. These will be considered on an individual basis, but it must be recognized that decisions have to be made to move forward with the project and not affect the schedule. As such, there comes a time where consideration of emerging technologies will no longer be possible if the schedule for the project is to be met. Special conditions will of course merit extraordinary considerations.

INTRODUCTION AND PURPOSE

This memorandum provides an evaluation of a number of treatment processes and technologies that were deemed viable for testing in a proposed pilot program for the Biscayne Bay Coastal Wetlands Rehydration Pilot Project (BBCWRPP). The treatment processes were shown in a 2007 document titled “Conceptual Plan and Basis of Design” (hereinafter CPBODR). This document provided recommendations for treatment processes to be tested in the BBCWRPP pilot program. The different processes and technologies initially identified in the CPBODR were selected to remove primarily certain constituents of concern that commonly remain after secondary treatment of wastewater. These constituents include residual suspended solids and BOD remaining after secondary treatment, nitrogen, phosphorus, and microconstituents.

This document provides a review and discussion of the treatment processes previously identified in the CPBODR. Also included is a literature review update of the reported removal of microconstituents by various treatment processes identified in a previous literature review conducted in 2004 by the U.S. Army Corps of Engineers (ACOE).

The objective of this technical memorandum is to provide an update and recommendations to the treatment processes found in the original CPBODR. Thus, this memorandum concludes with recommendations for treatment processes to be pilot tested in the proposed BBCWRPP, and initial recommendations of the design flows to be implemented for the pilot plant testing.

PROCESS EVALUATION OF ORIGINAL CPBODR

A process technology assessment was conducted herein to evaluate the original CPBODR recommendations. This evaluation focused mainly on the capability of the recommended processes to produce a product that could be used for the rehydration of a wetlands environment. As mentioned previously, various process options and recommendations were provided in the CPBODR.

The treatment train shown in the CPBODR was intended to provide additional treatment of SDWWTP secondary effluent to further reduce $CBOD_5$ TSS, to reduce nitrogen and phosphorus to very low levels, to provide disinfection, and to remove microconstituents of possible concern. The pilot facility was originally sized to produce a nominal flow of approximately 0.23 MGD (160 gpm) of reclaimed water from the main process train and capable of meeting effluent water quality goals for reuse and wetlands application. The main treatment train shown in the CPBODR consisted of the following:

- Nitrification using biological aerated filters (BAF)
- Denitrification in deep bed filters
- Chemical addition to remove phosphorus using ballasted flocculation technology and microfiltration/ultrafiltration (MF/UF) membranes
- Ultraviolet disinfection

In addition to these recommended treatment processes/technologies, provisions were also made for testing of side streams from the pilot plant. This consisted of evaluating other treatment processes (at a reduced flow) in order to investigate their effectiveness and performance in further removing nutrients and microconstituents beyond what was provided in the main process train. The Side Stream Plant (SSP) facility was originally designed to produce a nominal flow of approximately 0.07 MGD (approx. 49 gpm) of very high quality water and with the goal of matching proposed targets that are very strict for (total) phosphorus levels.

The main plant components in the CPBODR are illustrated in the process schematics presented in Figure 1, and summarized in Table 1. Provisions were made in the pilot plant pre-design for the SSP to accept pilot plant flow and have this flow treated in additional advanced treatment units. As shown in Figure 1, the individual SSP unit processes can be coupled together into combinations of alternative flows sheets as indicated below:

- IX[1] + AOP
- IX + GAC + AOP
- GAC + AOP
- RO + AOP
- RO + GAC + AOP
- RO + IX + AOP
- UV with H_2O_2 (AOP)
- Ozone with H_2O_2 (AOP)
- Ozone and UV (AOP)

[1]KEY:

IX: Ion exchange

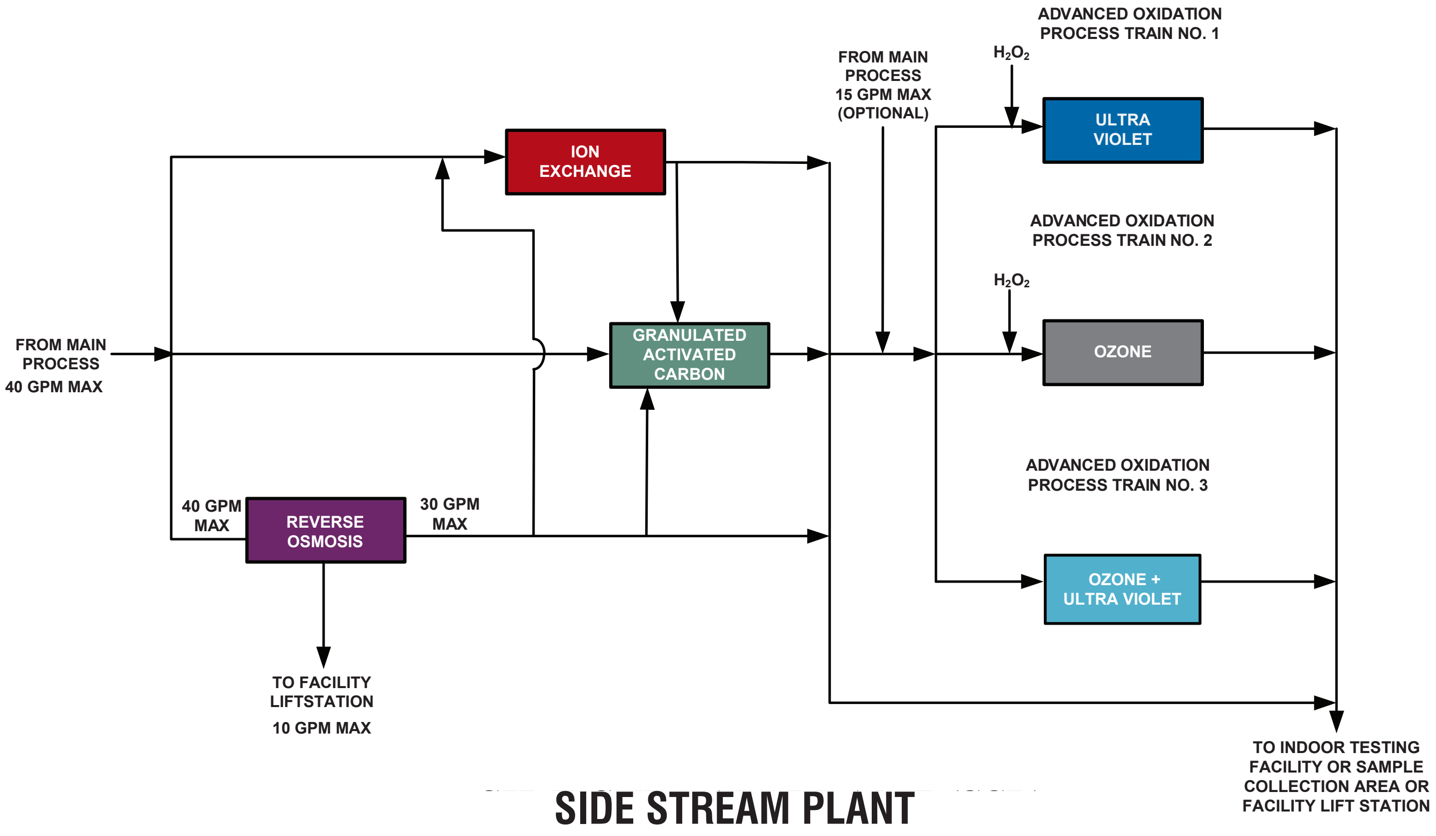
AOP: advanced oxidation processes

GAC: Granular activated carbon

RO: Reverse Osmosis

UV: Ultraviolet light disinfection

FIGURE 1. WRDP PROCESS DIAGRAMS (ADAPTED FROM THE CPBODR)



<u>ABBREVIATIONS/LEGEND</u>

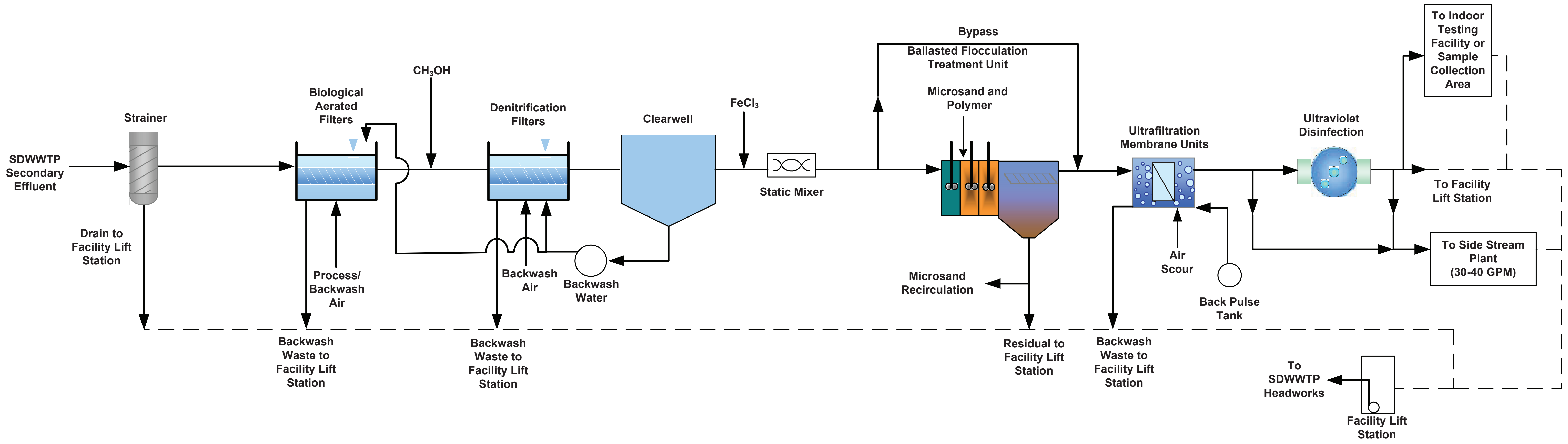
RO	REVERSE OSMOSIS
IX	ION EXCHANGE
GAC	GRANULATED ACTIVATED CARBON
AOP	ADVANCED OXIDATION PROCESS
H2O2	HYDROGEN PEROXIDE
CH_3OH	METHANOL
$FecL_3$	FERRIC CHLORIDE

COMBINATIONS FOR SIDE STREAM PLANT

- IX + AOP
- IX + GAC + AOP
- GAC + AOP
- RO + AOP
- RO + GAC + AOP
- RO + IX + AOP

AOP REFERENCED IN ABOVE COMBINATIONS TO BE THE BEST OF THE THREE AOP TRAINS FOR MICROCONSTITUENT REDUCTION

NOMINAL 0.23 MGD COASTAL WETLANDS REHYDRATION DEMONSTRATION PLANT (CWRDP)



TO INDOOR TESTING FACILITY OR SAMPLE COLLECTION AREA OR FACILITY LIFT STATION

TABLE 1. SUMMARY OF ORIGINAL CPBODR PROCESS

PLANT (CAPACITY)	PROCESS UNIT	TARGET PARAMETERS	EFFLUENT WATER QUALITY GOALS
WRDP (0.23 MGD)	Biological aerated filters for nitrification	Ammonia	REUSE AND WETLANDS APPLICATION
	Denitrification filters with methanol addition for denitrification	Nitrate/Nitrite	
	Ballasted flocculation treatment unit with chemical addition for phosphorus removal	Total Phosphorus	
	Traditional flocculation with chemical addition for phosphorus removal (alternate)	Total Phosphorus	
	Ultrafiltration (UF) submerged membranes	Total Phosphorus, TSS	
	Ultraviolet (UV) light disinfection	Disinfection	
SIDE STREAM PLANT (SSP)(0.07 MGD)	Reverse Osmosis (RO)	Orthophosphate, Refractory organic nitrogen and microconstituents	CLASS III/OFW
	Granular Activated Carbon (GAC)	Microconstituents	
	Ion Exchange (IX)	Refractory organic nitrogen, Nitrate	
	Advanced Oxidation Processes (UV disinfection with hydrogen peroxide (H_2O_2) and Ozone (O_3) and/or ozone with H_2O_2)	Disinfection and Microconstituents	

A review of the proposed processes in the CPBODR showed that the processes shown have the capability to meet the range of possible water quality requirements expected for sustaining a wetlands environment; albeit, only through pilot testing can this be stated with greater certainty, as there are many possible variables that will affect the outcome. Nevertheless, the processes and technologies proposed meet the following initial test:

- Processes/technologies proposed are appropriately targeted at constituents of concern
- Processes/technologies proposed can provide varying degrees of treatment for constituents of concern

Table 1 show that the various constituents of concern are targeted and removed to some extent in the treatment processes proposed in the CPBODR. The literature reviews that immediately follow provide additional information that will be used herein to: 1.) Finalize the CPBODR process evaluation, 2.) Develop any updates to the original processes proposed, and 3.) Make any recommendations as to process changes or modifications.

UPDATED LITERATURE REVIEW ON LIMITS OF TECHNOLOGY

This section provides a literature review that is designed to support updates to the pilot processes/technologies originally recommended in the CPBODR. The review provides an update of the limits of processes technology to document the most recent experiences on treatment methods and to also report on any viable and promising technologies that may also be considered for pilot testing. The literature review is divided into two distinct parts. The first part addresses removal of nitrogen and phosphorus. The second part addresses microconstituent removal.

The following were completed as part of this literature review:

- A survey of existing treatment facilities employing the same or similar advanced wastewater treatment processes recommended in the CPBODR.
- A survey of existing facility performance in full-scale application for processes recommended in the CPBODR.
- A survey of existing facilities that may not have a long history of performance but that show significant potential and promise because of the technology used, and that could potentially be considered along with or in lieu of the CPBODR processes, if found feasible.

The processes evaluated in the literature review herein include: nitrification using Biological Aerated Filters (BAFs), denitrification using deep bed filters, chemical phosphorus removal using available technologies, membrane processes consisting of microfiltration (MF), ultrafiltration (UF), and reverse osmosis (RO), and activated carbon, and ion exchange for nutrient removal. This initial section of the literature review concentrated on nutrient removal. The next section of the literature review focused on microconstituent removal and evaluates the use of activated carbon, advanced oxidation (AOP) processes, and other forms of disinfection.

NITRIFICATION

Biological aerated filters (BAF) are biological reactors with a submerged media bed that supports an attached biological growth. These filters combine biological treatment, clarification, and filtration for the removal of carbon, suspended solids, and ammonia. BAFs were proposed in the CPBODR for the nitrification process, which converts ammonia to nitrate. The BAF configuration resembles a deep bed filter, but flow is typically up through the filter medium. Process air is added to primarily meet the oxygen demands of the biomass in the removal of ammonia, and to promote better flow distribution in the filter bed. BAFs also remove residual dissolved carbon and TSS. BAFs are usually backwashed using gravity flow. During filter backwash, the water flows and expands the media bed to release accumulated solids and biomass.

Limited published literature on the performance of BAFs for nitrification in North America is available.

Holloway et al (2008) presented a comprehensive evaluation of the BAF at the Tahoe-Truckee Sanitation Agency (TTSA), in California. The NH_4-N loading rates at TTSA varied seasonally, with the winter, spring, summer, and fall loading set points being 31.6, 27.0, 33.2, and 23.9 lbs/1000 ft^3/d, respectively. On average, the nitrification stage converted 98 percent of the influent NH_4-N to NO_X-N. The nitrification stage removed approximately 30 percent of the influent TSS, 15 percent of the influent COD, but exhibited insignificant PO_4-P removal. Furthermore, the nitrification stage exhibited some capacity for organic nitrogen removal, especially at higher organic nitrogen influent concentrations.

Ganley et al (2007) reported performance data on the Metropolitan Syracuse WWTP, in New York. The nitrifying BAF system consistently removed ammonia to below summer effluent limit of 1.2 mg/L. Table 2 presents addition data for this facility. The average ammonia and removal efficiency for this facility corresponds to summer conditions only due to seasonal permit limit. Ganley et al indicated that effluent ammonia has been exceeded only four times, each related to a specific problem with the mechanical elements of the BAF system. However, the system showed an excellent recovery to these permit exceedances.

Table 2 summarizes historical performance data obtained for selected nitrifying BAF facilities. The performance of the nitrifying BAF systems is based on annual average conditions with the exception of the Syracuse Metro, which is based only on summer conditions. These data indicate that nitrifying BAFs are capable of producing low effluent ammonia concentrations. Based on the performance noted for these facilities, one could also make an argument that the nitrifying BAF could produce effluent ammonia concentrations as low as 0.3 mg/L under average conditions of flow and loads. Furthermore, based on the historical performance noted for these facilities, the average dissolved organic nitrogen (DON) concentration in the effluent from the noted BAF facilities was approximately 1.5 mg/L, which is consistent with observation reported by Bratby et al (2008) for secondary treatment processes.

A possible substitute to BAF would be a conventional activated sludge (suspended growth) system. Activated sludge processes (WEF/WERF, 2008) can produce lower effluent ammonia concentrations than nitrifying BAFs, but require much larger footprints for the process than BAFs. Based on information presented during a WEF/WERF Limits of Technology Workshop during WEFTEC 2008, nitrifying activated sludge plants were reported to consistently meet effluent ammonia concentrations as low as 0.1 mg/L. The difference in the attainable limits for ammonia between a BAF and a conventional activated sludge process does not justify a change away from BAF.

TABLE 2. PERFORMANCE SUMMARY FOR NITRIFYING BAF PLANTS

BAF TREATMENT PLANT	TYPE OF BAF	INFLUENT NH_3-N (MG/L)	EFFLUENT NH_3-N (MG/L)	REMOVAL EFFICIENCY (%)
TTSA, CA Capacity = 7 MGD	Krüger BIOSTYR®	21.71	0.32	98.53
East Greenwich, RI Capacity = 1.7 MGD	Severn Trent	6.5	0.3	95.38
Freeport, IL Capacity = 5 MGD	Krüger BIOSTYR®	8.3	0.1	98.80
Syracuse Metro, NY Capacity = 84 MGD	Krüger BIOSTYR®	8.64	0.36	95.83

Based on the information found in the literature, the BAF process originally recommended in the CPBODR should be considered as a viable technology for pilot testing. There is documented performance of existing BAF facilities within the size range expected in a full scale application for the BBCWRP. An ammonia removal efficiency of 95 percent and effluent concentration as low as 0.3 mg/L should be attained using BAF treatment.

Denitrification

Denitrification can be achieved in many ways. Deep bed filters were originally recommended in the CPBODR for denitrification. Denitrification filters consist of deep bed gravity sand filters that act as both filters and biological reactors. Flow is downwards (or upwards) through a filter medium that has an effective size of about 3 mm. When filter influent containing nitrate and a carbon source (methanol) are passed through the filter, a biomass of facultative heterotrophic bacteria grows on and between the sand particles and this biomass converts nitrate to nitrogen gas. The filter is periodically "bumped" with a pulse of water to remove accumulated gas in the filter bed. The denitrification filters need to be regularly backwashed with a combination of backwash water and air (scour) to remove accumulated suspended solids.

The literature and historical plant data from existing facilities that employ denitrification filter technologies were reviewed to document the performance and capabilities of deep bed denitrification filters. Overall, the literature shows that denitrification filters are a proven technology for meeting low total nitrogen limits. Concurrent denitrification and solids removal in a deep-bed filter was first patented in 1973, and then followed by a series of patents for other filter components including the use of backwash water to release nitrogen gas. De Barbadillo et al (2005) reported that beginning in the late 70s with the Gainesville (FL) Regional Utilities Kanapaha WWTP (Chen, 1980), and the Howard F. Curran AWTP in Tampa, FL, a number of large municipal facilities implemented down-flow denitrification filters and began to develop full-scale operating experience. This operating experience shows that nitrate-nitrogen (NO_3-N) can reliably be removed to less than 1 mg/L NO_3-N.

The following summarizes performance and capabilities of deep-bed denitrification filters from several facilities either reported in the literature or directly from plant data. **Table 3** provides performance data for a selected group of installations based on annual average conditions.

TABLE 3. PERFORMANCE SUMMARY FOR SELECTED DENITRIFICATION FILTER PLANTS

TREATMENT PLANT	TYPE OF DNF	INFLUENT NO_x-N (MG/L)	EFFLUENT NO_x-N (MG/L)	REMOVAL EFFICIENCY (%)
Fiesta Village WWTP, Ft. Myers, FL Capacity = 5 MGD	Tetra Deep-Bed	4.00	0.10	97.50
Largo WWTP, Largo, FL Capacity = 15 MGD	Tetra Deep-Bed	7.50	0.40	94.67
Howard Curran AWTP, Tampa, FL Capacity = 98 MGD	Tetra Deep-Bed	19.00	1.00	94.74
Kanapaha AWT, Gainesville, FL Capacity = 15 MGD	Tetra Deep-Bed	6.50	0.60	90.77
Dale Mabry, Hillsborough County, FL Capacity = 10 MGD	Tetra Deep-Bed	7.50	0.35	95.33
Bethune Point, Daytona Beach, FL Capacity = 5 MGD	Tetra Deep-Bed	7.00	0.50	92.86

The following was also noted in the literature review conducted regarding denitrification filters:

- Full scale testing of upflow filters at three small WWTPs in Puerto Rico achieved NO_3-N removal rates of 15 to 35 lbs/1,000 ft^3/d at average hydraulic loading rates of 1.1 to 2 gpm/ft^2, and methanol dosage ratios of 3.3 mg/mg NO_3-N.
- Koopman et al (1990) conducted pilot tests at the University of Florida in Gainesville, Florida and at Aberdeen, Maryland. Hydraulic loading rates ranging from 1.4 to 4.6 gpm/ft^2 were tested at influent NO_3-N concentrations of 9 to 12 mg/L. When methanol dosage ratios were below 3.3, effluent NO_3-N concentrations of 2 to 6 mg/L were achieved; but when methanol dosage was increased an effluent NO_3-N of < 1 mg/L was achieved.
- In full scale operation of an upflow facility in Sweden, Hultman et al (1994) showed a NO_3-N reduction from 20 mg/L to 2.2 mg/L.and from 7.3 mg/L to 0.5 mg/L. Testing showed that performance was impacted by temperature and hydraulic loading. The results indicated that the phosphorus concentration into the filter may limit denitrification at values less than 0.1 mg/L soluble phosphorus.
- Kramer and Rosmalen (2003) showed in full scale data from a plant in the Netherlands, removals averaging 70 lbs/1000 ft^3/d NO_3-N at an average hydraulic loading rate of 4.1 gpm/ft^2, but the filter received dry weather flows only and operated at an elevated methanol dosage ratio of 3.3. Data provided for a period of six months showed that at NO_x-N loading rates ranged from 27 to 117 lbs/1000 ft^3/d, an average effluent NO_x-N concentration of 1.2 mg/L was maintained.
- De Barbadillo et al (2005) showed with composite sampling data from a pilot upflow continuous backwash filter in Hagerstown, Maryland, NOx-N removals of up to 100 lbs/1,000 ft^3/day at an average hydraulic loading rate of 3.5 gpm/ft^2, operating under a diurnal flow variation of 63 percent to 125 percent of the average flow. The wastewater temperature averaged 14.5 °C.
- Schauer et al (2006) reported on pilot tests of UCB filters at the City of Hagerstown, Maryland for tertiary denitrification. The filter consistently achieved an effluent NO_x-N concentration of less than 1 mg/L under constant hydraulic loading rates of 4.0 gpm/ft^2 and peak hydraulic loading rates up to 6.0 gpm/ft^2. The filter performed well for an extended period of operation under average mass loading rates 30 to 40 lbs NO_x-N/1000 ft^3/d. The filter also performed well at higher mass loading rates of up to 100 lbs NO_x-N/1000 ft^3/day.

In summary, deep bed filters employed for denitrification have a proven track record of performance and can reliably attain total nitrogen concentrations of less than 1 mg/L. Based on the information found in the literature the denitrification process using deep bed filters is considered a viable process for denitrification and should be considered as a technology for pilot testing.

Chemical Phosphorus Removal

Phosphorus can be removed effectively in a number of ways, including biological, chemical, or combined biological and chemical processes. However, for the purpose of this literature review, the focus will be limited to only chemical/physical processes for the removal of phosphorus, since this is the recommended process for phosphorus removal in the CPBODR. Methods that incorporate use of biological processes would require substantial upgrades to the SDWWTP, and a larger footprint, as compared to chemical removal.

Chemical phosphorus removal relies on the reactions that take place between phosphorus and other chemical species or compounds in water, usually multivalent metal ions. These reactions result in the formation of precipitates of sparingly soluble phosphate that can subsequently be removed from the liquid using a solids separation process. The chemicals commonly used for phosphorus removal are aluminum (Al (III)) and ferric (Fe(III)). Neethling et al (2007) indicated the chemistry of phosphorus precipitation with iron or aluminum is quite complex due to the formation of various metal phosphorus complexes and metal hydroxyl complexes, as well as adsorption and co-precipitation of phosphorus onto the precipitates and complexes. Neethling et al (2007) reported that the lowest soluble phosphorus level that can be obtained is either determined by: 1) the solubility of phosphorus, if metal phosphate dominates, or 2) lower than the solubility limits, if the reaction condition allows for the occurrence of substantial adsorption/co-precipitation. The challenge for chemical phosphorus removal is to capitalize on these possible reactions to remove the phosphorus from the liquid efficiently. Finally, the efficiency of the solid/liquid separation process directly affects the final effluent phosphorus level (Bratby 2006).

In order to achieve ultra low values of phosphorus, Scherrenberg et al (2008) discussed the effect of effluent characteristics as a whole. Fractionation of phosphorus should be used to determine which species of phosphorus are present and must be targeted for removal. The various species of phosphorus typically found in wastewater include:

- ortho-phosphate
- metal bound phosphorus
- dissolved organic phosphorus
- particulate organic phosphorus

Knowledge about the distribution of the different phosphorus species in the wastewater is paramount to an improvement in process removal performance. This information makes it possible to compare different filtration concepts to achieve efficient solids/liquid separation. By quantifying possible phosphorus fractions as an optimization strategy for removal of phosphorus, ultra low phosphorus concentrations may be attained. Information on the distribution of phosphorus species should be obtained for the pilot demonstration project. The fractionation of phosphorus at the SDWWTP effluent is currently unknown. This information should be obtained during the pilot study, as the ability to efficiently meet low levels of phosphorus in the effluent and selection process is impacted by these fractions.

Neethling et al (2007) investigated the phosphorus speciation in wastewater effluents from various full or pilot-scale processes, including both conventional secondary chemical P removal and biological P removal, as well as more advanced tertiary treatment processes. Overall, advanced tertiary treatment process that have multiple stages and apply filtration, coagulation and adsorption, showed very efficient TP removal to approximately 20 µg/L. P speciation analysis of these tertiary effluents shows that dissolved (soluble) refractory organic P (rDOP) is the dominant component. Refractory organic phosphorus, which ranged from 0.01 to 0.05 mg/L, was present in all secondary and tertiary effluents studied and seemed to be mostly in soluble form (passed a 0.45 µm filter). Most rDOP exists in colloidal form and it is susceptible to removal by coagulation/flocculation. Membrane microfiltration processes showed very efficient particulate phosphorus removal. However, the removal of soluble P fractions, including both soluble reactive P (ortho-P) and rDOP, was not as effective as other tertiary treatment processes studied.

Benisch et al (2007) presented results from the pilot plant at the City of Coeur d'Alene, Idaho where they highlighted the technical challenges to meet low phosphorus limits. Four different technologies were tested on their ability to reliably produce effluent TP concentrations of less than 50 µg/L and less than 10 µg/L. The demonstration project showed that an effluent TP level of less than 50 µg/L could be reliably produced by at least two of the tested technologies (Dual Stage Blue PRO^{TM} Process and US Filter Trident® HS-1). Results highlighted that the ability of membrane ultrafiltration (UF) to meet an effluent TP concentration of 50 µg/L was not fully demonstrated. None of the technologies tested during this study demonstrated the ability to meet a 10 µg/L TP limit.

Blue PRO^{TM} (2008) reported data on an independent phosphorus removal pilot project conducted at a Southwest WWTP in Sunrise, FL with the purpose of providing a treatment process to maintain a total phosphates limit of 0.01 mg/L in the discharge water. In the independent study conducted by Blue PRO^{TM}, the two stage hydrous ferric oxide (HFO) reactive filtration configurations were able to meet the required discharge permit. The first option was a HFO reactive filter system configuration with doses of 10 mg/L Fe (from ferric chloride) and 0.5 mg/L ozone to each pass of the process. This configuration was able to produce average TP and OP (ortho phosphate) effluent concentrations of 23.6 µg/L and less than 5.2 µg/L, respectively. The second option, a HFO reactive filter system utilizing a ferric blend dosed at less than 10 mg/L Fe per process pass, achieved TP and OP effluent concentrations of less than 4.4 µg/L and less than 2.6 µg/L, respectively. Most of the sample analyses produced results lower than the detection limits for both TP and OP, those limits were 2.9 µg/L and 2.3 µg/L.

The Blue PRO^{TM} process consists of feeding a chemical, typically ferric chloride, to the wastewater to form ferric phosphate precipitate, which is followed by a proprietary pre-reactor zone and then a moving-bed filter. The process uses a Centra-flo continuous backwashing filter. Blue PRO^{TM} filtration system contains a bed of hydrous ferric oxide-coated media, in which the ferric phosphate is filtered. Blue PRO^{TM} reports that the abrasion of the sand particles against one another in the moving bed filter exposes new adsorption sites on the media.

Midorikawa et al (2008) presented data on a newly developed phosphorus adsorption and recovery system. The system consisted on two packed column in series equipped with a very high-speed adsorbent with a "unique porous structure". The secondary effluent with TP concentrations ranging from 0.1 to 2.1 mg/L P was passed through an adsorbent packed column at high space velocity. The TP of the treated water was as low as 0.02 to 0.04 mg /L, indicating that 97% of phosphorus in the secondary effluent was removed.

Ellis and Cathcart (2008) presented a technology assessment matrix that evaluated different technologies to meet low effluent phosphorus levels for the Town of Concord, Massachusetts. The CoMag process was selected and installed. The CoMag process consists of ballasted flocculation tank, solids contact clarification, and high gradient magnetic separation. In the first compartment of the flocculation basin, a metal salt is added and the pH is adjusted to optimize phosphorus removal. Fine magnetic particles are then added in the second compartment to increase the density of the floc, and finally a polymer is added to increase flocculation in the third compartment. The conditioned wastewater enters a solids contact clarifier, and the effluent is then sent to the disinfection process. The solids that are not wasted from the process are returned to the flocculation tank. The CoMag process was able provide an effluent of less than 50 µg/L TP. During the testing period, the influent averaged 0.84 mg/L TP and the effluent averaged 48 µg/L TP (Ellis and Cathcart (2008); Tozer (2008)).

Limited information was found in the literature for performance of the Ballasted Flocculation Process (BFP) for phosphorus removal. BFP is the technology recommended for phosphorus removal in the CPBODR. A BFP consists of a coagulation tank and clarifier equipped with lamella tubes. A metal salt and polymer are added upstream of the coagulation tank, and pH is adjusted to optimize phosphorus removal. In the coagulation tank the secondary effluent is mixed with fine sand and polymer. The fine sand provides a large surface area to which the formed floc can attach; it also increases the sedimentation rate by acting as ballast. The solids are settled in a clarifier. The microsand is recovered and returned to the process.

Historical plant data obtained for the BFP in the Syracuse Metro WWTP, NY was analyzed for this evaluation. This data showed an average TP removal efficiency of approximately 80 percent, and an average effluent concentration of 0.1 mg/L TP. However, this facility is not equipped with a final filtration step; hence, it is believed that a high fraction of the effluent is made up of particulate P that could be removed if an extra filtration step were added. Data presented at the Limits of Technology Workshop in WEFTEC 2008 (WEF/WERF, 2008) for the Iowa Hill Water Reclamation Facility (WRF), CO showed that BFP followed by filtration can achieve lower TP concentrations than those at the Syracuse Metro WWTP, NY. This configuration at the Iowa Hill WRF produces an average TP effluent concentration of 14 µg/L with effluent TP values below 30 µg/L 90 percent of the time.

Membranes provide a physical barrier that can retain nearly all particles larger than the pore size of the membrane. Several pilot studies have been conducted that evaluated the phosphorus removal capabilities of membranes and chemical addition. MWH (2008) reported at a pilot plant facility in Sunrise, FL, phosphate levels consistently below 0.10 mg/L using enhanced biological nutrient removal coupled with membrane bioreactors (MBR). Tests showed that chemical addition and MBRs could reduce phosphate levels as low as 30 µg/L consistently (greater than 96 percent of the time). In a similar pilot plant study conducted at the City of Plantation (FL) (Hazen and Sawyer, 2008), membrane ultrafiltration and alum addition resulted in effluent TP values ranging from 0.60 to 0.10 mg/L (alum dose from 40 to 120 mg/L).

Neethling et al (2007) concluded membrane microfiltration process showed very efficient particulate phosphorus removal. However, the removal of soluble P fractions was not as effective as other tertiary treatment processes studied. Neethling et al (2007) observed average effluent TP values of 24 µg/L TP, which is lower than values reported at both Florida pilot plants. Benisch et al (2007) indicated through pilot plant results that membrane ultrafiltration would likely be able to meet a total phosphorus level of 50 µg/L; however, this was not fully demonstrated during the experiments.

In summary, chemical phosphorus removal using the BFP has a limited track record in full scale facilities, but there are no indications in the facilities where it is used which support a change for this pilot program. Existing facilities using the BFP attain levels of phosphorus removal considered acceptable for this application, and acknowledging the fact that the information in the literature is limited, BFP is certainly considered a candidate technology for pilot testing.

Additionally, there is another promising technology for phosphorus removal that should also be pilot tested: HFO, or hydrous ferric oxide (Blue PRO™). HFO is recommended to be pilot tested for chemical phosphorus removal, as it offers an alternative to the BFP using a technology that although unproven at large scale, has potential to produce low levels of phosphorus in a relatively compact footprint.

Reverse Osmosis

Reverse osmosis (RO) is a pressure-driven and diffusion controlled membrane process. Osmosis is defined as the passage of a liquid from a dilute to a more concentrated solution across a semi permeable membrane. RO is achieved by providing adequate pressure to overcome osmotic pressure so that feed water flows from the more concentrated solution to the clean "water" side of the membrane. The product water (permeate) is collected in tubes and transported for use as high quality product water. In wastewater applications, RO is used to remove dissolved constituents from wastewater remaining after advanced treatment.

While limited information has been published on the removal efficiency of RO systems for nutrient removal, high removal efficiencies have been reported. **Table 4** summarizes removal efficiencies achieved in RO systems found in either the literature or direct plant data performance review.

It is important to note that skid arrays, temperatures, flux and recovery greatly influence the RO performance. Reverse osmosis (RO) provides a viable, proven membrane technology for removal of nitrogen and phosphorus species to very low levels; but at the price of incurring high power costs in its use. Based on the information found in the literature RO originally recommended in the CPBODR is considered as a viable technology for pilot testing for removal of nitrogen and phosphorus.

Activated Carbon

Very limited information was found on the effectiveness of activated carbon for nutrient removal. No plants were found that utilize this technology for this purpose. However, Randtke et al (1978) (as cited in Bratby et al (2008)) reported that activated carbon adsorption could be the most effective method of DON removal, in terms of ultimate percentage removed. They found that in secondary effluents, about 70 percent of the effluent DON was relatively non-polar, making this fraction particularly suitable for activated carbon adsorption. Activated carbon is most effective at removing less polar material. Molecules of higher polarity tend to be less absorbable, bind water more tightly, and are more soluble.

Activated carbon is not considered a viable process for removal of nitrogen and phosphorus and it is not recommended for such an application in proposed pilot tests.

TABLE 4. PERFORMANCE SUMMARY OF RO SYSTEMS

REFERENCE	AMMONIA	TKN	NITRATE	NITRITE	ON[2]	TN	OP
Metcalf and Eddy (2004)	90 – 98	--	65 – 85	--	--	--	95 – 99
Data Provided by Siemens	85 – 95	--	93 – 96	--	--	--	98 - 99
Dublin San Ramon Sanitary District1	96	--	96	--	--	--	99
Orange County GWR, CA	91 – 97	--	85 – 90	--	--	--	85 – 99
MWH (1997)	90 - 95	88 - 92	95 – 98	97 - 99	85 - 90	--	94 - 99.5
MWH (2008)	--	99.9%	99.4%	99.9%	--	99.7%	99.9%
Schimmoller et al (2008)	83	88	87	84	92	88	85
Hazen and Sawyer (2008)	--	--	--	--	--	65 - 85	93 - 99.5

[1] From Whitley and Burchett & Associates (1999)

[2] Organic nitrogen

Ion Exchange

Ion exchange is a unit process in which ions of a given species are displaced from an insoluble exchange material by ions of a different species in solution. Ion exchange has been used in wastewater applications from the removal of nitrogen, heavy metals, and total dissolved solids (TDS).

Ammonia removal by ion exchange is accomplished using clinoptilolite, a naturally occurring zeolite. Clinoptilolite has proven to have a greater affinity for ammonium ions than other ion-exchange materials.

Bratby et al (2008) reported that others have experimented on a series of physical-chemical processes for DON removal from secondary effluents. They found that cation exchange at pH 7 removed approximately 11 percent of the DON. Removals increased significantly as pH was reduced from 7 to 2. Additionally, anion exchange at neutral pH removed approximately 12 percent of the DON.

Gu et al (2007) investigated the potential of applying adsorptive media to further remove phosphorus in secondary and tertiary effluent to levels lower than the limits of technology in current use. On-site short-term bench scale adsorption column tests treating membrane microfiltration effluent were conducted in parallel using three different commercial adsorptive media including US filter GFH, ResinTech ASM-10-HP, and Purolite Arsenex. At influent TP concentrations ranging from 0.014 to 0.43 mg/L, effluent TP of 0.005 to 0.008 mg/L was achieved. The particulate P in the column effluent was negligible (<0.002 mg/L) for all tests, while effluent soluble P ranged from 0.004 to 0.007 mg/L. The results demonstrated that the adsorption column process can effectively remove both soluble reactive ortho-P and soluble nonreactive P, such as dissolved refractory organic P in the wastewater.

Conversations with Siemens Water Technology and Purolite have indicated that ion exchange systems can achieve very high nutrient removal efficiencies for ammonia, nitrate/nitrite and phosphate, on the order of 99 percent. Although the literature shows that ion exchange (IX) can provide effective removal of nitrogen, specifically ammonia, there is scarce experience in full scale applications of the size expected, and estimated resin regeneration costs are higher than other processes. Close consideration as to its applicability would need to be considered in a case-by-case basis for other projects. Furthermore, the process treatment includes a biological nutrient removal step that is anticipated to be sufficient for this application. The incremental reduction in ammonia that may be possible with the use of IX is not anticipated to be necessary or cost efficient for the BBCWRPP project and, as such, not recommended for pilot these tests.

LITERATURE REVIEW OF MICROCONSTITUENT REMOVAL

Microconstituents are unregulated trace compounds found in wastewater effluent that includes hormones, prescription and non-prescription pharmaceuticals, human and veterinary antibiotics, personal care products (PCPs), industrial and household chemicals, and disinfection byproducts (DBPs). Effects from many of these chemicals are generally unknown, but warrant investigation as there is potential to impact the environment. Microconstituents do not include all of the unregulated microcontaminants like pathogens and trace metals.

While there have been several studies focused on gathering information and data for sources, occurrence in wastewater treatment effluents, and the environmental fate and toxic effects of microconstituents, the scope of this literature review is primarily to evaluate treatment efficiencies for the removal of microconstituents with considerations to advantages and limitations.

A literature review of microconstituents of concern in wastewater effluents, and technologies adapted for their removal was previously conducted in 2004 as part of the ACOE Study[2]. The 2004 ACOE review also presented a succinct overview and description of the importance of microconstituents in secondary effluents. The literature review provided herein is an update of the 2004 ACOE review and has the objective of capturing the most recent experiences on removal of microconstituents from highly treated reclaimed water. Since the previous review was published in 2004, this review concentrates principally on literature references published in 2004 and later. In other words, this review is considered to be complementary to the 2004 ACOE review and is not intended to replace it.

Following are the processes that were included in this literature review and which were part of the SSP in the CPBODR:

- RO
- UV disinfection
- Membrane Filtration (micro, ultra)

- Ozone
- Activated Carbon (Powdered or granulated)
- AOP
- Combination of any of the above techniques

In addition to advanced treatment techniques, secondary treatment options were also examined, since for some compounds, secondary treatment alone has been shown to produce acceptable removal efficiencies. Secondary treatment inclusion also serves to establish a baseline for the degree of advanced treatment needed after secondary removal. Table 5 presents a summary of removal efficiencies of different microconstituents in various activated sludge configurations.

To carry out this review update, a considerable amount of published literature was reviewed to glean the information required. Only the literature from which useful information was abstracted is included in the reference list. The literature summary is presented in the form of tables, with notes included for clarification purposes. Therefore, textual and detailed descriptions of the experiences gleaned from the literature were kept to a minimum.

Overview of Treatment Technologies

Table 5 presents a compilation of experiences on microconstituents' removal from wastewater using advanced treatment technologies. The results demonstrate that microconstituents are removed to varying degrees by each of the following processes:

- **Coagulation and Softening**. Although hydrophobic compounds are able to bind to particles and be removed jointly with the particles, in general, coagulation is largely ineffective for the removal of most microconstituents[10].
- **Activated Carbon.** Powder activated carbon (PAC) can be highly effective for many compounds, but dose and contact time are critical. Granular activated carbon (GAC) columns are highly effective for most compounds. Steroid hormones and other hydrophobic contaminants are effectively removed with minimal breakthrough after 50,000 bed volumes. X-ray contrast media (such as iopromide) and some pharmaceuticals such as ibuprofen, meprobamate, sulfamethoxazole and diclofenac are some compounds that are the most recalcitrant for activated carbon removal[21]. GAC must be regenerated or replaced regularly to ensure efficient microconstituent removals[10]. The combination of ultrafiltration and PAC is very effective for removing microconstituents. This process, known as the Cristal® process, was developed by Suez-Environment in the early 1980s.
- **Free Chlorine and Chloramines.** Free chlorine is able to oxidize approximately half of the microconstituents investigated. Hormones with a phenol functional group (such as estrone, ethynyl estradiol and 17-estradiol) were rapidly oxidized with free chlorine, while hormones with ketone functional groups were only partially oxidized. Chloramines are much less efficient than free chlorine[10].It should be noted also that chlorine and chloramines create NDMA.
- **Ozone.** Work carried out by the European Union Poseidon Project identified ozone as a feasible add-on treatment for wastewater effluents. After secondary effluent treatment with 5 to 10 mg/L ozone, most pharmaceuticals, including estrogenic compounds are removed below the detection limit. Therefore, ozonation should significantly reduce the estrogenic potency of wastewater effluents on aquatic species[8]. Only the iodinated radiological contrast agents (mostly originating from hospital wastewater) should be still present in appreciable quantities. The effectiveness of ozone is dependent on the background level of dissolved organic carbon and the chemical properties of the residual substances. In Switzerland, ozone dosages to effluents from WWTPs of approximately 5 mg/L are sufficient for complete removal of most compounds. However, energy costs are significant, approximately 0.4 to 0.75 kWh/1,000 gallons. However, secondary degradation products formed with ozonation are a concern and need evaluation prior to any large-scale application[7].

Tests carried out in Nevada showed that although ozone was determined to be effective for removal of many microconstituents[9], some constituents resisted degradation. The hormones androstenedione, estradiol, aestriol, estrone, ethynylestradiol, progesterone and testosterone were not present at detect levels in filtered secondary effluents, so the effectiveness of ozone for these microconstituents could not be demonstrated. Some pharmaceuticals including acetaminophen, diazepam, gemfibrozil, pentoxifyline, and the pesticide atrazine, were also non-detect in the filtered secondary effluent. However, the pharmaceuticals carbamazepine, diclofenac, erythromycin, fluoxetine, hydrocodone, naproxen, and trimethoprim were removed by ozone to non-detect levels (<1 ng/L); caffeine was also degraded to non-detect levels. Other compounds were degraded to an extent depending on the ozone dosages:

- Dilantin removed ~ 65.3 x ln(O_3 dosage, mg/L) + 19 ng/l
- Iopromide was poorly removed by about 20 ng/L irrespective of dosage (from 2.1 to 8.7 mgO_3/L)
- Meprobamate was also poorly removed by about 265 ng/L irrespective of dosage (from 2.1 to 8.7 mgO_3/L)
- Sulfamethoxazole removed approximately 138.6 x ln(O_3 dosage, mg/L) + 521 ng/L
- DEET removed approximately 88 x ln(O_3 dosage, mg/L) – 11.3 ng/L

In some cases, ozone degradation products registered as increased concentrations of other compounds. For example, one set of experiments showed slight increases in estriol, estrone, ibuprofen, trichloroethylphosphate (TCEP), triclosan and oxybenzone concentrations.

In general, the flame retardant TCEP is one of the most challenging compounds to oxidize with ozone. Other compounds such as atrazine, iopromide and meprobamate are also resistant to ozone. The addition of hydrogen peroxide for advanced oxidation with ozone is only marginally more effective for these compounds, than ozone alone.

Although ozone appears to be an effective method of destruction of many microconstituents, one potential issue of concern is the amount of salinity in the effluent from the SDWWTP and the production of bromoform from natural bromides present in the secondary effluent.

- **UV and Advanced Oxidation Processes (AOP).** UV at typical disinfection dosages of approximately 40 mJ/cm^2 is generally ineffective for the removal of most compounds. Of the 36 target compounds, only 3 (sulfamethoxazole, triclosan and diclofenac) were removed by greater than 50% at this UV dose, while the other 33 target compounds were only poorly removed. The combination of UV at dosages greater than 400 mJ/cm^2 combined with hydrogen peroxide (>3 mg/L) provided excellent removal of most target compounds10. Removals observed with UV-H_2O_2 closely resembled removals obtained with ozone.
- **Other Processes.** Magnetic Ion-Exchange (MIEX) was found to be largely ineffective for the removal of most microconstituents[10]. While, diclofenac and triclosan were reasonably well removed (>80%) and naproxen had moderate removal (>50%),all other target compounds were removed by less than 50%, with most less than 20%. Fenton's reagent, even with low DOC and alkalinity conditions, was not found to be effective at removing microconstituents, so was not considered suitable for advanced wastewater treatment[8], [21].
- **Membranes.** Ultrafiltration (UF) and microfiltration (MF) membranes are of little value for the removal of microconstituents. Nanofiltration (NF) generally provides good removal of many target compounds. Reverse osmosis (RO) generally is highly effective for the removal of most target microconstituents[10]. Rejection of ionic pharmaceutical residues and pesticides by RO membranes exceeds 95% for the tighter membranes. Hydrophobic nonionic compounds such as bromoform and chloroform initially exhibit relatively high rejections, above 80%, but rejections drop off markedly with run time, to 20 to 40%. In general, the presence of effluent organic matter (EfOM) improves the rejection of ionic organics by tight NF and RO membranes[6].

Microfiltration with biological treatment (the membrane bioreactor, MBR process) could have merits in some cases, particularly where pre-treatment for advanced treatment processes is required. However, Table 6 shows that in general, removals of target compounds are similar to removals through activated sludge plants designed for biological nutrient removal.

Updated Literature Review of Microconstituents Removal

An update of a previous literature review was conducted as part of this project. The advanced treatment processes investigated include GAC, PAC, the PAC+UF process, RO, NF, O_3, O_3+hydrogen peroxide (H_2O_2), O_3+UV, UV+titanium oxide, UV+H_2O_2, UV+Fenton's reagent, coagulation processes, MIEX and chlorination.

Of these processes, the most effective in terms of their overall removal efficiencies are, GAC, PAC, PAC+UF, RO, NF, O_3+H_2O_2, and UV+H_2O_2. Processes such as coagulation with separation processes such as filtration, microfiltration, or UF are useful for removing some organics but particularly for pretreatment before the more effective advanced treatment processes previously mentioned.

Based on the information found in the literature there are two prime candidate processes for pilot testing for destruction/removal of microconstituents: 1.) AOP using UV and peroxide, and 2.) AOP using peroxide and ozone. The use of activated carbon is not considered viable at this time because of its expected life cycle costs, and the fact that there is not enough information currently on exactly which microconstituents need to be removed and to what extent, so the use of activated carbon cannot be justified for pilot testing.

TABLE 5. REMOVAL EFFICIENCIES OF DIFFERENT MICROCONSTITUENTS THROUGH VARIOUS ACTIVATED SLUDGE CONFIGURATIONS, INCLUDING MEMBRANE BIOREACTORS

PE= Primary effluent; SE= Secondary effluent; Rem%= percent removal

TREATMENT PROCESS	SRT		17-B ESTRADIOL EQUIV.	17A-ETHYNYL ESTRADIOL	17B-ESTRADIOL		ESTRIOL		ESTRONE	TESTOSTERONE		4-TERT-OCTYLPHENOL	BISPHENOL A	4-NONYLPHENOL
A. Nitrification; Bio-P activated sludge; UV disinfection	10.0													
		PE	17.4	1.9	7	19.9	234	15.9	41	75.2	136	17000	3642	8200
		SE	0.21	0.03	1	6.2	2	0.4	0.6	1	6.2	417	1155	1428
		Rem%	99	84	86	69	99	97	99	99	95	98	68	83
B. Chem-P activated sludge; Chlorination	8.5	PE	59.3	9.1	8.8	37.5	307	19.2	42	27	35.1	17000	47000	8200
		SE	1.55	0.3	1	0.6	1	0.4	1	1	1.3	417	3300	4900
		Rem%	97	97	89	98	99.7	98	98	96	96	98	93	40
C. Pre-aeration; Conventional activated sludge; Chlorination	1.7	PE	42	14.4	24.5	4.6		15.8	17.7		80.8	2200	3900	8200
		SE	7.91	4.2	4.4	0.6		0.4	0.15		1.9	417	1155	2283
		Rem%	81	71	82	87		97	99		98	81	70	72
		PE	94.7	<.015	23.9	37.6		29.9	60.3		79.1	488	2500	1940
D. NdeN activated sludge; Filtration; Clorination; dechlorination	10.0	SE	3.12	<.015	1.5	0.6		0.4	50.4		0.5	417	1155	604
		Rem%	97		94	98		99	16		99	15	54	69
		PE	94.1	<.015	15.3			38.3	65.2		49.1	3825	2941	8200
E. NdeN activated sludge; Filtration; UV disinfection	10.4	SE	1.57	<.015	6	4.1		0.7	11.1		4.1	417	1155	2023
		Rem%	98		61			98	83		92	89	61	75
		PE	35.1	<.015	39.4	25.9		2.7	39.4		45.2	1330	4012	8200
F. Partial nitrification activated sludge; Filtration; Clorination	4.4	SE	0.18	<.015	0.15	0.69		0.4	27.5		0.5	417	1155	1460
		Rem%	99		100	97		85	30		99	69	71	82
		PE	32.9	<.015	12.8	13.1		<0.4	80.3		188	2085	2782	8200
G. NdeN activated sludge; Filtration; Clorination, dechlorination	7.0	SE	2.1	<.015	1.8	0.62		<0.4	16.4		2.4	417	1155	1777
		Rem%	94		86	95			80		99	80	58	78
		PE	81.5	10.3	21.7	11.1		7.8	52.6		50.4	521	3109	1685
H-1 MBR (Kubota)	10.0	SE	1.35	0.15	0.15	0.6		0.4	17.3		0.5	417	1155	756
		Rem%	98	99	99	95		95	67		99	20	63	55
		PE	81.5	10.3	21.7	11.1		7.8	52.6		50.4	521	3109	1685
H-2 MBR (Zenon)	21.0	SE	0.62	0.15	0.15	0.6		0.4	12.3		0.5	417	1155	541
		Rem%	99	99	99	95		95	77		99	20	63	68

PE= Primary effluent; SE= Secondary effluent; Rem%= percent removal

TABLE 6. REMOVAL EFFICIENCIES OF DIFFERENT MICROCONSTITUENTS USING VARIOUS TREATMENT PROCESSES

MICROCONSTITUENT	REMOVAL METHOD	COMMENTS
1-chloronaphthalene (CINt)	UV[2]	40μM removed 94%.
1,4-dichlorobenzene (1,4-DCilBz)	UV[2]	300μM removed 93%.
2-chloropyridine	GAC[2]	Removed 90%.
2,3,7,8 TCDD	Coagulation, sedimentation and filtration[1]	Coagulation, sedimentation, and filtration would be very effective as advocated by the EPA due to lower solubility and so preference to the solid phase when entering water treatment.
2,4-D	UV[1]	Under laboratory conditions, 70 μg/m1 2,4-D is reduced to 20 μg/m1 in 10 hours; in the same time, 30 μg/m1 degrades to 5 μg m1-1 due to photolysis.
2-Naphthol	RO[2]	110 μg/l removed 43%
	NF[2]	110 μg/l removed 12%
9-ACA	RO[2]	Removal 96%
	NF[2]	Removal 93%
Acetaminophen	UV1[0]	Removal >80% (439 mJ/cm^2)
	GAC[10]	Removal 99%
	PAC[10]	Removal 50-80% (5 mg/l and 4-5 hr contact).
	MIEX[10]	Removal <20%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Alkylphenol polyethoxy carboxylates (APnECs)	RO[1]	Highly hydrophilic and persist through lime addition, coagulation, rapid sand filtration, activated carbon adsorption, and chlorination; efficiently removed by reverse osmosis.
Alkylphenols (APs)	GAC[1]	Advocated by the EPA, with PAC being substituted for GAC for systems that include mixing basins, precipitation, or sedimentation and filtration.
	UV and catalyst[1]	For UV only no change in concentration was observed; with the titanium dioxide (TiO_2) catalyst, 90% decomposition occurred within 60 minutes; octylphenol was the least stable with 90% degradation in <20 minutes; after 5 hours, 80% of initial APs was completely mineralized.
Alkylphenol ethoxylates (APEOs)	GAC[1]	Advocated by the EPA, with PAC being applicable for systems that include mixing basins, precipitation or sedimentation and filtration; nonylphenol ethoxylates not always reduced due to saturation with competitive adsorption favoring other contaminants in the water sample.
Androstenedione	UV[10]	Removal <20% (439 mJ/cm^2)
	PAC[10]	Removal 50-80% (5 mg/l and 4-5 hr contact).
	GAC[10]	Removal >60%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Antibiotic (oxytetracycline, OTC)	RO[2]	1,000 mg/l removed >92%.
Antibiotics (several)	RO[2]	50 ug/l each of carbadox, sulfachlorpyridazine, sulfadimethoxine, sulfamerazine, sulfamethazine, sulfathiazole, trimethoprim. Removal >99%.
	Ozone[2]	50 ug/l each of carbadox, sulfachlorpyridazine, sulfadimethoxine, sulfamerazine, sulfamethazine, sulfathiazole, trimethoprim. Removal >95%.
Antibiotics (ceftriaxone sodium, penicillin VK, enrofloxacin)	Ozone[2]	250 mg/l as COD; removed 71-82% as COD.
	Ozone – hydrogen peroxide[2]	75-99% removal as COD with O_3/H_2O_2 .

MICROCONSTITUENT	REMOVAL METHOD	COMMENTS
Antibiotics (carbadox, sulfachlorpyridazine, sulfadimethoxine, sulfamerazine, sulfamethazine, sulfathiazole, trimethoprim)	PAC[2]	50 ug/l for each compound, removed 57-97% for PAC dosage of 10 mg/l; and 81-98% for PAC dosage of 20 mg/l.
5 antibiotics, 1 antiepileptic, 4 antiphlogistics, 2 lipid regulators, 5 betablockers, 2 musk fragrances, estrone, caffeine, 4 Iodinated X-ray contrast media (ICMs)	Ozone – peroxide[2]	Removed 25-89% with O_3/H_2O_2.
	Ozone – UV[2]	Removed 36-90% of the 4 ICMs with O_3/UV
Atrazine	Ozone[1]	No hydroxyl derivatives were observed; 30 minutes required to reach 60% degradation.
	Ozone/hydrogen peroxide[1]	2 minutes were needed to reach the same level of degradation as ozone only; with raw water levels of 0.1 µg/l, the new EU regulation cannot be met by ozone and ozone/ hydrogen peroxide.
	UV[10]	Removal 50-80% (439 mJ/cm^2)
	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	GAC10	Removal 3%
	RO10	Removal >80% (ND)
	RO[11]	Removal ~100% (ND)
Benzo(a)pyrene	PAC[10]	Removal >80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80% (ND)
Benzo[e]pyrene (BeP) Benzo[k]fluoranthene (BkF)	Ozone[1]	Two-stage O_3 system (retention time 10 minutes) formed oxidation products though no mutagenicity detected; aerobic biodegradation eliminated ozonation products within one hour.
Benzo[a]anthracene (BaA)	Ozone[1]	Varying ozone dosages used; 15 oxidation products resulted.
BaA, BbF, BkF, BaP Dibenzo[a,h]anthracene	UV/Ozone[1]	Destroyed by more than 90% for concentrations between 200 ng/l and 12 µg/1; superior to UV or ozone only treatment.
Bisphenol A (BPA)	UV with catalyst[1]	UV and TiO^2 catalyst resulted in complete mineralization within 20 hours; estrogenic activity decreasing to <1% of initial BPA activity within 4 hours; 90% decomposition occurred within 50 minutes; after 3 hours, 90% mineralization was achieved.
	UV with catalyst[2]	UV with H_2O_2 and Fe(II) – also known as photo-Fenton process. 100% degradation after 9 minutes.
	RO[2]	Removal 99%
	RO[20]	Removal 63%
	NF[2]	Removal 45%
	GAC[2]	0.13 µg/l removed >96%.
Bisphenol A, 17-estradiol, 17-ethynyl estradiol	PAC[2]	500 ng/l removed >99% for PAC dosage of 15 mg/l.
Bromacil	UV[2]	0.38 mM removed 95% with 1.25 mM DO and 5 second exposure time (84% removal with 0.25mM DO and 5 seconds exposure time).
Bromoform	GAC[2]	Removed 57%.
Bromoform	RO[6]	Rejections: XLE (hydrophobic, MWCO 100) 42%; TFC-HR (hydrophilic, MWCO 100) 35%.

MICROCONSTITUENT	REMOVAL METHOD	COMMENTS
Caffeine	UV[10]	Removal <20% (439 mJ/cm^2)
	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 16%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Carbamazepine	UV[10]	Removal 20-50% (439 mJ/cm^2)
	UV/H_2O_2[10]	Removal >80% (372 mJ/cm^2 + 5 mg/l H_2O_2)
	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 16%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
	PAC-UF[12]	Removal 96% (Initial conc. 1-2 μg/l)
Chloroform	RO[6]	Rejections: XLE (hydrophobic, MWCO 100) 30%; TFC-HR (hydrophilic, MWCO 100) 20%.
Chlorobenzene (CIBz)	UV[2]	200 μM removed 92.5%.
Clofibric acid	UV[2]	Removal 29% for simulated solar UV light.
Clofibric acid, ibuprofen, diclofenac	Ozone + peroxide	2μg/l removed >98% with 3.7 mg/l O_3 and 1.8 mg/l H_2O_2.
DCAA	RO[2]	Removal 95%
	NF[2]	Removal 91%
DDT	GAC[1]	GAC is the BAT advocated by the EPA.
	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80% (ND)
DEET	UV[10]	Removal <20% (439 mJ/cm^2)
	PAC[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal >60%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Diazepam	UV[10]	Removal <20% (439 mJ/cm^2)
	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Diclofenac	RO[2]	Removal 95%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
	UV with catalyst[2]	UV with H_2O_2 84% removal.
	NF[2]	Removal 93%
	Ozone[2]	1 mM removed 97%.
	UV[10]	Removal >80% (439 mJ/cm^2)
	PAC[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 69%
Diethyl phthalate	GAC[1]	GAC is the BAT advocated by the EPA; [6] GAC evaluated and bituminous coal was the most efficient GAC for removal.
Di-(2ethyl hexyl) phthalate (DEHP)	GAC[1]	GAC is the BAT advocated by the EPA; the Freundlich coefficient K gives GAC removal for a chemical; values >200 are economically feasible; at 8308 μg/g, this was the highest value for 130 chemicals tested.

MICROCONSTITUENT	REMOVAL METHOD	COMMENTS
Dilantin	UV[10]	Removal 50-80% (439 mJ/cm^2)
	UV/H_2O_2[10]	Removal >80% (372 mJ/cm^2 + 5 mg/l H_2O_2)
	PAC[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 23%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Endosulfan	GAC[1]	GAC is the BAT advocated by the EPA; for small water systems, PAC may be used.
Erythromycin	GAC[10]	Removal 8%
	UV[10]	Removal 50-80% (439 mJ/cm^2)
	RO[10]	Removal >80%
	RO1[1]	Removal ~100% (ND)
Estrone (E1)	Pre-ozone[1]	Potable water pilot plant – pre-ozonation removed 72% (spiked with 1,580 ng/l).
Estrone (E1)	Pre-ozone with coagulation-flocculation; and clarification[1]	Removal 78%.
	Above with filtration[1]	Removal 38% (reason for release through filtration unexplained).
	Above with post-ozonation[1]	Removal 89%.
	Above with GAC[1]	Removal 99.7%.
	Ozone[22]	Removal 94%.
	UV[1]	20% decomposition was observed.
	UV[19]	85% decomposition at 8 minutes irradiation.
	RO[2]	15-100 ng/l removed 95 to 99%.
	RO[4] (TFC-HR)	Removal 95.5% (43.2 ng/l reduced to <2 ng/l).
	UV[10]	Removal >80% (439 mJ/cm^2)
	MIEX[10]	Removal <20%
	RO[11]	Removal ~100% (ND)
Estrone, estradiol	NF[2]	100 ng/l removed 75-95%
	PAC[2]	15 ng/l; Removed 95% at 50 mg/l PAC.
	PAC[10]	Removal 50-80% (5 mg/l and 4-5 hour contact time).
	RO1[0]	Removal >80%
Estradiol, estrone, testosterone, progesterone	NF[2]	100 ng/l removed 100% by NF-90 and NF-270 membranes. Removals declined to 95% at run times greater than 400 minutes.
17-estradiol (E2)	Ozone[1]	Potable water pilot plant – pre-ozonation removed 63% (spiked with 1,580 ng/l).
	Above with coagulation-flocculation; clarification[1]	Removal 76%.
	Above with filtration[1]	Removal 34% (reason for release through filtration unexplained).
	Above with post-ozonation[1]	Removal 87%.
	Above with GAC[1]	Removal 99.4%.
	UV[19]	Removal 40% with 8 minutes irradiation.

MICROCONSTITUENT	REMOVAL METHOD	COMMENTS
17-estradiol (E2)	UV with catalyst[1]	No change observed for only UV irradiation; 90% reduction after 2 hours of UV and TiO^2 catalyst.
	Filtration (sand) [1]	Readily transported through sand with 85% in the effluent; some degradation occurred forming a metabolite.
	GAC[2]	1-100ng/l; removed 49-81% depending on feed concentration.
	RO4 (TFC-HR)	Removal 86.3% (21.9 ng/l reduced to <3 ng/l)
17-ethinylestradiol (EE2)	Ozone1	Potable water pilot plant – pre-ozonation removed 76% (spiked with 1,580 ng/l).
	Above with coagulation-flocculation; clarification[1]	Removal 80%.
	Above with filtration[1]	Removal 37% (reason for release through filtration unexplained).
	Above with post-ozonation[1]	Removal 88%.
	Above with GAC[1]	Removal 99.4%.
	UV[19]	Removal 45% (Irradiation for 8 minutes)
	UV with catalyst[1]	With UV and TiO^2 catalyst, photodegradation was faster than for E2; 90% decrease in original concentration for the two steroids occurred within 30 minutes.
	GAC[2]	15,000 ng/l removed 99.8%.
	RO[4] (TFC-HR)	Removal 97.6% (24.9 ng/l reduced to <0.6 ng/l).
	PAC[10]	Removal 50-80% (5 mg/l and 4-5 hour contact time).
Estradiol equivalent (EEQ)	RO[2]	45-68 ng/l removed 97 to 99%. Estrogenicity detected after RO (but not after GAC treatment).
	GAC[2]	Removed 98.7%.
Fluorene	PAC[10]	Removal >80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80% (ND)
Fluoxetine	UV[10]	Removal >80% (439 mJ/cm^2)
	PAC[10]	Removal >80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Galaxolide	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80%
Gemfibrozil	UV[10]	Removal 20-50% (439 mJ/cm^2)
	UV/H_2O_2[10]	Removal >80% (372 mJ/cm^2 + 5 mg/l H_2O_2)
	PAC[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	MIEX[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 8%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Hydrocodone	UV[10]	Removal >80% (439 mJ/cm^2)
	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal >56%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)

MICROCONSTITUENT	REMOVAL METHOD	COMMENTS
Ibuprofen	UV[10]	Removal 20-50% (439 mJ/cm^2)
	UV/H_2O_2[10]	Removal >80% (372 mJ/cm^2 + 5 mg/l H_2O_2)
	PAC[10]	Removal <20% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 16%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
ICMs (iomeprol, iopromide, iohexol, iopamidol)	Ozone followed by GAC[3]	Overall removal (coagulation-flocculation, ozonation, filtration, GAC) ~70%. Intermediate ozonation removed 30% and GAC an additional 50%. Over 100 ng/l of ionic diatrizoic acid and 40-100 ng/l of non-ionic ICM were found in treated water.
Iomeprol	UV[2]	Removal 33% for simulated solar UV light.
Iopromide	Ozone[9]	Removed by about 20 ng/l irrespective of dosage (from 2.1 to 8.7 mg O_3/l).
	Ozone-H_2O_2[13]	Removal 85% (0.025 mgH_2O_2/mgO_3)
	UV[10]	Removal 50-80% (439 mJ/cm^2)
	UV+H_2O_2[14]	Removal 99%
	PAC[10]	Removal <20% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 72%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
	PAC-UF[12]	Removal 86% (Initial conc. 1-2 µg/l)
Isoproturon	Hypochlorite[1]	Forms 4 chlorinated and/or hydroxylated ring substituted derivatives; reaction was faster than observed for chlorine dioxide.
	Chlorine dioxide[1]	Forms two hydroxylated aromatic ring substituted derivatives.
Lindane	UV with catalyst[1]	Mineralization by TiO^2-UV photocatalytic degradation.
	PAC10	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80% (ND)
Meprobamate	UV[10]	Removal <20% (439 mJ/cm^2)
	PAC[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 13%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Methoxychlor	GAC[1]	Wide range of water treatment processes tested and GAC determined to be the best removal meeting the maximum contaminant level (MCL) of 0.1 mg/1; GAC is the best available technology (BAT) advocated by the EPA.
Metolachlor	PAC[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80%
Musk ketone	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80%
Naproxen	UV[10]	Removal >80% (439 mJ/cm^2)
	PAC[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	MIEX[10]	Removal 50-80%.
	GAC[10]	Removal >6%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
NDMA	MBR[17]	Removal 80%

MICROCONSTITUENT	REMOVAL METHOD	COMMENTS
Nonylphenol	GAC[2]	2.8 µg/l removed >98%.
	PAC[4]	12,000 ng/l reduced to 450 ng/l at 10 mg/l PAC dose (96% removal); to 60 ng/l at 100 mg/l dose (99.5%); and non-detect at 1,000 mg/l dose (~100%).
Oxybenzone	UV[10]	Removal >80% (439 mJ/cm^2)
	PAC[10]	Removal >80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Pentoxifylline	UV[10]	Removal 20-50% (439 mJ/cm^2)
	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal >26%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Polyethoxylated nonylphenols	GAC[2]	Removed 47%.
Bromo polyethoxylated nonylphenols	GAC[2]	Removed 91%.
Paracetamol	Ozone[2]	5 mM/l removed 75-97% as TOC removal, depending on reaction time.
Paracetamol	Ozone – hydrogen peroxide	5 mM/l removed by 87% as TOC with O_3/H_2O_2 .
Pentachlorophenol (PCP)	GAC[1]	GAC fluidized bed reactor at EBCT 2.3 hours; Anaerobic degradation to chlorophenol (>99%) with second stage aerobic for complete removal of chlorophenol; adsorption decreases with increasing temperature (10 to 60°C) and decreasing pH (6-11). Desorption required for regeneration increases with increasing temperature.
Pentachlorophenol (PCP)	Reverse osmosis[1]	Ultra-low pressure RO membrane rejects PCP by over 90%.
	Ozone[2]	10 µg/l removed 100% after 10 minutes.
PCBs	GAC[1]	GAC is the BAT advocated by the EPA.
	UV[1]	Some highly chlorinated PCB congeners were resistant to short duration of UV, requiring 300 minutes of photolysis to be completely destroyed; dechlorination is the major photolytic mechanism.
Pharmaceuticals (various)	RO[2]	Initial concentrations for ketoprofen, diclofenac, gemfibrozil, naproxen, ibufrofen were 47, 200, 4600, 1800 and 2300 ng/l respectively. All non-detect after RO.
Pharmaceuticals (various)	RO[6]	TFC-SR2 (400 MWCO) rejected Naproxen 27%, Diclofenac 55%, Ibuprofen 34%, Mecoprop 32%, Ketoprofen 32%, Gemfibrozil 67%, Primidone <10%.
Pharmaceuticals (various)	RO[6]	TFC-HR (100 MWCO) rejected Naproxen 98%, Diclofenac 93%, Ibuprofen 97%, Mecoprop 99%, Ketoprofen 99%, Gemfibrozil 90%, Primidone 91%.
Pharmaceuticals (bezafibrate, carbamazepine, diclofenac, ethinylestradiol, sulfamethoxazole)	Ozone[2]	10-40 µg/l removed 95% for O_3 dose >0.2 mg/l, and <80% for O_3 dose <0.2 mg/l.
Pharmaceuticals (bezafibrate, clofibric acid, carbamazepine, diclofenac)	Ozone[2]	1-8 µg/l removed as follows: >97% for carbamazepine and diclofenac; <40% for clofibric acid; >50% for bezafibrate.
Pharmaceuticals, ICMs, musk fragrances	Ozone[5]	5 antibiotics (0.34-0.63 µg/l), 5 betablockers (0.18-1.7 µg/l), 4 antiphlogistics (0.10-1.3 µg/l), 2 lipid regulator metabolites (0.12-0.13 µg/l), antiepileptic drug carbamazepine (2.1 µg/l), estrone (0.015 µg/l), 2 musk fragrances (0.1-0.73 µg/l) were removed to non-detect by 10-15 mg/l ozone at 18 minute contact time. 4 ICMs (highest concentrations diatrizoate, 5.7 µg/l and iopromide, 5.2 µg/l) were only removed 14% diatrizoate and 80% iopromide. Advanced oxidation (O_3/H_2O_2)did not perform better than O_3 alone with the ICMs.

MICROCONSTITUENT	REMOVAL METHOD	COMMENTS
Phenacetine	RO[2]	Removal 71%
	NF[2]	Removal 19%
Phenanthrene	Ozone with catalyst[1]	Baked sand acted as a catalyst removing 90% of which 60% degraded in the first minute.
Polychlorinated dibenzo-p-dioxins (PCDDs)	Ozone then powder sorbent1	O_3 followed by filtration through powder sorbents removed majority of ditetra- and penta-CDDs; 30% to 60% of hexa- and hepta-CDDs remaining.
Polychlorinated dibenzofurans (PCDFs)	Filtration through granular sorbents[1]	Filtration through granular sorbents removed 90 to 95% of PCDDs and PCDFs.
	Coagulation[1]	In coagulation sludge, PCDDs present at higher concentrations than PCDFs; PCDD is congener dependent favoring larger congeners.
	GAC[1]	Similar pattern to coagulation sludge, majority of PCDDs and PCDFs having been removed during coagulation.
	UV[1]	No significant degradation observed.
	Ozone[1]	No significant degradation observed.
	UV/Ozone[1]	No significant degradation observed.
Primidone	RO[2]	Removal 84%
	NF[2]	Removal 87%
	RO[14]	Removal 90%
	RO[16]	Removal 100% (ND)
Progesterone	UV[10]	Removal 20-50% (439 mJ/cm^2)
	UV/H_2O_2[10]	Removal >80% (372 mJ/cm^2 + 5 mg/l H_2O_2)
	GAC[2]	Removed 77% of 8.98x10-5 M.
	PAC[10]	Removal >80% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Salicylic acid	RO[2]	Removal 92%
	NF[2]	Removal 92%
Sulfamethoxazole	UV[10]	Removal >80% (439 mJ/cm^2)
	PAC[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 84%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
TCAA	RO[2]	100 µg/l removed 96%
	NF[2]	100 µg/l removed 94%
TCEP	Ozone[9]	Minimal removal (in some cases concentrations increased with ozone).
	UV[10]	Removal <20% (439 mJ/cm^2)
	UV+H_2O_2[14]	Removal 35%
	PAC[10]	Removal 20-50% (5 mg/l dose and 4-5 hour contact).
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
	RO[18]	Removal 97%
Terbuthylazine	GAC[2]	Removed 86%.

MICROCONSTITUENT	REMOVAL METHOD	COMMENTS
Testosterone	UV[10]	Removal 20-50% (439 mJ/cm^2)
	UV/H_2O_2[10]	Removal >80% (372 mJ/cm^2 + 5 mg/l H_2O_2)
	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 74%
	RO[10]	Removal >80% (ND)
	RO[11]	Removal ~100% (ND)
Tetrabromobisphenol A	Filtration (sand)[1]	Extensive sorption with only 4.5% identified in the effluent.
Trichlorobenzenes	GAC[2]	Removed 96%.
Triclosan	UV[10]	Removal >80% (439 mJ/cm^2)
	PAC[10]	Removal >80% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal <1%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
Trimethoprim	UV[10]	Removal 20-50% (439 mJ/cm^2)
	UV/H_2O_2[10]	Removal >80% (372 mJ/cm^2 + 5 mg/l H_2O_2)
	PAC[10]	Removal 50-80% (5 mg/l dose and 4-5 hour contact).
	GAC[10]	Removal 64%
	RO[10]	Removal >80%
	RO[11]	Removal ~100% (ND)
	RO[14]	Removal 99%

UPDATE TO PROCESS ALTERNATIVES

Summary of Literature Review

Results of the literature review are considered positive and show that significant changes to the original treatment processes and technologies are not warranted, but some changes such as addition of advanced oxidation process instead of UV disinfection by itself is recommended.

A summary of the literature review is shown below on **Table 7,** below.

TABLE 7. SUMMARY OF LITERATURE REVIEW FOR TREATMENT PROCESSES

TREATMENT PROCESS	TECHNOLOGY	PROVEN PERFORMANCE AND EXPERIENCE AT FULL SCALE	PROMISING NEW TECHNOLOGY WITH ONLY LIMITED EXPERIENCE	CANDIDATE FOR PILOT SCALE TESTING	REMARKS
Nitrification	BAF	Yes	NA	Yes	BAF offers advantage of proven performance and smaller footprint for nitrification
Denitrification	Deep bed Filters	Yes	NA	Yes	Proven technology that should be considered for denitrification
Chemical Removal of Phosphorus	Ballasted Flocculation	Yes	NA	Yes	Performance and experience at full scale not as deep as desired and warrants consideration of another process to provide backup technology
Chemical Removal of Phosphorus	HFO	No	Yes	Yes	Promising technology with ability to filter and adsorb phosphorus and consistently produce low P levels.
Membrane Separation	Microfiltration (MF)	Yes	NA	Yes	Proven technology in similar applications and scale
	Ultrafiltration (UF)	Yes	NA	No	No justification for inclusion given that MF provides similar results and if greater removal efficiencies required, RO is more effective
	Reverse Osmosis (RO)	Yes	NA	Yes	Proven technology that effectively removes N and P as well as other constituents of concern. High power consumer.
Ion Exchange	Ion exchange	No	NA	No	Not proven in large scale applications. Estimated resin regeneration costs are higher than other processes.
Disinfection	UV	Yes	NA		Limited effectiveness in microconstituent destruction
	Advanced Oxidation Process		NA	Yes	Considered principal process for destruction of microconstituents
Adsorption	Granular Activated Carbon (GAC)	Yes	NA	No	Although it has BAT status and provides effective removal of microconstituents, consideration for use should be given only for removal of specific microconstituents not removed by AOP

Notes:
NA - Not Applicable

Figure 2 below depicts the summary of the process update for BBCWRPP in graphical form.

FIGURE 2. SUMMARY OF PROPOSED TREATMENT PROCESSES FOR PILOT SYSTEM TESTING FOR BBCWRPP

Treatment Process	Nitrification	Denitrification	Chemical Phosphorus Removal	Membrane Separation	Adsorption	Advanced Oxidation
Principal Constituent(s) Targeted	Ammonia Nitrogen	Nitrite and Nitrate Nitrogen	Phosphorus	TSS and colloids, Metals, Nitrogen and Phosphorus	Microconstituents	Microconstituents
Technologies Recommended for Pilot Studies	1. Biological Aerated Filter (B AF)	1. Deep Bed Filter	1. Ballasted Flocculation 2. Hydroferric oxide filtration(HFO)	1. Microfiltration (MF) 2. Reverse Osmosis is (RO)	1. Granular Activated Carbon (GAC)	1. Advanced Oxidation Process (AOP) with UV/ Peroxide 2. Advanced Oxidation Process (AOP) with Peroxide/Ozone

Mass Balance

A preliminary mass balance was developed for TN and TP concentrations with the intention of more clearly seeing the projected removal capabilities of the proposed process units and to be able to estimate the capability of various processes being considered to produce target water quality. This mass balance was developed using information obtained in the current literature review. The actual level of performance achieved at a pilot and a full scale level will largely depend on: 1.) site specific factors, 2.) reclaimed water characteristics of the influent treated, and 3.) actual technology performance during pilot and full scale operation.

Based on the results of the literature review and historical effluent data for the SDWWTP, the combination of biological aerated filters and denitrification filters originally recommended for the baseline process most likely would meet TN of less than 3.0 mg/L on an annual average basis (Table 8). It should be noted, however, that both these processes have limited capability for removal of DON in the wastewater. Hence, if the DON fraction in the effluent from the SDWWTP rises, the current processes may not be able to meet the selected effluent criteria. However, for now it appears this is not the case.

Achieving very low levels of TP poses the toughest challenge in developing treatment solutions for the pilot plant. For the mass balance, no specific process was selected for chemical phosphorus removal as there are several attractive technologies currently available for use. Based on the literature review, most of the chemical treatment technologies can produce phosphorus effluent values ranging from 0.1 to 0.05 mg/L TP. To achieve lower P concentrations than this range, additional treatment will be needed to complement chemical treatment. The final process chemical treatment process selection will be made based on reliability and operability of the various available technologies as determined by the pilot study results. A mass balance was conducted around the RO unit and the results are presented in **Table 9.**

UPDATE TO CPBODR PROCESS ALTERNATIVES

This section provides a summary of the updates to the original CPBODR that resulted from completion of the literature review and the process review. The update to the original CPBODR resulting from the work completed in this memorandum can be summarized as follows:

- Retain BAF for nitrification studies
- Retain Deep bed filters for denitrification studies
- Modify chemical phosphorus removal by adding one technology to pilot test in addition to ballasted flocculation process (BFP)
- Retain use of membrane processes consisting of MF and RO
- Eliminate consideration of Ion Exchange and activated carbon in pilot studies
- Modify disinfection by using both UV and peroxide and peroxide and ozone for AOP

TABLE 8. RESULTS OF PRELIMINARY MASS BALANCE FOR THE TREATMENT PROCESSES UNDER CONSIDERATION

PARAMETER (MG/L)	SDWWTP INFLUENT	BIOLOGICAL AERATED FILTER	DENITRIFICATION FILTERS	CHEMICAL P REMOVAL	UF OR MF MEMBRANE	ULTRAVIOLET DISINFECTION
NH_3-N	25	0.5	0.5	0.5	0.5	0.5
NOx-N	0.75	25.25	0.5	0.5	0.5	0.5
TN	27	27	2.2	1.85	1.85	1.85
TP	2.7	2.3	1.95	0.1	0.1 - 0.05	0.1 - 0.05

TABLE 9. MASS BALANCE FOR THE RO SYSTEM

PARAMETER (MG/L)	REVERSE OSMOSIS FEED	REVERSE OSMOSIS PERMEATE
NH_3-N	0.5	0.05
NOx-N	0.5	0.02
TN	1.85	0.2
TP	0.1 – 0.05	0.003 – 0.0015

Overall, the nitrification and denitrification systems currently recommended in the CPBODR are technologies that are proven in full scale applications and can provide adequate removal of nitrogen. Therefore, these technologies (BAF for nitrification followed by denitrification biological filters with methanol addition) should be implemented during the pilot demonstration project.

Based on the processes recommended, phosphorus would be removed by a series of processes starting with chemical removal of phosphorus followed by either UF or MF membrane filtration. Additionally, the SSP is currently equipped with RO to further reduce the total phosphorus limits to trace levels. A wastewater quality study to determine the species (fractionation) of phosphorus is recommended at the SDWWTP. Knowledge about the distribution of phosphorus species would facilitate the selection and comparison of different filtration concepts to achieve ultra low phosphorus levels.

Based on the literature review, there are no specific reasons to exclude the BFP (ballasted flocculation process) recommended originally in the CPBODR in pilot testing. BFP has shown the capability to reduce phosphorus to low levels, but operating experience is currently limited so it is considered prudent to test another chemical phosphorus removal process. Based on the literature review and pilot plant data at several facilities, the technology considered the best candidate to supplement BFP consists of HFO filtration. This technology uses a different mechanism (adsorption) for the removal of phosphorus and shows good potential in consistently reducing phosphorus to low levels. The available adsorptive capacity found in the HFO filtration system appears capable of reliably producing ultra low effluent phosphorus levels so HFO should be pilot tested. It may provide a very attractive alternative to BFP.

Currently, the recommended processes in the CPBODR also include membrane separation technologies consisting of UF and MF membrane filtration, and RO. Data presented in the literature at Sunrise, FL, Plantation, FL and Coeur D' Alene, ID shows that membrane filtration performs well for phosphorus removal. Therefore, there are no reasons to change use of MF. UF can provide effective removal of phosphorus, but at present does not provide an order of magnitude improvement over MF; especially in cases when RO is also included in the process train. There is no obvious order of magnitude improvement in P removal by using UF over MF, or is there any other clear advantage at present. RO, which is recommended for pilot testing, can provide any additional treatment required that MF may lack.

The SSP system currently includes RO, ion exchange, granular activated carbon and advanced oxidation processes. Based on information presented in Table 9, both the RO system and AOP should be included in the demonstration project to provide high levels of removal of the nutrient components and to provide disinfection and destruction of microconstituents. GAC and IX are not considered necessary for these pilot tests. GAC provides good removal of organics and can effectively remove microconstituents, but at this point, AOP is believed to provide equal or better performance. Based on conversation with ion exchange manufacturers, this process technology appears to be very costly and largely unproven at the expected scale so it is not considered viable for this application.

TREATMENT PROCESS RECOMMENDATIONS FOR PILOT STUDIES

Pilot plant process recommendations for the Biscayne Bay Coastal Wetlands Rehydration Pilot Project (BBCWRPP) are provided in this section. Recommendations for the treatment processes to be studied in a pilot demonstration project are an update to previous process recommendations and take into consideration the following:

- Updated results of literature review included in this technical memo.
- Targeted range of water quality requirements for discharge of reclaimed water into wetlands.
- Time limitations for pilot tests which limit the number of technologies that can be tested for any given process to two (2). Therefore, no more than two technologies are shown for any given process in the recommendations.

Quantitative water quality parameters that are needed for wetlands rehydration will be developed as part of forthcoming ecological studies. The approach used herein was to first develop a range of probable water quality parameters acceptable for the ecological system and develop a number treatment process that could fall within this range.

The treatment processes recommended in this section are conceived so as to provide a product of acceptable water quality for a wetlands environment, meeting broad limits of water quality.

The original recommended baseline process consisted of the following:

- Nitrification/denitrification
- Chemical phosphorus removal
- Microfiltration or ultrafiltration membranes
- Ultraviolet light (UV) disinfection

As a result of the process evaluation conducted, a number of treatment processes were identified as viable for pilot testing. These were discussed in the previous section and consist of the following:

- Nitrification
- Denitrification
- Chemical Phosphorus Removal
- Membrane Separation
- Reverse osmosis
- Disinfection

The CPBODR pilot treatment processes discussed previously were configured into three (3) treatment trains that are being recommended for BBCWRPP testing. The treatment trains have been recommended for testing to simulate different qualities of reclaimed water that may be suitable for a wetlands environment.

Also shown on the graphic for each recommended treatment train is information as follows:

- Principal constituents targeted
- Description of proposed technology to be tested
- Scale up factor for technology
- Projected water quality for selected constituents
- Site Footprint
- Energy Footprint

Baseline Treatment Train

The baseline treatment train (Train A) provides nitrogen and phosphorus removal and disinfection using AOP. Figure 3 shows the recommended configuration for the Baseline Treatment Train. This baseline train is expected to produce a product that can clearly meet the nitrogen and phosphorus levels required for FDEP Wetlands application (5, 5, 3, 1) and to also provide some destruction of microconstituents using AOP. A maximum of two technologies are to be tested for the chemical P removal process and the AOP as shown on the Baseline Train.

FIGURE 3. PROPOSED PROCESS TRAIN CONFIGURATION FOR BASELINE

Effluent from SDWWTP →	Nitrification →	Denitrification →	Chemical Phosphorus Removal →	Microfiltration →	Advanced Oxidation Process →	Caustic or Lime Addition →
Principal Constituent(s) Targeted	Ammonia Nitrogen	Nitrite and Nitrate Nitrogen	Phosphorus	TSS and colloids	Microconstituents	Corrosivity
Description of Proposed Technology	Biological Aerated Filters (BFA). Biological reactors with submerged media bed that supports an attached biological growth	Deep bed gravity sand filters that support biogrowth and act as both filters and biological reactors (denitrification) for conversion of nitrate and nitrite to nitrogen gas	Ballasted Flocculation (BF): Coagulation/flocculation tank and clarifier equipped with lamella tubes. In the coagulation tank the secondary effluent is mixed with fine stand (ballast) and polymer. Hydrous Ferric Oxide (HFO): proprietary (Blue PRO®) prereactor zone and moving-bed filter. Filtration system contains a bed of hydrous ferric oxide-coated media, in which ferric phophate is filtered	Membrane process that filters out constituents such as N and P but does not require as high operating pressures as RO	UV/Peroxide: Disinfection process that combines ultravoilet light such as microconstituents very effectively. Peroxoide Ozone: Newer disinfection process that combines peroxide and ozone to rapidly oxidize and destroy compounds such as microconstituents very effectively.	As result of treatment rendered upstream there may be need to stabilize product water with some form of caustic addition to reduce corrositivity; i.e. increase pH and Langlier Index
Scale up Factor	Good	Good	Good	Good	Good	Good
Operational Issues	Operational Labor Low; Highly Automated	Operational Labor Low to medium as result of methanol addition; Highly Automated	BF: Higher operational attention and monitoring required. HFO: Less attention for operations, more automated	Highly Automated	Highly Automated	Highly Automated
Projected Water Quality						
Nitrogen, ppm Ammonia	0.5	0.5	0.5	0.5	0.5	0.5
Nitrate	25.3	0.5	0.5	0.5	0.5	0.5
Total N	27.0	2.5	2.5	2	2	2
Phosphorus, ppm Total P	2.3	2.0	0.1	0.1-0.05	0.1-0.05	0.1-0.05
Microconstituent Removal	None	None	None	None	None	None
Site Footprint	Compact to Medium	Medium to Large	Compact	Compact	Compact	Compact
Energy Footprint	Low to Medium	Low	Low	Medium	Medium	Low
Other		Methanol Addition requires storage on site	Fractionation tests of Phosphorus species critical to effective removal evaluations during pilot phase			

▨ **Baseline Process**

□ **Sidestream Process**

Treatment Train B

Treatment Train B is shown below in Figure 4. This train provides a similar process as the Baseline treatment train, but replaces chemical phosphorus removal with RO. Figure 4 shows the recommended configuration for Treatment Train B. This train is expected to produce a product that can clearly meet much lower levels of nitrogen and phosphorus than the Baseline Train, and to also provide some destruction of microconstituents using AOP. A maximum of two technologies are to be tested only for the AOP technologies, as shown on the figure.

FIGURE 4. PROPOSED PROCESS TRAIN CONFIGURATION FOR TREATMENT TRAIN B

Effluent from SDWWTP →	Nitrification →	Denitrification →	Microfiltration →	Dual or Multiple Pass Reverse Osmosis →	Advanced Oxidation →	Caustic or Lime Addition →
Principal Constituent(s) Targeted	Ammonia Nitrogen	Nitrite and Nitrate Nitrogen	TSS and colloids	Residual Nitrogen, Phosphorus, and metals	Microconstituents	Corrosivity
Description of Proposed Technology	Biological Aerated Filters (BFA). Biological reactors with submerged media bed that supports an attached biological growth	Deep bed gravity sand filters that support biogrowth and act as both filters and biological reactors (denitrification) for conversion of nitrate and nitrite to nitrogen gas	MF is membrane process that filters out TSS and colloids and in some N and P. Does not require as high operating pressures as RO	Reverse osmosis (RO) is a pressure-driven and diffusion controlled membrane process that's filters out to molecular size	UV/Peroxide: Disinfection process that combines ultravoilet light such as microconstituents very effectively. Peroxoide Ozone: Newer disinfection process that combines peroxide and ozone to rapidly oxidize and destroy compounds such as microconstituents very effectively.	As result of treatment rendered upstream there may be need to stabilize product water with some form of caustic addition to reduce corrositivity; i.e. increase pH and Langlier Index
Scale up Factor	Good	Good	Good	Good	Good	Good
Operational Issues	Operational Labor Low; Highly Automated	Operational Labor Low; Highly Automated	Highly Automated	Highly Automated. High Power consumption	Highly Automated	Highly Automated
Projected Water Quality *Nitrogen, ppm* *Phosphorus, ppm*	Ammonia 0.5 Nitrate 25.3 Total N 27.0 Total P 2.3	Ammonia 0.5 Nitrate 0.5 Total N 2.5 Total P 1.95	Ammonia 0.5 Nitrate 0.5 Total N 2 Total P 1	Ammonia 0.05 Nitrate 0.075 Total N 0.2 Total P 0.5	Ammonia 0.5 Nitrate 0.075 Total N 0.2 Total P 0.5	Ammonia 0.5 Nitrate 0.075 Total N 0.2 Total P 0.5
Microconstituent Removal	None	None	Low	Low to Medium	High	None
Site Footprint	Compact to Medium	Large	Compact	Compact	Compact	Compact
Energy Footprint	Low to Medium	Low	Medium	High	Medium	Low
Other		Methanol Addition requires storage on site				

▨ **Baseline Process**

□ **Sidestream Process**

Treatment Train C

Treatment Train C is shown below in Figure 5. This train is very similar to Train A, as it retains chemical phosphorus removal. This train adds the additional step of RO. This train is expected to produce a product that can meet the levels of nitrogen and phosphorus required for Class III Outstanding Florida Waters (OFW), and to also provide destruction of microconstituents using AOP. A maximum of two technologies are to be tested for chemical P removal and for the AOP technologies, as shown on the figure.

Recommended Flow Rates for Pilot Systems

Flow rates required for the recommended pilot systems are a function of several variables. These include the characteristics of the treatment process as well as the physical limitations on scale up of the results, the minimum volume of product water (flows) required for biological testing studies, and limitations on the size and costs of the pilot system.

Table 10 shows proposed sizing of the recommended treatment processes/technologies and the basis for the values shown.

FIGURE 5. PROPOSED PROCESS TRAIN CONFIGURATION FOR TREATMENT TRAIN C

Effluent from SDWWTP →	**Nitrification** →	**Denitrification** →	**Chemical Phosforrus Removal** →	**Microfiltration** →	**Dual or Multiple Pass Reverse Osmosis** →	**Advanced Oxidation** →	**Caustic or Lime Addition** →
Constituent(s) Targeted	Ammonia Nitrogen	Nitrite and Nitrate Nitrogen	Phosphorus	TSS and colloids	Residual Nitrogen, Phosphorus, and metals	Microconstituents	Corrosivity
Description of Proposed Technology	Biological Aerated Filters (BFA). Biological reactors with submerged media bed that supports an attached biological growth	Deep bed gravity sand filters that support biogrowth and act as both filters and biological reactors (denitrification) for conversion of nitrate and nitrite to nitrogen gas	Ballasted Flocculation (BF): Coagulation/flocculation tank and clarifier equipped with lamella tubes. In the coagulation tank the secondary effluent is mixed with fine stand (ballast) and polymer. Hydrous Ferric Oxide (HFO): proprietary (Blue PRO ®) prereactor zone and moving-bed filter. Filtration system contains a bed of hydrous ferric oxide-coated media, in which ferric phophate is filtered	Membrane process that filters out constituents such as N and P but does not require as high operating pressures as RO	Reverse osmosis (RO) is a pressure-driven and diffusion controlled membrane process that's filters out to molecular size	UV/Peroxide: Disinfection process that combines ultravoilet light such as microconstituents very effectively. Peroxoide Ozone: Newer disinfection process that combines peroxide and ozone to rapidly oxidize and destroy compounds such as microconstituents very effectively.	As result of treatment rendered upstream there may be need to stabilize product water with some form of caustic addition to reduce corrositivity; i.e. increase pH and Langlier Index
Scale up Factor	Good	Good	Good	Good	Good	Poor	Good
Operational Issues	Operational Labor Low; Highly Automated	Operational Labor Low to medium as result of methanol addition; Highly Automated	BF: Higher operational attention and monitoring required. HFO: Less attention for operations, more automated	Highly Automated	Highly Automated. High Power consumption	Highly Automated	Highly Automated
Projected Water Quality *Nitrogen, ppm* *Phosphorus, ppm*	Ammonia 0.5 Nitrate 25.3 Total N 27.0 Total P 2.3	Ammonia 0.5 Nitrate 0.5 Total N 2.5 Total P 2.0	Ammonia 0.5 Nitrate 0.5 Total N 2.5 Total P 0.1	Ammonia 0.5 Nitrate 0.5 Total N 2 Total P 0.1- 0.05	Ammonia 0.05 Nitrate 0.075 Total N 0.2 Total P 0.005- 0.0025	Ammonia 0.5 Nitrate 0.075 Total N 0.2 Total P 0.005- 0.0025	Ammonia 0.5 Nitrate 0.075 Total N 0.2 Total P 0.005- 0.0025
Microconstituent Removal	None	None	None	None	Low to Medium	High	None
Site Footprint	Compact to Medium	Medium to Large	Compact	Compact	Compact	Compact	Compact
Energy Footprint	Low to Medium	Low	Low	Medium	High	Medium	Low
Other		Methanol Addition requires storage on site	Fractionation tests of Phosphorus species critical to effective removal evaluations during pilot phase				

🟫 **Baseline Process**

⬜ **Sidestream Process**

TABLE 10. PROPOSED FLOWS FOR RECOMMENDED PILOT SYSTEMS

TREATMENT TRAIN DESIGNATION	TREATMENT PROCESSES/ TECHNOLOGY	DESIGN FLOW, GPM[1]	BASIS OF FLOW
Treatment Train A- Baseline	BAF, Deep Bed Filters, BFP	200	Flow governed by minimum size for reliable BFP scale up
	HFO, MF, AOP	80	Minimum flow/volume required for biological tests
Treatment Train B	BAF, Deep Bed Filters	200	
	MF, RO, AOP	80	Minimum flow/volume required for biological tests
Treatment Train C	BAF, Deep Bed Filters, BFP	200	Flow governed by minimum size for reliable BFP scale up
	HFO, MF, RO, AOP	80	Minimum flow/volume required for biological tests

[1] Final design flow to be determined in the Preliminary Engineering Report.

Emerging Technologies

Recommendations for treatment processes and technologies have been provided as a result of an evaluation of the original processes recommended. It is very likely that during the period when pilot testing takes place, that there will be emerging technologies that may merit consideration. These will be considered on an individual basis, but it must be recognized that decisions have to be made to move forward with the project and not affect the schedule. As such, there comes a time where consideration of emerging technologies will no longer be possible if the schedule for the project is to be met. Special conditions will of course merit extraordinary considerations.

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