United States Army Corps of Engineers

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November 9, 2004

Task 5-Final Report South Dade Advanced Wastewater Treatment Alternatives

Contents

Acronyms

An, Ax, Ox –Anaerobic, Anoxic, and Aerobic Zones
AOP - Advanced Oxidation Process, including Ozone, Ozone/Hydrogen Peroxide
AS - Activated Sludge
BAC - Biologically Activated Carbon
BNR - Biological Nutrient Removal
Cl - Chlorination
CIP – Clean In Place
EHRC – Enhanced High Rate Clarification
G – Mean Gradient Velocity
GAC - Granular Activated Carbon
HPO – High Purity Oxigen
IEx - Ion Exchange
MC - Molecular Charge
MF - Microfiltration
MW - Molecular Weight
PAO – Phosphorus Accumulating Organisms
Q/IR – Internal Recycle
RO - Reverse Osmosis
SWD – Side Water Depth
UF - Ultrafiltration
UV/Hydrogen Peroxide
VFD – Variable Frequency Drive

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Section 1
Introduction

1.1 Background

Miami Dade Water and Sewer Department (MDWASD) currently operates the South District wastewater treatment plant (WWTP). The South District WWTP has a design capacity of 112.5 million gallons per day (MGD) on an annual average daily flow (AADF) basis. The flow is anticipated to reach 131 MGD by the year 2020. This facility provides secondary treatment disposal to deep injection wells.

The South District WWTP is located in southeastern Miami-Dade County close to the shores of Biscayne Bay. Like the entire County, the area surrounding the South District WWTP is rapidly developing with residential and commercial properties. Development over time in Miami-Dade County has reduced the flow of freshwater which enters Biscayne Bay. This reduced flow of fresh water is increasing the salinity of the near shore brackish waters of Biscayne Bay. Since this area is an important habitat for wildlife it has become an area of critical biological importance on a global scale.

1.2 Purpose

On April 23, 2004, CDM was authorized by the Army Corps of Engineers (Corps) to investigate and evaluate the available technologies required to treat wastewater from the South District Wastewater Treatment Facility (130 MGD) and use it for environmental restoration, as part of the Comprehensive Everglades Restoration Plan (CERP). A cost effective treatment technology is being sought that will provide the desired water quality for discharge to freshwater wetlands tributary to Biscayne Bay. In accordance with the scope of work (SOW) dated March 10, 2004, CDM is assisting the Corps with conceptual evaluations, cost estimates and recommendations for various alternatives to provide advanced wastewater treatment at the South District WWTP. Results will support the CERP Wastewater Reuse Pilot Project where the best treatment alternative identified under this contract will be evaluated at pilot scale (1.0 MGD) to further investigate the feasibility of replacing the freshwater flows that once went into wetlands and Biscayne Bay with highly treated wastewater effluent.

1.3 Report Organization

On May 28, 2004, CDM presented to the Corps a survey (Task 2) of existing advanced wastewater treatment systems at municipalities at three regional levels. The first level included those facilities in the State of Florida, the second level included facilities throughout the United States, while the final level identified international facilities. All of the surveyed facilities employed advanced wastewater treatment technologies and have successful track records in full scale installations of 10 MGD or greater. The search resulted in a list of nine (9) representative treatment facilities identified in this survey and further described in Section 2 of this report.

Two (2) potential treatment alternatives were created using the unit processes discussed in Task 2 for each of three (3) water quality categories for the treated effluent. These categories; Reuse, Class III, and OFW will be described in Section 3. CDM created and evaluated six (6) alternative treatment systems and developed preliminary pilot scale (1 MGD) process layouts for each of the alternatives. Information developed for each pilot scale alternative includes design criteria, process and instrumentation diagrams, capital and operating costs, and a solids management plan. In order to develop these preliminary designs, CDM used the data from the Task 2 survey and data from prior work. CDM contacted different equipment manufactures to get equipment proposals and pricing. One alternative was selected from the six to develop full scale (130 mgd) costs. The results of this report were summarized by the project delivery team (PDT) and summarized in the final section.

This Task 5 Report is a requirement of the SOW, and consists of the following sections:

- Section 1- Introduction
- Section 2- Literature Search/Survey of Treatment Facilities
- Section 3 - Treatment Considerations
- Section 4 - Detailed Description of Alternatives and Full Scale Facility
- Section 5 – Conclusions and Recommendations

In addition to the 5 Sections this report includes the following Appendices:

- Appendix A – PDT kick-off meeting minutes
- Appendix B – Pharmaceuticals and Personal Care Products in the Water Cycle

Section 2
Literature Search/Survey of Wastewater Treatment Facilities

2.1 Introduction

This Section of the report is a specific requirement of Task 2 - Literature Search of Wastewater Treatment Facilities. The Army Corps of Engineers contracted CDM to perform a survey of advanced wastewater treatment facilities and to select 6-9 facilities that meet high effluent quality standards, having successful track records of full-scale installations of 10 MGD and greater, and can serve as models for the full-scale project. As discussed in the project kick-off meeting (Task 1) the representative facilities would be grouped into three general water quality criteria.

1. Treatment facilities that meet State of Florida Reuse Standards (Chapter 62-610, Florida Administrative Code (F.A.C.)): Meeting the requirements for public access irrigation with TSS of 5.0 mg/L or less, and high level disinfection.

2. Treatment facilities that meet State of Florida Wetlands Application Standards (Chapter 62-611, F.A.C.): meet criteria for discharge to receiving wetlands with effluent quality equal to or less than, TSS 5.0 mg/L, BOD 5.0 mg/L, TN 3.0 mg/L, TP 1.0 mg/L

3. Treatment facilities with the potential to meet State of Florida Class III Standards (Chapter 62-302, F.A.C.) / Outstanding Florida Water (OFW)for Biscayne Bay: No degradation of ambient water quality. Based on the discussions at the kick off meeting, target effluent concentrations for the wastewater reuse pilot project for Biscayne Bay are based on Nearshore/Alongshore baseline water quality conditions in the bay and the recommended BBPI target concentrations, as shown in Table 2.1

Table 2-1 comprises a list of treatment goals as stated in the Treatment Objectives Final Draft Report (9/25/03) prepared by the US Army Corps of Engineers and the South Florida Water Management District (SFWMD) and a listing of technologies that can potentially meet such goals (some proven, some speculative).

TABLE 2-1

RECOMMENDED BASELINE WATER QUALITY CONDITIONS AND TREATMENT TECHNOLOGIES RECOMMENDED FOR ESTABLISHING EFFLUENT QUALITY FOR THE SOUTH MIAMI-DADE WASTEWATER REUSE PILOT PROJECT.

Parameter	Range	Statute/Rule targets	Antidegradation targets	Treatment Technology
BOD-5		5 mg/L		MF, RO, AOP, GAC
TOC		3 mg/L		MF, RO, AOP, GAC
COD		10 mg/L		MF, RO, AOP, GAC
TSS		5 mg/L		MF, RO, media filtration with chemical addition and clarification
Total Residual Chlorine		0.01 mg/L		No chlorine, dechlorination
Total Ammonia- N			0.02 –0.05 mg/L(depends on method of collection and analysis)	AS nitrification, RO
Nitrite/Nitrate-N			0.01 mg/L	AS nit/denit single stage down to ~0.5 to 1.0 mg/L AS nit followed by deep bed denit filters down to <0.3 mg/L, RO, reductive membrane
TKN			0.22 mg/L	AS nitrification down to ~1 to 1.5 mg/L, RO
Total Nitrogen		3	0.27 mg/L	See above
Ortho-P			0.002 mg/L	AS - BNR, down to 0.05 to 0.1 mg/L, RO
Total P		1	0.005 mg/L	Chemical/ Physical removal down to 0.1 mg/L, RO
Fecal coliforms Total coliform			<10 cfu/100 mL <10 CFU/100 ml	MF, RO, AOP, UV
Dissolved Oxygen	5.0-7.3			

Parameter	Range	Statute/Rule targets	Antidegradation targets	Treatment Technology
Turbidity			0.5 NTU	Media filtration with chemical addition, MF, UF, RO
Salinity			Shall not change salinity in test site by more than 5 ppt	
pH	6.5-7.5 (*)			
Heavy Metals			See Table 5.2	MF, UF, RO
EPOC			Lowest possible levels(**)	MF and UF (particle associated only), RO, AOPs, BAC, reductive membranes, Ion Exchange
Cryptosporidium and Giardia			Lowest possible levels(**)	Cl, MF, UF, RO, UV

(*) Appropriate limits for pH in the estuarine zone will require further evaluation.

(**) Even though, currently there are no established numerical criteria or antidegradation targets for these parameters, available information shall be gathered on removal efficiency of various treatment technologies and detectable levels after advanced treatment for these parameters for comparative assessment. In practical terms, the objective would be to identify the technology that reduces such contaminants to the lowest level.

2.2 Task 2 – Literature Search of Wastewater Treatment Facilities

In accordance with Task 2 of the scope of work, CDM conducted a survey of existing advanced wastewater treatment systems at municipalities at three levels. The first survey focused was locally in the State of Florida, the second level expanded the search through the rest of the United States, and finally internationally. All of the surveyed facilities employ innovative treatment technologies and have successful track records in employing advanced wastewater treatment to meet stringent water quality goals in full scale installations of 10 MGD or greater. The following resources were searched as part of the survey: HATS EEPS Report - Hong Kong Environmental Division, Membrane Treatment of Secondary Effluent for Subsequent Use –WERF (Draft), European Plants Survey-internal memo by CDM, FDEP Reuse Website, and CDM internal records. From this list 9 representative treatment facilities were selected summarized in **Table 2-2** and further described herein (4 treatment systems in Florida, 3 treatment systems in the USA, and 2 treatment systems internationally).

Table 2-2

ADVANCED WASTEWATER TREATMENT REPRESENTATIVE FACILITIES

Plant Name	Location	Plant Capacity (MGD)	Treatment Process (Effluent Permit Limits TSS, BOD, TN, TP mg/L)	Effluent Disposal or Reuse Applications	Effluent Criteria
Orange County EWRF	Florida	19	Modified Bardenpho™ (5,5,3,1)	Infiltration basins, cooling towers, and natural wetlands.	Reuse-wetland application
City of Daytona Beach Bethune Point	Florida	13	A²/O™ with Denitrification Filters, UV (5,5,3,1)	Halifax River and Reuse	Reuse-wetland application
City of West Palm Beach	Florida	10	Denitrification filters and ballasted flocculation for P removal (5,5,2,0.05)	Natural wetlands and groundwater recharge(indirect potable reuse)	Reuse-wetland application
City of Sarasota	Florida	13	Modified Bardenpho™ (5,5,3,1.25)	Surface water and agricultural reuse	Reuse-land application
Scottsdale Water Campus	Arizona	10	Activated sludge, sand filters, MF, RO, Soil Filtration.	Non-potable reuse, aquifer recharge	Reuse
R.M. Clayton Water Reclamation Center	Georgia	122	Biological Nutrient Removal (10, 5, 1.5-6.0 NH_3 - seasonal, 0.2 TP)	River outfall-Chattahoochee River	Reuse
West Basin Water Recycling Plant	California	7.5 (1)	MF, RO, UV	Drinking water aquifer recharge	Indirect Potable Reuse
Kranji WRF	Singapore	10.6	MF, RO, UV (Primary and Secondary DW Stds. – EPA, WHO DW Guidelines)	Indirect potable reuse	Indirect Potable Reuse
VEAS	Norway	84.5	CEPT, BAF (10, 10, 10, 1)	Ocean discharge	Reuse

(1) The West Basin WRP also includes a 30 MGD reuse facility and 4.32 MGD boiler feed facility.

Facility Descriptions

The following section describes the facilities in greater depth. Key features that may be applicable to the design of processes at the South Dade facility are listed following each facility write-up.

Major Reuse Facilities in Florida

- Orange County EWRF

The Orange County Eastern Water Reclamation Facility is located in East Orange County, Florida, one of the fastest growing areas of the country. The plant is permitted for 19.0 MGD annual average daily flow (AADF) of total treatment capacity, but its current flows average 13 MGD. The treatment process train includes: grit removal, a modified five–stage Bardenpho, traveling bridge filters, chlorination; and dechlorination prior to entering the wetlands. Air from the headworks is treated with three biofilters for odor. Waste sludge discharged from the clarifiers is dewatered in belt filter presses and hauled to a landfill.

The Orange County EWRF initially had an experimental exemption in their permit for discharge to a man-made wetland. As this was prior to the adoption of the Wastewater to Wetlands Rule 62-611, F.A.C., they had an 8-year initial operational period where the permit conditions required extensive monitoring. The effluent water quality meets State of Florida (1.6 mg/L TSS, 1.6 mg/L BOD, 2.36 mg/L TN, and 0.25 mg/L TP) reuse standards for receiving wetlands applications. The reclaimed water from this AWT facility feeds natural /artificial wetlands (6.2 MGD) before reaching a small creek that is connected to the Econlockhatchee River designated as an Outstanding Florida Water; reduces demand on potable groundwater by providing sufficient reclaimed water for non-potable uses including golf courses and green areas; supplies cooling water for the Orlando's Utilities Stanton Energy Facility, and recharges the aquifer with infiltration basins (2.5 MGD).

Key Features:	Biological Nutrient Removal, Discharge to Wetlands/OFW

- **City of Daytona Beach Bethune Point WWTF**

The City of Daytona Beach Bethune Point Wastewater Treatment Facility in Daytona Beach is currently rated at 13 MGD AADF. The AWT process was designed (1993) to meet State of Florida (5.0 mg/L TSS, 5.0 mg/L BOD, 3.0 mg/L TN, and 1.0 mg/L TP) reuse standards for receiving wetlands applications. The treatment process was designed around an Air Products A_2/O patented process with polishing of the nitrates and nitrites to 3.0 mg/L TN via a deep-bed denitrificiation filter. Methanol is used as the carbon source for the denitrification filter. Phosphorous removal is via alum addition in the filters. The effluent discharges to the Halifax River and Reuse. In 1999, the plant was converted from chlorination/dechlorination to an ultraviolet (UV) disinfection system ensuring the plants ability to provide citywide public access reuse. The new UV system is the largest in the State of Florida.

Key Features:	Denitrification Filters, Chemical P removal, UV Disinfection

- **City of West Palm Beach ECRWWTP**

The West Palm Beach East Central Region Wastewater Treatment Facility is located in West Palm Beach, Florida. The treatment process includes denitrification filters for removal of nitrate and solids, ballasted flocculation for phosphorus and color removal, polishing filters, and UV high-level disinfection. The plant is currently designed for a 6.0 MGD AADF and 10.0 MGD peak flow. The permitted limits for this AWT facility exceed the State of Florida's (5.0 mg/L TSS, 5.0 mg/L BOD, 2.0 mg/L TN, and 0.05 mg/L TP) standards for receiving wetlands. The plant effluent is permitted to go to natural wetlands with reject water to a deep injection well; the plant is currently under construction but has experienced delays. It is anticipated to be on line in the summer of 2004.

Key Features:	Dentrification Filters, Ballasted Floccutation, UV, Discharge to Wetlands, Reject to Deep Wells.

- **City of Sarasota WWTF**

The City of Sarasota Wastewater Treatment Facility is located in Sarasota, Florida, and is designed for 12.2 MGD AADF and 13 MGD Maximum Monthly ADF. The treatment process was designed around modified five-stage Bardenpho biological nutrient removal process with alum addition for effluent phosphorus polishing. This facility discharges primarily to the Bobby Jones golf course and a large agricultural site. Treatment plant modifications were necessary to meet stringent water quality requirements. Backup surface water discharge to a tributary to Sarasota Bay, is allowed under the Grizzle Figg Statue, which has additional provisions for discharges into marine surface waters and OFWs, including a demonstration that the discharge will result in minimal negative impact. This statute was designed to protect the sensitive estuarine and coastal systems in the Southwest District. Current effluent records indicate the process effluent averages 1.02 mg/L TN and 0.06 TP.

Key Features:	Biological Nutrient Removal, Discharge to OFW,

Major Reuse Facilities in the United States

- **Scottsdale Water Campus, Arizona**

The Scottsdale Water Campus facility is located approximately 30 miles east of Phoenix, Arizona. The reclamation plant is rated at 12 MGD, and the advanced water treatment portion can process 10 MGD. Here, wastewater is reclaimed for use in parks, golf courses, and ground water recharge. The AWT process at the Water Campus includes Microfiltration (0.2 Microns), reverse osmosis, and discharge of water by injection into the local aquifer. The concentrate from the RO system is discharged to the regional WWTP. The RO permeate is blended with surface water that has been treated by MF or has been stabilized with lime prior to recharge into the aquifer. From discussions with operations staff the tertiary membrane processes provide high removal of hardness (92%), TDS (97%), BOD (80%), NH_4^+-N (54%), TOC (92%), nitrate-N (88%), silica (95%), and total nitrogen (90%).

Key Features:	MF, RO, discharge of RO concentrate to WWTP, permeate stabilization

- **City of Atlanta Clayton WRC, Georgia**

The R.M. Clayton Water Reclamation Center is an activated sludge plant located in northwest Atlanta and it is one of the largest wastewater treatment facility in the southeast United States. The treatment process includes influent screening, biological nutrient removal (N and P) deep bed filters (with ferric chloride for P polishing), and the largest in-channel UV system in the United States, sophisticated odor containment and control facility. The reclaimed water leaving the system meets the Florida Reuse criteria of TSS < 5.0 mg/L. The effluent discharges to the Chattahooche River. The plant has met its effluent discharge criteria (BOD_5 <10 mgh TSS <5 mg/L, NH_3 <1.5-6.0 (seasonal), TP <0.2) since coming on-line in the Fall 2001.

Key Features:	Large Facility, Biological Nutrient Removal, Chemical P Removal, Deep Bed Filters, UV, Discharge to River

- **West Basin Water Recycling Plant, California**

The West Basin Water Recycling Plant is located in El Segundo, California. This AWT plant produces high quality water using secondary effluent from the City of Los Angeles Hyperion treatment plant (500 mgd ADF, High Purity Oxygen (HPO)). There are three different effluent flow streams: 1) the Title 22 treatment system has 30 MGD capacity (filtered secondary effluent, NTU<2 and high level disinfection) used for irrigation and non-potable reuse, 2) the Chevron Boiler feed water with 4.32 MGD capacity (microfiltration, single pass RO and some of the RO water being further treated by second pass RO, and 3) the Barrier Water treatment system (currently upgrading/expanding) with 7.5 MGD capacity including microfiltration, RO, UV with peroxide for NDMA destruction and post-disinfection alkalinity adjustment. The Barrier product water is pumped into injection wells to protect against seawater intrusion. Note that the barrier water is injected into a drinking water aquifer and is therefore permitted by the State of California's DHS (drinking water permit). Based on discussions with operations staff the plant reduces total nitrogen to less than 2 mg/L primarily in the form of $NH_{3.}$ This is due to the soluble unnitrified effluent from the Hyperion WWTP (NH_3>35mg/L). Phosphorus is undetectable in the effluent, however, the detection limit of the testing was not known by staff.

Key Features:	Treatment of Secondary Effluent (HPO), MF, RO, UV w/ peroxide for NDMA Control, Disposal of Concentrate by Ocean Outfall, permeate stabilization

International Reuse Facilities

- **Kranji WWRF, Singapore**

Singapore has a comprehensive wastewater infrastructure. Three new AWT plants have recently been constructed including the Kranji Wastewater Reclamation Facility (10.6 MGD). Singapore's goal is to supply 15 percent of the countries overall water demands with reclaimed water. The full-scale Kranji plant is currently operating, but effluent water quality data was not accessible at the time of this report. The process includes: bar screens, nitrifying activated sludge with partial denitrification, secondary clarification, microfiltration (MF), reverse osmosis (RO) and ultraviolet light (UV).Results from a 2.64 MGD (Bedok, Singapore) demonstration plant that used the same process showed effluent quality parameters of 0.6 mg/L TSS, 0.19 mg/L BOD, 3.28 mg/L TN, and 0.04 mg/L TP. The demonstration plant was built in 2000 to demonstrate that a tertiary process considering of MF, RO, and UV disinfection could produce a water quality that meets all the criteria of the U.S. EPA primary and secondary drinking water standards and the WHO guidelines for drinking water.

Key Features:	Treatment of Secondary Effluent, MF, RO, UV

- **VEAS Plant, Norway**

  The VEAS plant is located in Slemmestad near Oslo, Norway. The plant is located inside caverns constructed underground into hard rock. One of the unique features of this plant its compact footprint (<3.5 acres). This AWT satisfies stringent regulations imposed by the EU Urban Wastewater Treatment Directive (10, 10, 10, 1) treating an average annual flow of 84.5 MGD. The effluent water quality meets Florida Reuse criteria of TSS < 5.0 mg/L and data shows the plant performance of of 3.4 mg/L TSS, 10 mg/L BOD, 5.9 mg/L TN, and 0.11 mg/L TP. The process includes Chemically Enhanced Primary Treatment (CEPT), Biological Aerated Filters (BAF) - for Nitrification/Denitrification, and disposal through an ocean outfall.

Key Features:	Compact Footprint, CEPT, BAF (Nitrification/Denitrification)

2.3 Summary

Based on CDM's review of the various treatment facilities and discussions with plant process engineers and operations staff, the following conclusions will be carried forward in selecting treatment technologies for the pilot project:

- Designing a process to meet Florida's Reuse Standards for public access irrigation is possible with several large examples available.

- There are several options available to meet Florida's reuse standards for wetlands application.

- Currently, there are a diverse number of drinking and wastewater treatment technologies that when used in combination have the potential for meeting the non-degradation requirements of the OFW and antidegradation criteria established for Biscayne Bay as indicated in Table 2-1.

- Biological nutrient removal prior to membrane treatment should be considered to improve the membrane performance.

- If RO is utilized, concentrate disposal (Deep Well, Ocean Outfall, WWTP) will need to be determined for the South Miami-Dade Facility.

- Stabilization of the permeate from a RO process may be necessary to prevent effluent corrosivity.

Components of the plants presented in this Section will be carried forward into the treatment considerations for the proposed pilot plant for South Miami-Dade WWTP and will be combined to select the best components of these facilities for full scale implementation.

Section 3
Treatment Consideration for the South Dade WWTP

3.1 Current Wastewater Treatment Facilities

Figure 3-1 shows the South district WWTP location and a process flow diagram is provided in **Figure 3-2**. Areas under consideration as locations for the pilot plant and potential discharge points for the Biscayne Bay Coastal Wetlands (BBCW) are also shown on Figure 3-1. All wastewater treated at the WWTP is currently treated under Florida Department of Environmental protection (FDEP) Permit Number FLA042137 Average water quality for the South District effluent from 1999 to 2004 is presented in **Table 3.1**.

TABLE 3-1

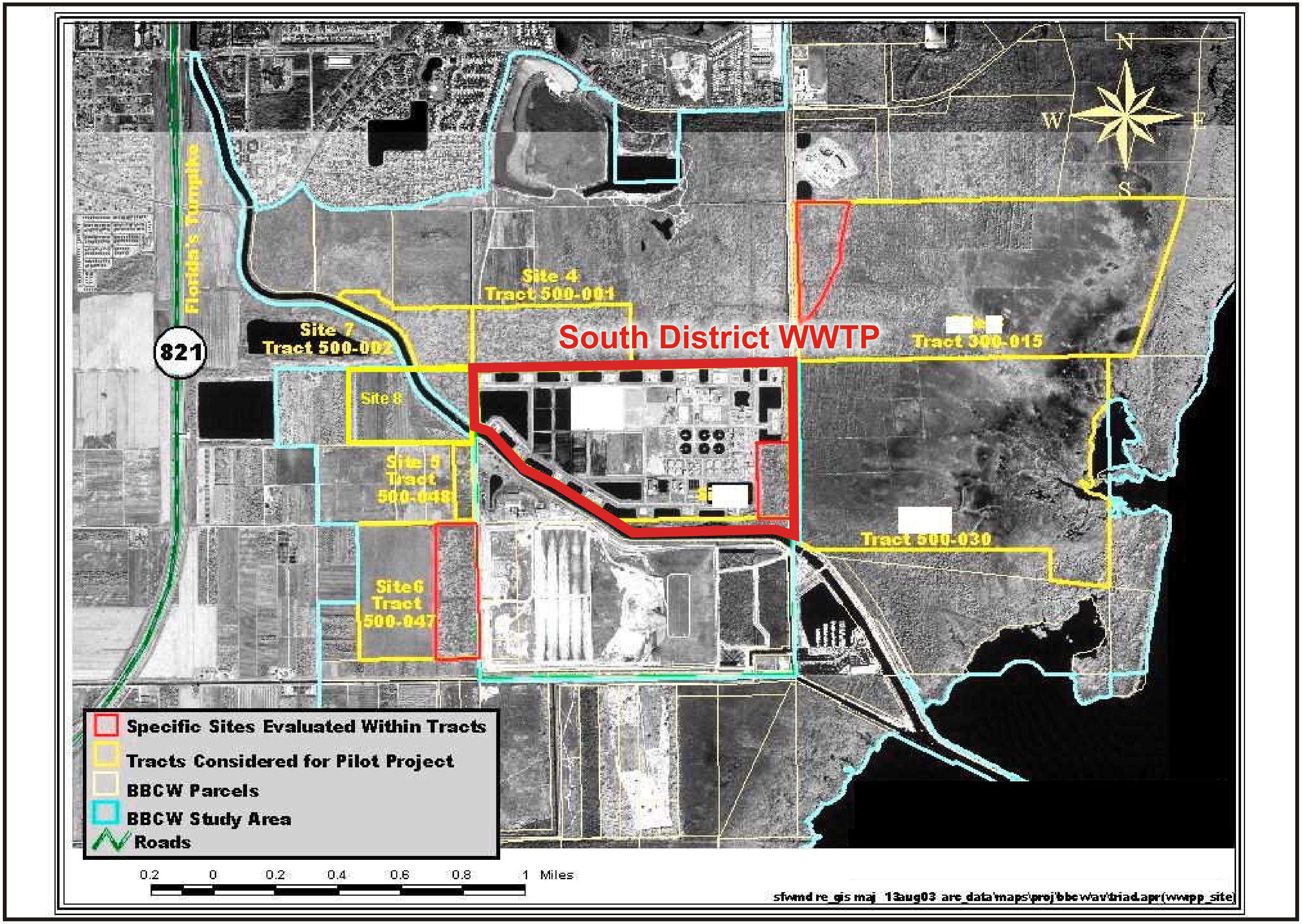
SDWWTP AVERAGE EFFLUENT WATER QUALITY (1999-2004)

Parameter	**Secondary Effluent**
TDS, mg/ L	379
Sulfate, mg/ L	33
Chlorides, mg/L	71
TKN, mg/ L	17.55
NH3, mg/ L	13.18
Fecal Coliform, # Col/100ml	55,385
Conductivity, Micromho/cm	719
Temp., ^{o}C	
High	31
Low	22
pH	6.6
TP, mg/ L	1.09
TOC mg/ L	11.47
NO_3 mg/ L	0.87
TSS mg/ L	9.06

3.2 Treatment Levels

The facilities surveyed in Task 2 were selected for their ability to meet the three general water quality categories described below:

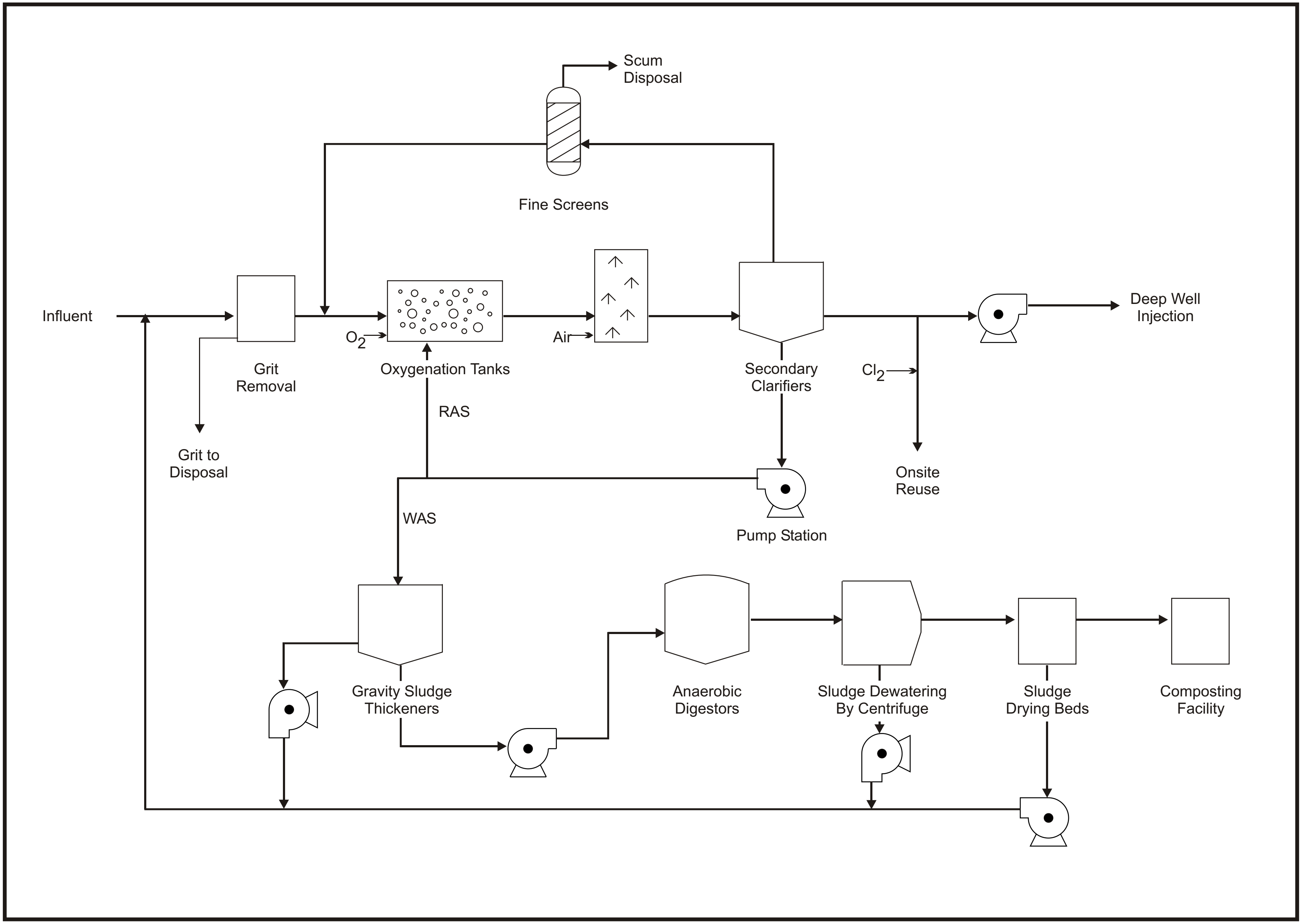
- Reuse Water Quality – Water quality must meet the State of Florida standards for reuse of reclaimed water and land application (Chapter 62-610, FAC). Public access



CDM

South District WWTP and Reuse Pilot Project Site

Figure 3-1



CDM

South District WWTP
Process Flow Diagram
Figure 3-2

irrigation requires no more than 5.0 mg/L total suspended solids (TSS) and high level disinfection.

- Wetlands Application Standards – Water that meets State of Florida wetlands application rule standards (Chapter 62-611, FAC). Criteria for discharge to receiving wetlands include no more than 5.0 mg/L of TSS, 5.0 mg/L of BOD_5, 3.0 mg/L of total nitrogen (TN), and 1.0 mg/L of total phosphorous (TP).

- Class III / OFW Water Quality – Water quality must be sufficient to prevent degradation of the waters of Biscayne Bay, a Outstanding Florida Water (OFW) body. (refer to Table 2-1)

The project is anticipated to utilize a wetlands disposal system to receive the treated effluent. The receiving wetlands however will be tributary to Biscayne Bay. The wetlands are not anticipated to provide any treatment to the effluent as it flows to the Bay. For this reason, the effluent discharged to the wetlands will need to meet the more stringent quality of the OFW criteria described in the preceding section. The Reuse and wetlands application alternatives however will also be considered to assess the incremental costs of meeting increased treatment levels.

3.2.1 State of Florida Reuse Standards

Part III of Chapter 62-610, FAC contains the rules governing reclaimed water for areas of public access and irrigation. This section regulates water quality for irrigation of areas such as golf courses, parks, landscape, and edible crops. Under these standards, reclaimed water receives high-level disinfection and meets, at a minimum, secondary treatment. Moreover, the reclaimed water shall not contain more than 5.0 mg/L of total suspended solids before the application of a disinfectant. NPDES permits issued by the FDEP typically include a requirement for continuous on-line monitoring of effluent turbidity to demonstrate the safety of the reclaimed water. Compliance with the TSS limit is monitored using grab samples. Continuous on-line monitoring is used in conjunction with an approved operating protocol for operational control and to ensure that only acceptable quality reclaimed water goes to the reuse system.

Two treatment alternatives were selected to meet this criteria. Both alternatives provide tertiary filtration of the effluent from the South District WWTP followed by disinfection with ultraviolet (UV) light. One alternative uses deep, mono-medium sand fitlers while the other uses cloth media filters.

3.2.2 State of Florida Wetlands Application (Receiving Wetlands Discharge) Standards

Discharge to wetlands systems is governed by Chapter 62-611, FAC. Treatment criteria prior to discharge are dependent on the type of wetland. Wetlands are categorized as herbaceouse or woody, hydrologically altred or unaltered, treatment or receiving, and natural or man made. Based on the discussions at the kick off meeting, this project will be discharging to receiving wetlands. Reclaimed water discharged to a receiving wetland must contain no more, 5.0 mg/L TSS, 5.0 mg/L BOD5, 3.0 mg/L TN, and 1.0 mg/L TP on an annual average basis.

The South District WWTP use a High Pure Oxygen (HPO) activated sludge process and is not capable of nutrient removal. Chapter 62-611, FAC has stringent limits for total nitrogen (3.0 mg/L as N) and total phosphorous (1.0 mg/L). Nitrogen can be reduced to meet this criterion with biological treatment processes such as a Bardenpho process or biological aerated filters (BAFs). The term BAF is commonly used to describe both aerated biological filters for nitrification, and anoxic biological filters used for nitrogen removal. Phosphorous can be removed by either chemical means (P precipitation using iron or aluminum) or microbiologically; however it is common to use a combination of both. As recommended at the kick-off meeting, CDM prepared one treatment alternative using biological nutrient removal, even though implementation of BNR in the full-scale plant will involve significant modifications. To reduce the amount of new tankage required and to minimize the plant foot print, the BNR process is combined with a membrane bioreactor (MBR) process. MBR processes are a variation of the activated sludge process that use semi-permeable membranes – either microfiltration (MF) or ultrafiltration (UF) – in lieu of traditional secondary clarifiers. All other treatment alternatives for nutrient removal use tertiary treatment processes such as nitrification filters, denitrification filters, and chemical phosphorus removal.

3.2.3 Class III / Outstanding Florida Waters (OFW) Standards

Discharge to Outstanding Florida Waters is regulated by Chapter 62-302.700; FAC. The standard is stringent with respect to new or expanded surface water discharges. Discharges must not degrade the ambient water quality. Based on discussions with the project review team, water quality goals for the treated effluent from the treatment alternatives were set at 0.27 mg/L for total nitrogen and 0.005 mg/L for total phosphorus. Based data prepared for the USACE West Dade Reuse Project (PBSJ 2001), average BOD_5 in Biscayne Bay is 3.5 mg/ L and average TSS is 12 mg/ L (although this value varies greatly). A full suite of chemical analysis including traditional pollutants, nutrients, emerging pollutants of concern (EPOC), metals, and pesticides must be conducted for both the current plant influent, pilot plant effluent, Biscayne Bay, and the receiving wetland water as part of part of the pilot plant effort to demonstrate that Biscayne Bay would not be degraded by discharge of the reclaimed water.

3.3 Design Criteria

Feedwater to the proposed pilot plant facilities will be either raw degritted wastewater influent from the plant headworks or clarified effluent from the secondary clarifies depending on the nature of the treatment technology and its location in the liquid treatment process. **Table 3-2** summarizes the assumed water quality to be used as the basis of design for the treatment alternatives. The water quality goals for the reclaimed water are shown in **Table 3-3.**

TABLE 3-2

WASTEWATER CHARACTERISTICS OF EXISTING SOUTH MIAMI-DADE WASTEWATER TREATMENT FACILITY FOR DESIGN PURPOSES

Parameter	Raw Wastewater	Secondary Effluent to pilot plant (AWT)(*)
Average flow, mgd	1.00	1.00
Peak flow, mgd	1.00	1.00
BOD_5, mg/L	125	20
TOC, mg/L	NA	12
TSS, mg/L	150	10
TDS, mg/L	NA	380
TKN, mg/L	25	18
Nitrate nitrogen, mg/L	0	1
Ammonia nitrogen, mg/L		14
TP, mg/L		1
Alkalinity, mg/L $CaCO_3$	75	75
Minimum wastewater Temperature, ^oC	20	22
Maximum wastewater Temperature, ^oC	32	31
Minimum air temperature, ^oC		0
Maximum air temperature, ^oC		34
pH	7	6.6
Chloride, mg/L		71
Sulfate, mg/L		33
Fecal coliform #/100 ml		56,000
Conductivity, µmho/ cm		720
Calcium, mg/L		20
Magnesium, mg/L		5
Sodium, mg/L		60

(*) Prior to High Level Disinfection

TABLE 3-3

EFFLUENT WATER QUALITY GOALS

Parameter	Reuse	Wetlands Application	Class III / OFW
TSS, mg/ L	5(1)	5	3.5
$CBOD_5$, mg/ L	20(2)	5	
Total Nitrogen, mg/l as N		3	0.27
Total Phosphorous, mg/L as P		1	0.005
Fecal Coliform, # / 100ml	<1.0	<1.0	<1.0
Total Ammonia- N, mg/L			0.02 –0.05
Nitrite/Nitrate-N, mg/L			0.01 mg/L
TKN, mg/L			0.22 mg/L
Ortho-P (mg/L)			0.002 mg/L
Dissolved Oxygen range (mg/L)			5.0-7.3
Turbidity, NTU			0.5 NTU
Salinity			Shall not change salinity in test site by more than 5 ppt
pH range			6.5-7.5 (*)
Heavy Metals			See Table 3.4
EPOC			Lowest possible levels(**)
Cryptosporidium and Giardia			Lowest possible levels(**)

(1) Single sample maximum

(2) Annual average

(*) Appropriate limits for pH in the estuarine zone will require further evaluation.

(**) Even though, currently there are no established numerical criteria or antidegradation targets for these parameters, available information shall be gathered on removal efficiency of various treatment technologies and detectable levels after advanced treatment for these parameters for comparative assessment. In practical terms, the objective would be to identify the technology that reduces such contaminants to the lowest level.

TABLE 3-4
TREATMENT OBJECTIVES AND MDLS/PQLS FOR METALS OF INTEREST

Heavy Metals Except for those listed with **	Methodology Required or Equivalent	Required MDL (ug/L)	Required PQL (ug/L)	Sea Water Composition (ug/L) [1,2]	Target Levels (ug/L)
Aluminum*	EPA 200.9	7.8	30	10	10
Antimony	EPA 200.9	0.8	3	0.5	0.8
Arsenic, tot	EPA 200.9	0.5	2	3	3
Barium*	EPA 200.7	1	4	30	30
Cadmium	EPA 200.9	0.05	0.2	0.1	0.1
Chromium, total	EPA 200.9	0.1	0.4	0.05	0.1
Copper	EPA 200.9	0.7	3	3	3
Iron	EPA 200.7	7	30	10	10
Lead	EPA 200.9	0.7	3	0.03	0.7
Manganese	EPA 200.9	0.3	1	2	2
Mercury, total	EPA 1631C	0.0001	0.0005	0.03	0.03
Mercury, methyl	EPA 1630 Draft	0.00002	0.00005		0.03
Nickel	EPA 200.9	0.6	2	2	2
Selenium*	EPA 200.9	0.6	2	4	4
Silver	EPA 200.9	0.5	2	0.04	0.5
Thallium	EPA 200.9	0.7	3	< 0.01	0.7
Tin	EPA 200.9	1.7	7	3	3
Zinc	EPA 200.7	2	8	10	10

Bolded Metals:

Indicates typical parameters monitored in waste water

Bolded and Italic Metals

Metal added because it was part of the Class III Surface Water FDEP Rule

Italic Metals:

Total Mercury is monitored in waste water and it is part of the Class III Surface Water FDEP Rule. Methyl and total mercury at low levels are not, but were added to be consistent with current District monitoring.

1 - Geological Survey Water-Supply Paper 1473, Study and Interpretation of the Chemical Characteristics of Natural Water, Second Edition, p. 11 (1971)
2 - Horne R.A. , Marine Chemistry The Structure of Water and the Chemistry of the Hydrosphere, Wiley-Interscience, 1969

Section 4
Detailed Description of Alternatives

4.1 General

This section describes the proposed alternatives to treat screened, degritted wastewater or secondary effluent from the South District WWTP to meet the three treatments goals described in Section 3.2. As discussed in Section 3 it is acknowledged that the final treatment scheme will need to meet the OFW criteria prior to discharge to the receiving wetlands. A pilot scheme will be selected to develop to full scale (130 MGD) costs.

4.1.1 Location

Based on the size of the facilities required to treat 1.0 mgd of flow it is assumed that the pilot facilities will be located on the South District WWTP site. This reduces piping runs, and the energy cost to pump the influent and effluent flows.

4.1.2 Miscellaneous General Assumptions

For purpose of this report the following assumptions were made:

- Power will be provided from the South District WWTP so that Florida Power & Light (FPL) will not need to bring power to a new undeveloped site. A new meter will be provided to monitor the pilot plants power consumption.

- Staffing will be provided by MDWASD and reimbursed through the CERP. This allows part time monitoring of the pilot facilities.

- Ultraviolet light (UV) will be used for disinfection for all alternatives. UV was selected because no disinfection by products are created, and UV does not need post disinfection (ie. dechlorination) before to discharge to wetlands. MDWASD is currently designing a system at the South District WWTP to disinfect its effluent to meet Florida's High Level Disinfection (HLD) criteria. Once MDWASD's HLD project has progressed to the point where a process has been selected; the scope of the pilot plant design should be modified to incorporate the selected process, and any necessary post disinfection treatment.

- No redundancy will be provided in the pilot plant. In the event of electrical or mechanical failures the pilot facility will be shut down and its flow or reject water diverted to the South District WWTP process. Similarly reject storage or alternate disposal methods were not included in the conceptual design of the treatment alternatives.

- A constant flow of 1.0 mgd will be fed to the pilot plant. Influent and effluent flow will be delivered through dedicated pump stations to and from the pilot. Gravity flow may be possible and should be investigated as part of the pilot plant design.

4.2 Alternative 1

4.2.1 Description of Treatment Process

The first proposed treatment process alternative is designed to meet the State of Florida Reuse water quality criterion by removing suspended solids (TSS < 5.0 mg/L) with granular media filters and providing high level disinfection. Effluent from the secondary clarifiers will be fine screened and pumped to deep bed granular filters prior to ultraviolet light disinfection and subsequent deep well injection.

Gravity filtration through beds of granular media is the most common method of removing suspended solids in wastewater as tertiary treatment. A fine screen prior to the filters is recommended to avoid additional operational labor costs associated with removing floating objects (i.e. plastics) that escape the clarifiers. As mentioned previously, ultraviolet light will be used to provide disinfection for this project. The expected lower transmissivity (55%) associated with gravity filters when compared to higher levels of treatment will increase the UV equipment requirements and operational costs.

Deep Bed filters must be backwashed periodically to remove the suspended solids being filtered from the secondary effluent. Backwash are initiated based upon the differential water level across the filter. Wash water can be pumped back to the head of the South District Plant, where it will have negligible effect on the influent water quality. There is no sludge produced by this process.

4.2.2 Design Criteria

Design criteria for alternative one, gravity sand filters followed by UV disinfection are detailed in **Table 4-1** based on the design feedwater quality presented in Table 3-2. The facility requirements calculated from the design criteria are presented in **Table 4-2**.

TABLE 4-1
ALTERNATIVE 1 PROCESS DESIGN CRITERIA

Deep Bed Filters		
Media type	Sand	
Nominal hydraulic loading rate	gpm/ft²	4
Specific solids loading rate	lb/ft²/cycle	2
Concurrent air wash rate	cfm/ft²	6
Concurrent backwash water	gpm/ft²	6
Water only backwash	gpm/ft²	8
Ultraviolet Light Disinfection		
Bulb type	Medium pressure	
Minimum transmittance	%	55
Minimum dose	mJ/cm²	100
Effluent fecal coliform	No./100ml	non detectable

TABLE 4-2
ALTERNATIVE 1 FACILITY REQUIREMENTS

Fine Screens		
Type	Perforated plate or rotary drum screen	
Opening size	mm	3
Filters		
Type	Deep bed granular media	
Number	2	
Length	feet	16
Width	feet	10
Unit surface area	ft²	170
Media depth	feet	6
Backwash volume	gal	24,480
Ultraviolet Light Disinfection		
Type	In-line, medium pressure	
Number	2 (1 stand-by)	
Number lamps per chamber	12	
Total number of lamps	24	
Bulb power	watts	3750
Total system power	kW	36
Pipe diameter	inch	14

4.2.3 Process and Instrumentation Diagram

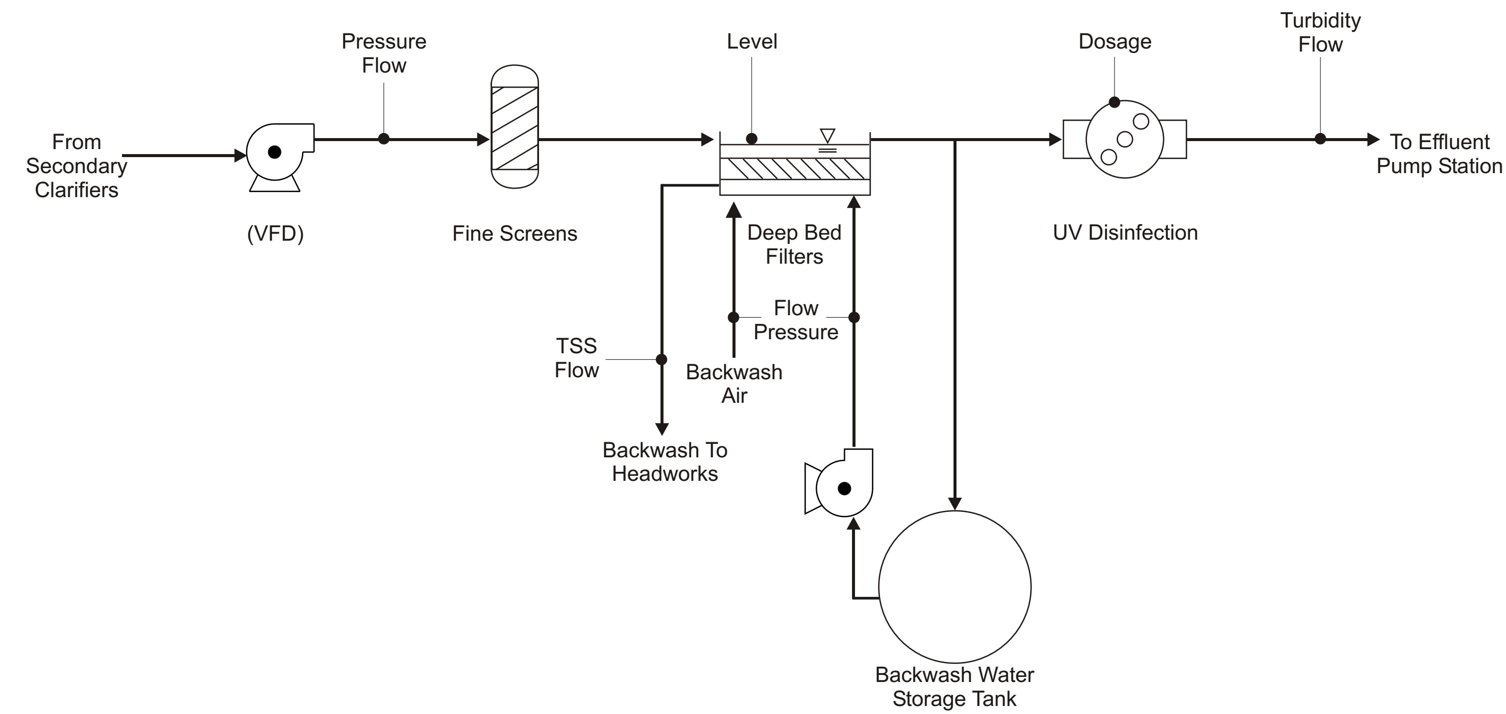
The process and Instrumentation diagram for Alternative one is presented as **Figure 4-1.**

4.2.4 Preliminary Cost Evaluation

Based on quotations from various equipment suppliers preliminary projects costs were prepared and presented in **Table 4-3.**

TABLE 4-3
ALTERNATIVE 1 PRELIMINARY COST EVALUATION

Item/Description	Quantity	Cost
Capital		
Fine screens	LS	$45,000.00
Filters	LS	$500,000.00
UV Disinfection	LS	$157,300.00
Subtotal		$702,300.00
Yard Piping @ 10 %		$70,230.00
Mechanical Allowance @ 10 %		$70,230.00
Electrical Allowance @ 10 %		$70,230.00
Instrumentation Allowance @ 8%		$56,184.00
Site work Allowance @ 10%		$70,230.00
Subtotal		$1,039,404.00
Contingency @ 30 %		$312,000.00
Subtotal Construction Cost		$1,351,404.20
Contractor Profit @ 15%		$202,690.00
Engineering, legal & Admin. @ 25 %		$337,800.00
Total Project Capital Cost		$1,892,000.00
O & M (year)		
Labor	(1 part-time)	$26,000.00
Power		$30,768.00
Total Project O&M Cost (Annual)		$57,000.00



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Alternative 1: Granular Media Filters followed by UV Disinfection

Figure 4-1

4.3 Alternative 2

4.3.1 Description of Treatment Process

Similar to Alternative 1, the second treatment process alternative is also designed to meet the State of Florida Reuse water quality criterion for public access irrigation. In alternative two, suspended solids are removed from the secondary effluent using cloth media filters in lieu of granular media. Effluent from the secondary clarifiers is pumped directly into the disk filter tanks prior to ultraviolet light disinfection and subsequent deep well injection

Disk filters (cloth media) are a proven filtration technology that uses a nylon fiber material to provide a consistent removal of very fine particular matter (< 5.0 mg/L of TSS). Secondary effluent is pumped into the tank and then flows by gravity through the cloth-membrane disks. The filter disks do not move during filtration. Disk filters require less head than deep bed sand filters and are designed to backwash automatically based upon reaching a maximum water differential.

As solids accumulate on the media, the liquid level of the tank increases up to a predetermined level or pre-set time interval when the backwash cycle starts. Solids are vacuumed from the surface by applying suction on both sides of the cloth-membrane rotating disk and directing the backwash to the head of the plant. Filtration is not interrupted during the backwash cycle, which can clean one or multiple disks at a time. The wash water will be pumped back to the head of the South District Plant. For disinfection, the expected lower transmissivity (55%) associated with disk filter effluent will raise the UV equipment requirements and costs.

4.3.2 Design Criteria

Based on the secondary effluent feedwater quality detailed in Table 2-2, design criteria were established for the cloth media (disk) filters. The process design criteria are presented in **Table 4-4.** The facility requirements are presented in **Table 4-5.**

TABLE 4-4
ALTERNATIVE 2 PROCESS DESIGN CRITERIA

Disk Filters		
Media type	Cloth	
Pore size	micron	10
Nominal hydraulic loading rate	gpm/ft²	4
Filter Area Required	ft²	174
Ultraviolet Light Disinfection		
Bulb type	Medium pressure	
Minimum transmittance	%	55
Minimum dose	mJ/cm²	100
Disinfection:	No. /100ml	non detectable

TABLE 4-5
ALTERNATIVE 2 FACILITY REQUIREMENTS

Filters		
Type	Cloth Disk	
Number units		1
Disk diameter	feet	7
Unit surface area per disk	ft^2	53.8
Number disks per unit		4
Total surface area	ft^2	170
Ultraviolet Light Disinfection		
Type	In-line, medium pressure	
Number	2 (1 stand-by)	
Number lamps per chamber	12	
Total number of lamps	24	
Bulb power	watts	3750
Total system power	kW	36
Pipe diameter	inch	14

4.3.3 Process and Instrumentation Diagram

The process and instrumentation diagram for Alternative two is presented as **Figure 4-2.**

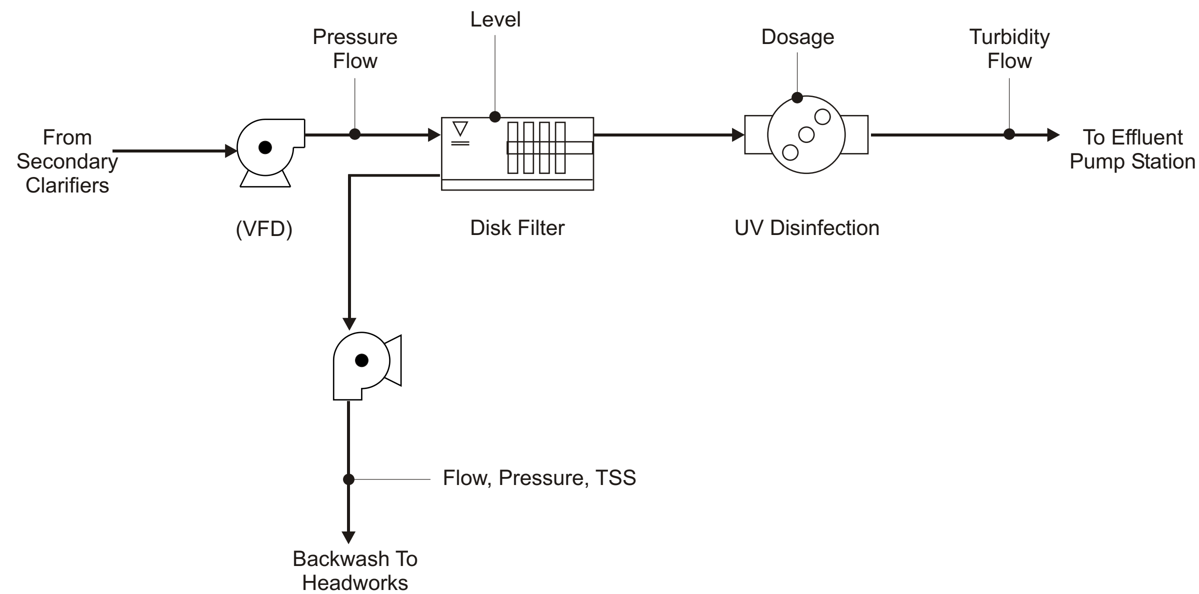
4.3.4 Preliminary Cost Evaluation

Based on quotations from various equipment suppliers preliminary projects costs were prepared and presented in **Table 4-6.**

4.4 Alternative 3

4.4.1 Description of Treatment Process

Alternative three is intended to meet the State of Florida water quality criteria for discharge to receiving wetlands (see Section 3.2.2 in this report), and is based on the use of a four-stage biological nutrient removal (BNR) activated sludge configuration combined with a membrane bioreactor (MBR) process. In BNR processes anaerobic, anoxic and aerobic zones are created to select for the microbiological activity needed to achieve low effluent total nitrogen and total phosphorus concentrations. Raw sewage instead of secondary effluent will feed this treatment process alternative since organic matter is necessary to develop a microbial community capable of removing nutrients. Therefore, a side stream will be diverted from the grit chamber of the South District WWTP and pumped, or fed by gravity, into the pilot plant.



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Alternative 2: Disk Filters followed by UV Disinfection
Figure 4-2

TABLE 4-6
ALTERNATIVE 2 PRELIMINARY COST EVALUATION

Item/Description	quantity	Unit cost
Capital		
Disk Filter (stainless steel)		$ 138,800.00
UV Disinfection	LS	$ 157,300.00
Subtotal		$ 296,100.00
Yard Piping @ 10 %		$ 29,610.00
Mechanical Allowance @ 10 %		$ 29,610.00
Electrical Allowance @ 10 %		$ 29,610.00
Instrumentation Allowance @ 8%		$ 23,688.00
Site work Allowance @ 10%		$ 29,610.00
Subtotal		$ 438,228.00
Contingency @ 30 %		$ 131,470.00
Subtotal Construction Cost		$ 569,698.00
Contractor Profit @ 15%		$ 85,455.00
Engineering, legal & Admin. @ 25 %		$ 142,424.10
Total Project Capital Cost		$ 798,000.00
O&M		
labor	(1 part-time)	$ 26,000.00
Power		$ 30,223.00
Chemical		$ -
Total Project O&M Cost (Annual)		$ 56,000.00

The MBR process alternative consists of one (1) anaerobic, one (1) aerobic, and two (2) anoxic tanks, followed by microfiltration (or ultrafiltration) membranes in dedicated tanks. The sequence of an anaerobic zone followed by an aerobic zone promotes the growth of phosphorous accumulating organisms (PAOs) that are capable of removing phosphorus from the wastewater. Tank 2 is anoxic and is used for denitrification using the native carbon in the raw wastewater. Tank 3 is aerobic and is the main bioreactor used for carbonaceous oxidation, nitrification, and for microbial phosphorous uptake. The mixed liquor from tank 3 is returned to the head of the pilot plant to recycle the high nitrate mixed liquor to the anoxic tank 2. In addition, a second anoxic zone (tank 4) is provided after the main aerobic zone (tank 3) to remove any remaining nitrate. Lastly, the mixed liquor goes to the membrane tanks were clean water is separated from its suspended biomass by hollow fiber membranes. A recycle stream takes excess solids (biomass) from the membrane tanks back the anaerobic tank, Waste sludge is intermittently removed from the MBR process using a dedicated waste sludge pump.

Waste produced by Alternative 3 consists of high concentration mixed liquor removed from the activated sludge process that can either be taken directly to the thickeners or sent to the South District WWTP headworks. There is no reject (concentrate) stream created by from the membranes.

4.4.2 Design Criteria

Based on the raw wastewater quality detailed in Table 2-2 design criteria were prepared for the Bardenpho/MBR process. The design criteria are presented in **Table 4-7.** The facility requirements calculated from the design criteria are presented in **Table 4-8.**

4.4.3 Process and Instrumentation Diagram

The process and instrumentation diagram for Alternative 3 is presented as **Figure 4-3**.

4.4.4 Preliminary Cost Evaluation

Based on quotations from various equipment suppliers preliminary projects costs were prepared for alternative three and are presented in **Table 4-9.**

4.5 Alternative 4

4.5.1 Description of Treatment Process

Alternative four is intended to meet the State of Florida water quality criteria for discharge to receiving wetlands (see Section 3.2.2 in this report),and is based on biologically aerated filters (BAFs). Effluent from the secondary clarifiers will go through fine screens prior to being pumped to a Nitrifying Biologically Aerated Filter (NBAF) followed by a Denitrification Filter. After the biological filters, phosphorous is chemically precipitated (i.e. alum, FeCl3) and filtered using disk filters, as discussed in Alternative 2. The objective in Alternative 4 is to remove enough nitrogen (TN < 3.0 mg/L) and phosphorous (TP < 1.0 mg/L) to meet the State of Florida water quality criterion for discharge to receiving wetlands. The existing effluent phosphorus concentration is low enough that it may be demonstrated through the pilot testing that phosphorus uptake by the biomass created by the nitrification/denitrification process may reduce the effluent phosphorus concentration below 1 mg/L, thus eliminating the need for the disk filters.

The NBAF, denitrification filter, and disk filter in Alternative 3 need to be occasionally backwashed to remove accumulated suspended solids. Similar to previous alternatives, wash water can be disposed to the headworks of the South District WWTP. The expected sporadic flows should have negligible effects on the 112 MGD treatment capacity of the plant.

4.5.2 Design Criteria

Based on the secondary effluent water quality detailed in Table 2-2 design criteria table were selected for the NBAFs, denitrification filters and disk filters. The design

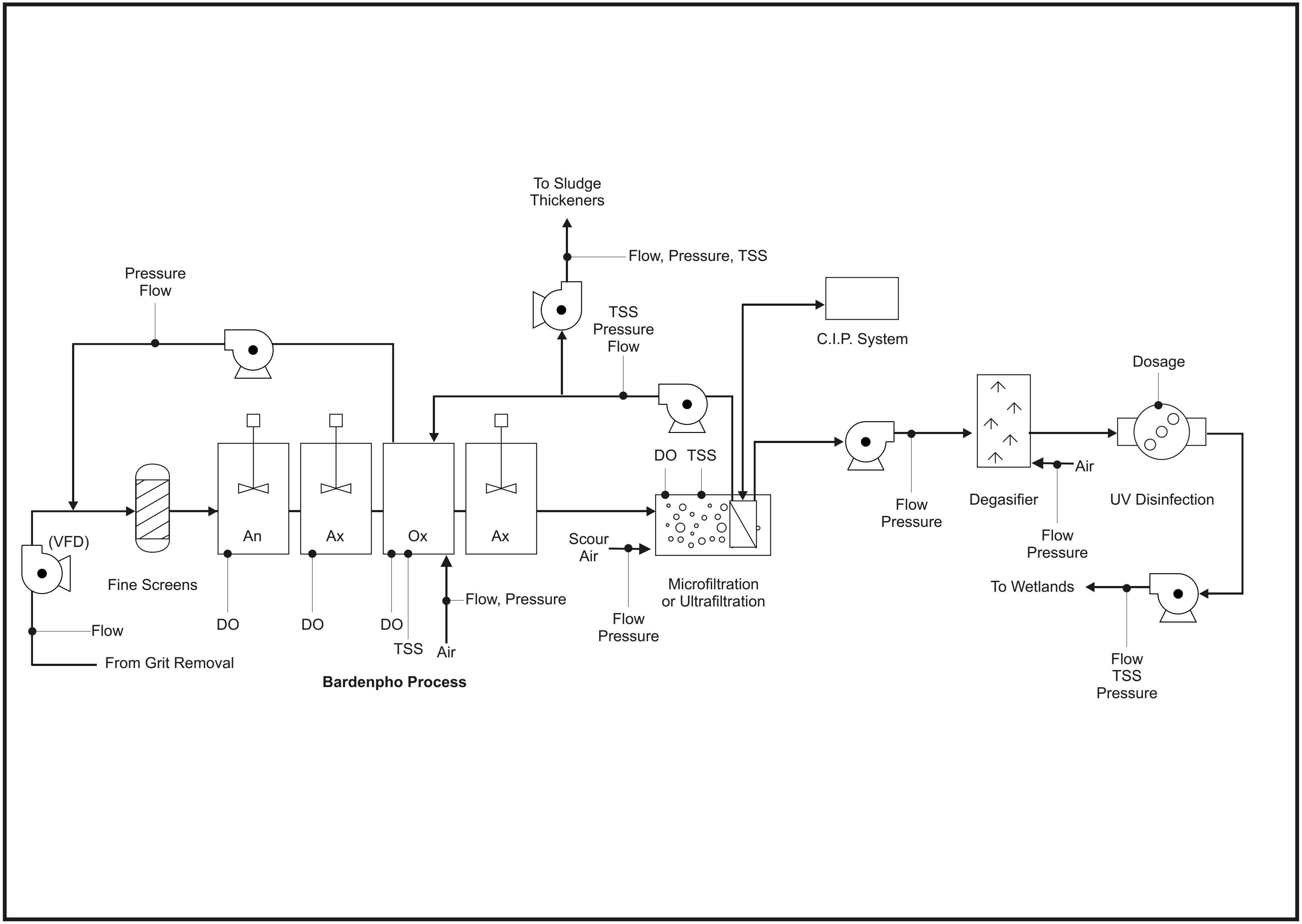
TABLE 4-7
ALTERNATIVE 3 DESIGN CRITERIA

Bardenpho Process		
Net observed yield coefficient	lb TSS/lb	0.9
Aeration solids retention time	days	6
MLSS	mg/L	8000
MLVSS/MLSS		0.75
Mixed liquor recycle ratio		6
Anaerobic hydraulic detention time	hr	1
% P in MLSS		0.06
First anoxic denitrification rate		0.03
Internal recycle ratio (QIR/Q)		6
Nitrogen content of waste sludge		8
Second anoxic denitrification rate	lb N/lb TSS/d	0.02
Alpha (fine pore)		0.5
Beta		0.95
Oxygen use		
For BOD removal	lb O_2/lbBOD_5	1.2
For nitrification	lb O_2/lb NH_4	4.6
Oxygen recovered from	lb O_2/lb NO_3	2.86
Membrane Bioreactor Process		
Membrane type	Immersed hollow-fiber	
Nominal pore size	um	0.035
Design flux	gfd	15
Ultraviolet Light Disinfection		
Bulb type	Medium pressure	
Minimum transmittance	%	65
Minimum dose	mJ/cm^2	80
Disinfection:	fc/100ml	non detectable

TABLE 4-8
ALTERNATIVE 3 FACILITY REQUIREMENTS

Fine Screen		
Type	Perforated plate or rotary drum screen	
Opening size	mm	3
Bardenpho Process		
Tank volumes		
Anaerobic	gallons	30,000
First Anoxic	gallons	40,000
Aeration	gallons	80,000
Second Anoxic	gallons	25,000
Total	gallons	175,000
Anaerobic Zones		
Number	1 total, split into 2 cells	
Length	feet	10
Width	feet	10
SWD	feet	15
Unit volume	gallons	16,000
First Anoxic Zones		
Number	1 total, split into 2 cells	
Length	feet	14
Width	feet	14
SWD	feet	15
Unit volume	gallons	22,000
Aeration Zones		
Number	1 total, split into 2 cells	
Length	feet	24
Width	feet	12
SWD	feet	15
Unit volume	gallons	32,000
Diffuser System	_	
Type	9-inch membrane discs	
Number of diffusers		800
Second Anoxic Zones		
Number		1
Length	feet	15
Width	feet	15
SWD	feet	15
Unit volume	gallons	25,000

Membrane Bioreactor Process		
Model No. (or equal)	Zenon ZW 500B	
Membrane area per cassette	ft^2	14,300
Cassette height	ft	6.52
Cassette length	ft	16.02
Cassette width	ft	2.40
No. of membrane trains		2
Membrane Tanks		
Length	feet	12.3
Width	feet	7
Depth	feet	7.5
Nominal capacity per cassette	gpd	143,000
Total no. of membrane cassettes		8
Scour Air Blowers		
Air required per cassette	cfm	228
Total scour air required	cfm	1,824
Blower discharge pressure	psig	8
Total air required	icfm	2,056
Blower motor power	hp	100
Degasifier		
Volume	ft^3	
Total air required	cfm	
Ultraviolet Light Disinfection		
Type	In-line, medium pressure	
Number	2 (1 stand-by)	
Number lamps per chamber	6	
Total number of lamps	12	
Bulb power	watts	3750
Total system power	kW	27
Pipe diameter	inch	14



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Alternative 3: Convert the Current HPO System into a Membrane Bioreactor (MBR), Bardenpho Process, followed by UV Disinfection

Figure 4-3

TABLE 4-9
ALTERNATIVE 3 PRELIMINARY COST EVALUATION

Item/Description	quantity	Unit cost
Capital		
Screens		$ 45,000.00
Tankage	LS	$ 20,000.00
Process Equipment	LS	$ 152,000.00
Membrane Bioreactor unit process		$ 1,639,000.00
Degasifier w/ blower	2	$ 25,000.00
UV Disinfection	LS	$ 123,700.00
Subtotal		$ 2,004,700.00
Yard Piping @ 10 %		$ 200,470.00
Mechanical Allowance @ 10 %		$ 200,470.00
Electrical Allowance @ 10 %		$ 200,470.00
Instrumentation Allowance @ 8%		$ 160,376.00
Site work Allowance @ 10%		$ 200,470.00
Subtotal		$ 2,966,956.00
Contingency @ 30 %		$ 890,090.00
Subtotal Construction Cost		$ 3,857,046.00
Contractor Profit @ 15%		$ 578,560.00
Engineering, legal & Admin. @ 25 %		$ 964,260.00
Total Project Capital Cost		$ 5,400,000.00
O&M		
labor	(1 part-time)	$ 26,000.00
Power		$ 141,215.00
Chemical		-
Total Project O&M Cost (Annual)		$ 167,000.00

criteria are presented in **Table 4-10.** The facility requirements are presented in **Table 4-11.**

4.5.3 Process and Instrumentation Diagram

The process and Instrumentation diagram for alternative four is presented as **Figure 4-4**.

4.5.4 Preliminary Cost Evaluation

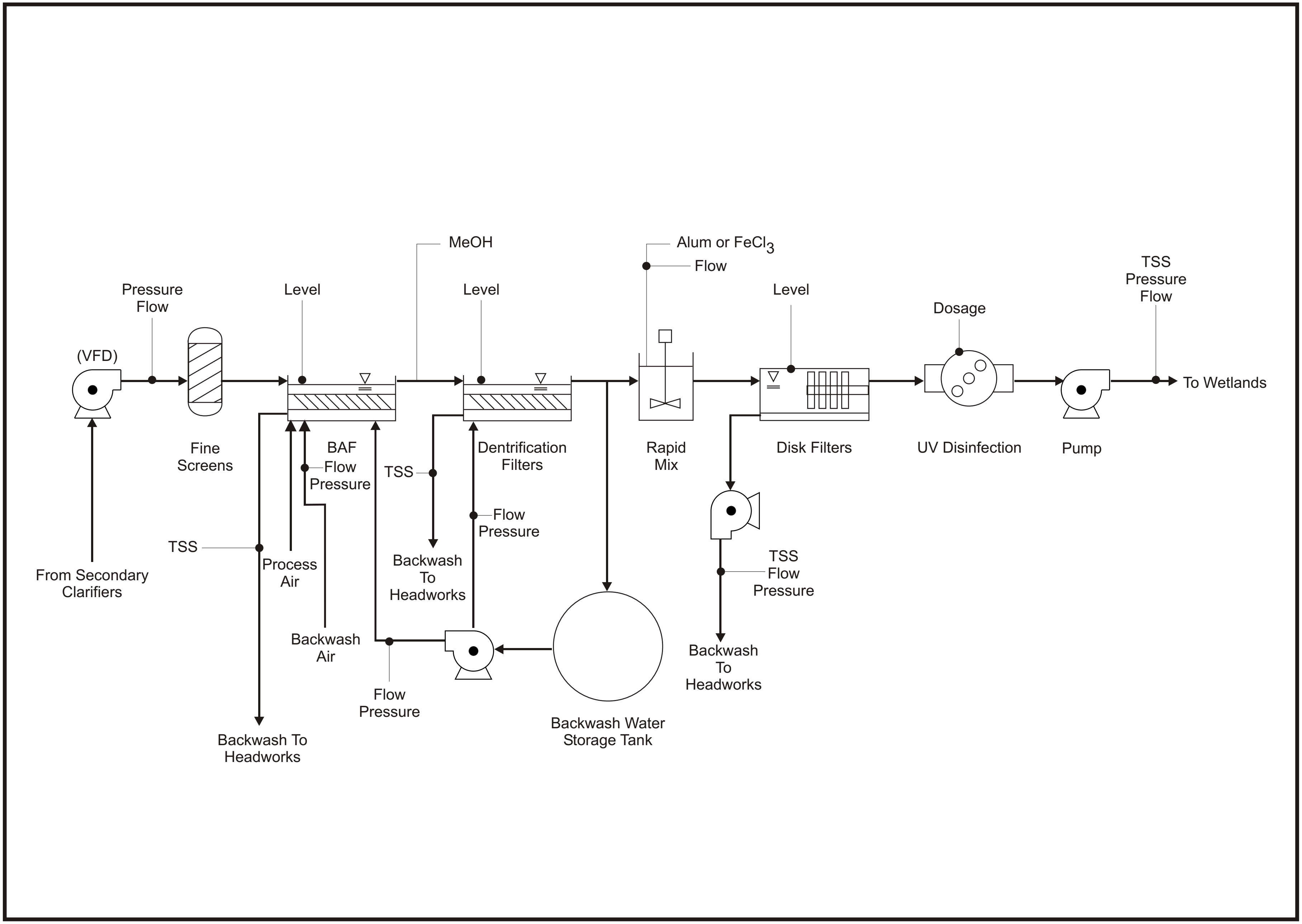
Based on quotations from various equipment suppliers preliminary project costs were prepared for alternative four and are presented in **Table 4-12.**

TABLE 4-10
ALTERNATIVE 4 DESIGN CRITERIA

Nitrifying Biological Aerated Filter		
BAF loading	kg NH_4-N/m^3/d	1.2
BAF overflow rate	m/hr,average	10.0
Media depth	m	4.0
Denitrification Filter Process Design Criteria		
Type	Deep-bed Granular Media	
Nominal hydraulic loading rate	gpm/ft2	2.0
Specific solids loading rate	lb/ft2/cycle	2.0
Air rate	cfm/ft2	6.0
Backwash water	gpm/ft2	6.0
Methanol feed dose	gpd	100.0
Denitrification rate (with methanol)	kg NO_3/kg TSS-day	0.19
Filters		
Media type		Cloth
Nominal hydraulic loading rate	gpm/ft^2	4
Filter Area Required	ft^2	174
Specific solids loading rate	lb/ft^2/cycle	2
Air rate	cfm/ft^2	6
Backwash water	gpm/ft^2	6
Ultraviolet Light Disinfection		
Bulb type	Medium pressure	
Minimum transmittance	%	55
Minimum dose	mJ/cm^2	100
Disinfection:	fc/100ml	non detectable

TABLE 4-11
ALTERNATIVE 4 FACILITY REQUIREMENTS

Fine Screen		
Type	Perforated plate or rotary drum screen	
Opening size	mm	3
N B A F		
Type	Deep bed granular media	
Number	2	
Length	feet	20
Width	feet	20
Surface area	ft^2	400
Media depth	feet	11
Denitrification Filters		
Type	Deep bed granular media	
Number	2	
Length	feet	20
Width	feet	10
Surface area	ft^2 -	200
Media depth	feet	6
Disk Filters		
Type	Cloth Disk	
Number units		1
Disk diameter	feet	7
Unit surface area per disk	ft^2	53.8
Number disks per unit		4
Total surface area	ft^2	170
Ultraviolet Light Disinfection		
Type	In-line, medium pressure	
Number	2 (1 stand-by)	
Number lamps per chamber	12	
Total number of lamps	24	
Bulb power	watts	3750
Total system power	kW	36
Pipe diameter	inch	14



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Alternative 4: NBAF, Dentrification Filters, Disk Filters, followed by UV Disinfection

Figure 4-4

TABLE 4-12
ALTERNATIVE 4 PRELIMINARY COST EVALUATION

Item/Description	quantity	Unit cost
Capital		
Fine screens	LS	$ 45,000.00
NBAF (Infilco Biofor)	LS	$ 1,000,000.00
Denitrification filter	LS	$ 695,000.00
Disk filters	LS	$ 138,800.00
UV Disinfection	LS	$ 157,300.00
Subtotal		$ 2,036,100.00
Yard Piping @ 10 %		$ 203,610.00
Mechanical Allowance @ 10 %		$ 203,610.00
Electrical Allowance @ 10 %		$ 203,610.00
Instrumentation Allowance @ 8%		$ 162,888.00
Site work Allowance @ 10%		$ 203,610.00
Subtotal		$ 3,013,428.00
Contingency @ 30 %		$ 904,030.00
Subtotal Construction Cost		$ 3,917,457.00
Contractor Profit @ 15%		$ 587,620.00
Engineering, legal & Admin. @ 25 %		$ 979,364.00
Total Project Capital Cost		$ 5,484,000.00
O&M		
Labor	(1 part-time)	$ 26,000.00
Power		$ 138,464.90
Chemical (methanol only)		$ 192,346.00
Total Project O&M Cost (Annual)		$ 357,000.00

4.6 Alternative 5

4.6.1 Description of Treatment Process

Alternative five is intended to meet the Class III/OFW State of Florida water quality criteria (see Section 3.2.3 in this report),and is based on a reverse osmosis (RO) membrane treatment process. Similar to Alternative 3, this treatment alternative also uses the Bardenpho/MBR process for nutrient removal, but adds RO post treatment in an effort meet the stringent OFW water quality criterion for nitrogen (TN < 0.27 mg/L) and phosphorous (TN < 0.005 mg/L). Various full-scale examples of the use of RO to treat secondary effluent were presented as part of Task 2 of this project.

The use of an RO system creats a concentrate stream which must to treated or discharged. The most popular concentrate disposal alternatives are deep well injection, ocean outfall, or discharge to a municipal sewer system not tributary to the RO facility. For pilot purposes, the estimated 200,000 gal/day of concentrate can be either pumped back to the head of the SDWWTP or combined with the total plant effluent and deep well injected.

4.6.2 Design Criteria

Based on the secondary water quality detailed in Table 3-2 design criteria were selected for the Bardenpho MBR, and RO unit processes. The design criteria are presented in **Table 4-13.** The Facility requirements are presented in **Table 4-14.**

4.6.3 Process and Instrumentation Diagram

The process and Instrumentation diagram for Alternative five is presented as **Figure 4-5**.

4.6.4 Preliminary Cost Evaluation

Based on quotations from various equipment suppliers a preliminary project costs were prepared for alternative five and are presented in **Table 4-15.**

TABLE 4-13
ALTERNATIVE 5 DESIGN CRITERIA

Bardenpho Process		
Net observed yield coeffiicient	lb TSS/lb BODr	0.9
Aeration solids retention time	days	6
MLSS	mg/L	8000
MLVSS/MLSS		0.75
Mixed liquor recycle ratio (Qmlr:Qmax day)		6
Anaerobic hydraulic detention time	hr	1
% P in MLSS		0.06
First anoxic denitrification rate		0.03
Internal recycle ratio (QIR/Q)		6
Nitrogen content of waste sludge		8
Second anoxic denitrification rate	lb N/lb TSS/d	0.02
Alpha (fine pore)		0.5
Beta		0.95
Oxygen use		
For BOD removal	lb O_2/lb BOD_5	1.2
For nitrification	lb O_2/lb NH_4	4.6
Oxygen recovered from denitrification	lb O_2/lb NO_3	2.86
Membrane Bioreactor Process		
Membrane type	Immersed hollow-fiber	
Nominal pore size	µm	0.035
Design flux	Gfd	15
Reverse Osmosis Process Design Criteria		
Membrane type	Thin-film composite polyamide	
Element type		Spiral wound
Design flux	gfd	12
Water Recovery	%	85
Number stages		2
Ultraviolet Light Disinfection		
Bulb type		Medium pressure
Minimum transmittance	%	90
Minimum dose	mJ/cm²	60
Disinfection:	fc/100ml	non detectable

TABLE 4-14
ALTERNATIVE 5 FACILITY REQUIREMENT

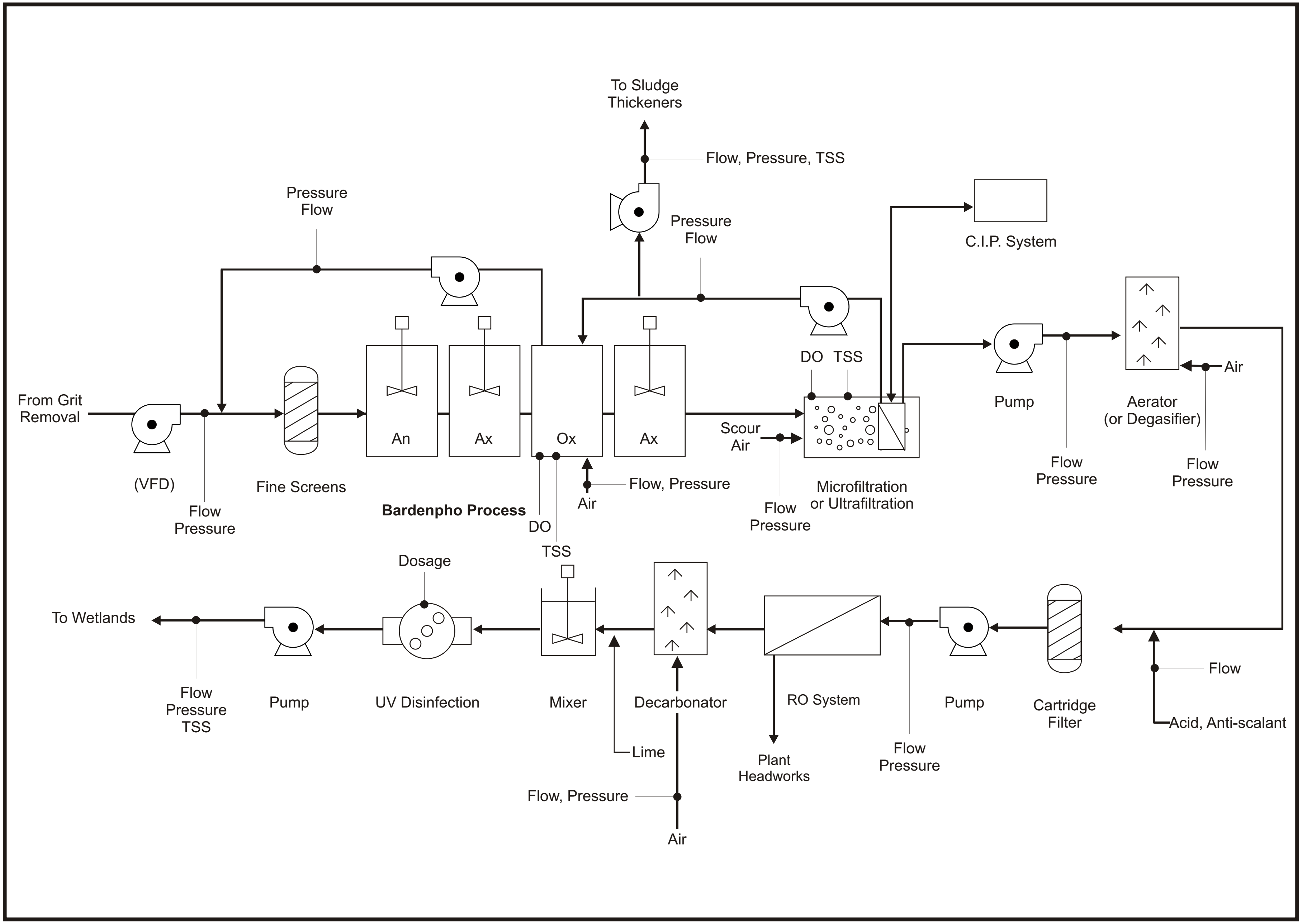
Fine Screen		
Type	Perforated plate or rotary drum	
Opening size	mm	3
Bardenpho Process		
Tank volumes		
Anaerobic	gallons	30,000
First Anoxic	gallons	40,000
Aeration	gallons	80,000
Second Anoxic	gallons	25,000
Total	gallons	175,000
Anaerobic Zones		
Number		1 total, split into 2 cells
Length	feet	10
Width	feet	10
SWD	feet	15
Unit volume	gallons	16,000
First Anoxic Zones		
Number	1 total, split	into 2 cells
Length	feet	14
Width	feet	14
SWD	feet	15
Unit volume	gallons	22,000
Aeration Zones		
Number	1 total, split	
Length	feet	24
Width	feet	12
SWD	feet	15
Unit volume	gallons	32,000
Diffuser System		
Type	9-inch membrane discs	
Number of diffusers	800	
Second Anoxic Zones		
Number		1
Length	feet	15
Width	feet	15
SWD	feet	15
Unit volume	gallons	25,000

TABLE 4-14
Continuation

Membrane Bioreactor Process		
Model No. (or equal)	Zenon ZW 500B	
Membrane area per cassette	ft^2	14,300
Cassette height	ft	6.52
Cassette length	ft	16.02
Cassette width	ft	2.40
No. of membrane trains	2	
Membrane Tanks	6	
Length	feet	12.3
Width	feet	7
Depth	feet	7.5
Nominal capacity per cassette	gpd	143,000
Total no. of membrane cassettes		8
Scour Air Blowers		
Air required per cassette	cfm	228
Total scour air required	cfm	1,824
Blower discharge pressure	psig	8
Total air required	icfm	2,056
Blower motor power	hp	100
Degasifier		
Volume	ft^3	
Air required	cfm	
RO System		
Type	Polyamide - Hydranautics	
Design flux	gpd/ft^2	12.0
Area required	ft^2	115,741
Unit area per element	ft^2	400
Number elements per pressure		6
Length per element	inch	40
Length per pressure vessel	feet	20
Unit area per pressure vessel	ft^2	2,400
Number pressure vessel per		42
Unit area per skid	ft^2	100,800
Number stages		2
Number skids		1
Nominal flow per skid	mgd	1.2
Decarbonator		
Volume	ft^3	1,728
Total air required	cfm	

TABLE 4-14
Continuation

Ultraviolet Light Disinfection		
Type	In-line, medium pressure	
Number	2 (1 stand-by)	
Number lamps per chamber	4	
Total number of lamps	8	
Bulb power	watts	2240
Total system power	kW	10
Pipe diameter	inch	6



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Alternative 5: Convert the Current HPO into a Membrane Bioreactor (MBR), Bardenpho Process and RO, followed by UV Disinfection

Figure 4-5

TABLE 4-15
ALTERNATIVE 5 PRELIMINARY COST EVALUATION

Item/Description	Quantity	Unit cost
Capital		
Screen		$45,000.00
Tankage	LS	$20,000.00
Process Equipment	LS	$152,000.00
Membrane Bioreactor unit		$1,639,000.00
Degasifier w/ blower	2	$25,000.00
RO system		$1,335,000.00
Decarbonator	2	$25,000.00
UV Disinfection	LS	$67,700.00
Subtotal		$3,308,700.00
Yard Piping @ 10 %		$330,870.00
Mechanical Allowance @ 10 %		$330,870.00
Electrical Allowance @ 10 %		$330,870.00
Instrumentation Allowance @ 8%		$264,696.00
Site work Allowance @ 10%		$330,870.00
Subtotal		$4,896,876.00
Contingency @ 30 %		$1,469,060.00
Subtotal Construction Cost		$6,365,956.00
Contractor Profit @ 15%		$954,890.00
Engineering, legal & Admin. @ 25		$1,591,484.00
Total Project Capital Cost		$8,912,000.00
O & M		
labor	(1 part-time)	$26,000.00
Power		$441,956
Chemical (acid, antiscalant, cleaning, lime)		$177,348.00
Total Project O&M Cost (Annual)		$645,000.00

4.7 Alternative 6

4.7.1 Description of Treatment Process

Alternative six is intended to meet the Class III/OFW State of Florida water quality criteria (see Section 3.2.3 in this report), and adds a ballasted flocculation unit process to Alternative 4. Alternative 6 is based on BAFs followed by high-rate clarification to attempt to remove phosphorous by chemical precipitation to meet the OFW criterion without generating a hard to dispose of concentrate stream. Enhanced high-rate clarification (EHRC) units can remove total phosphorous down to about 0.01 mg/L, which is analytically challenging to detect. A disk filter after the high-rate clarification unit may not be necessary in the full-scale plant, but it is herein suggested for pilot testing to remove particulates that escape the EHRC process. It has been suggested that microfiltration membranes be evaluated at the pilot scale in lieu of the EHRC and disk filters. At the pilot level these two processes could be easily compared.

The addition of an enhanced high-rate clarification unit adds a sludge waste stream to the system, which can be either pumped back to the head of the South District WWTP or combined with the plant sludge for processing and disposal.

4.7.2 Design Criteria

Based on the secondary effluent water quality detailed in Table 2-2 design criteria table was selected for the combination of NBAFs, denitrification filters, EHRC, and disk filters. The design criteria are presented in **Table 4-16.** The facility design requirements are presented in **Table 4-17.**

4.7.3 Process and Instrumentation Diagram

The process and Instrumentation diagram for Alternative six is presented as **Figure 4-6.**

4.7. 4 Preliminary Cost Evaluation

Based on quotations from various equipment suppliers a preliminary project costs were prepared for Alternative six and are presented in **Table 4-18.**

4.8 Cost Summary

Treatment cost for the six alternatives are presented in **Table 4-19.** Capital Costs are presented rounded to the nearest hundred thousand dollars and in a cost per gallon basis. The annual operation and maintenance costs are rounded to the nearest thousand dollars and summarized, for the six alternatives.

4.9 Full Scale Project Costs

Driven by the need to meet anti-degradation requirements the pilot scale facility will need to utilize either Alternative 5 or 6. Upon further review and comment by the PDT, Alternative 6, with a modification replacing ballasted fluctuation and filtration with microfiltration was chosen to develop costs for the full scale process.

4.9.1 Full Scale Process Selection

The selection of the treatment process to develop full scale costs was based on the following items:

- There is a concern related with the use of RO (Alternative 5) that concentrate disposal will be too expensive to be feasible. MDWASD has already had difficulty disposing of treated effluent through deep well injection. Although the concentrate would be denser than the effluent and would tend to stay deeper once injected, permitting the injection wells would be difficult. Receiving a permit to dispose of the concentrate through an ocean outfall would be impossible due to the location of Biscayne Bay and its OFW status. The only other feasible alternative would be

TABLE 4-16
ALTERNATIVE 6 DESIGN CRITERIA

Nitrifying Biological Aerated Filter		
BAF loading	kg NH_4-N/m^3/d	1.2
BAF overflow rate	m/hr, average	10.0
Media depth	m	4.0
Backwash water	gpm/ft^2	6.0
Denitrification Filter Process Design Criteria		
Type	deep-bed granular Media	
Nominal hydraulic loading	gpm/ft^2	2.0
Specific solids loading rate	lb/ft^2/cycle	2.0
Air rate	cfm/ft^2	6.0
Backwash water	gpm/ft^2	6.0
Methanol feed dose	gpd	100.0
Denitrification rate (with methanol)	kg NO_3/kg TSS-day	0.19
High-Rate Clarification		
Type	Ballasted flocculation	
Coagulation tank		
hydraulic detention time	min	1
G	s-1	300
Ferric chloride dose	mg/L	100
Injection tank		
hydraulic detention time		
G	s-1	260
Polymer dose	mg/L	1
Sand dose	g/L	1
Maturation tank		
hydraulic detention time	min	3
G	s-1	250
Settling Tank		
Overflow velocity	gpm/ft^2	30
Sludge density	g/l	3
Sludge volume	%Q	1

TABLE 4-16
Continuation

Filters		
Media type	cloth	
Nominal hydraulic loading	gpm/ft²	4
Filter Area Required	ft²	174
Backwash water	gpm/ft²	6
Ultraviolet Light Disinfection		
Bulb type	Medium pressure	
Minimum transmittance	%	55
Minimum dose	mJ/cm²	100
Disinfection:	fc/100ml	non detectable

TABLE 4-17
ALTERNATIVE 6 FACILITY REQUIREMENTS

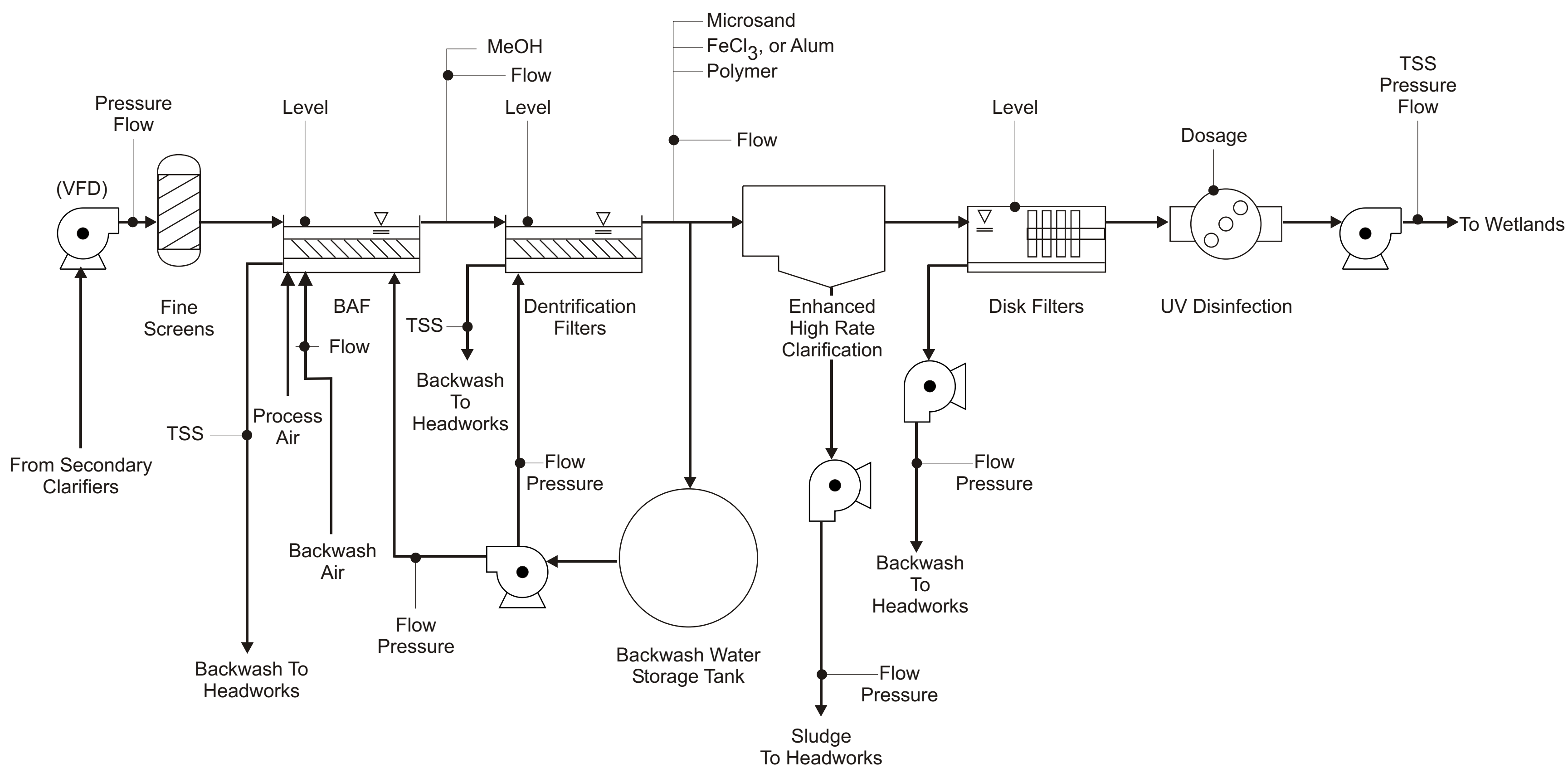
Fine Screen		
Type	Perforated plate or rotary drum	
Opening size	mm	3
NBAF		
Type	Deep bed granular media	
Number	2	
Length	feet	20
Width	feet	20
Surface area	ft^2	400
Media depth	feet	11
Denitrification Filters		
Type	Deep bed granular media	
Number	2	
Length	feet	20
Width	feet	10
Surface area	ft^2	200
Media depth	feet	6
High-Rate Clarification		
Coagulation Tanks		
Number duty		1
Number standby		0
Design Flow /Unit	mgd	1
Unit mixer power	hp	0.25
Length	ft	3
Width	ft	3
SWD	ft	15
Unit Volume	gal	1,010
Detention Time	sec	60
G	sec^{-1}	260
GT		15,000

TABLE 4-17
Continuation

Injection Tank		
Number duty		1
Number standby		0
Unit Power	hp	1
Length	ft	6
Width	ft	6
SWD	ft	15
Unit Volume	gal	4,200
Total Volume	gal	4,200
Detention Time	min	4.0
G	sec^{-1}	255
Maturation Tank		
Number duty		1
Number standby		0
Unit mixer power	hp	1
Length	ft	6
Width	ft	6
SWD	ft	15
Unit volume	gal	4,000
Total volume	gal	4,000
Detention Time	min	4.0
G	sec^{-1}	260
Settling Tank		
Number duty		1
Number standby		0
Length	ft	8
Length lamella zone	ft	6
Width	ft	8
Width lamella zone	ft	6
SWD	ft	15
Unit rake power	hp	1
Unit volume	mgal	7,200
Unit surface area	sf	36
Total volume	mgal	7,200
Overflow Rate	gpm/ft2	29

TABLE 4-17
Continuation

Disk Filters		
Type	Cloth Disk	
Number units		1
Disk diameter	feet	7
Unit surface area per disk	ft^2	53.8
Number disks per unit		4
Total surface area	ft^2	170
Ultraviolet Light Disinfection		
Type	In-line, medium pressure	
Number	2 (1 stand-by)	
Number lamps per chamber	12	
Total number of lamps	24	
Bulb power	watts	3750
Total system power	kW	36
Pipe diameter	inch	14



CDM

Alternative 6: NBAF, Dentrification Filters, High-Rate Clarification, Disk Filters, followed by UV Disinfection

Figure 4-6

TABLE 4-18
ALTERNATIVE 6 PRELIMINARY COST EVALUATION

Item/Description	quantity	Unit cost
Capital		
fine screens		$ 45,000.00
NBAF (Infilco Biofor)		$ 1,000,000.00
Denitrification Filter (Tetra)		$ 695,000.00
High-Rate Clarification		$ 530,000.00
Disk filters		$ 138,800.00
UV Disinfection	LS	$ 157,300.00
Subtotal		$ 2,566,100.00
Yard Piping @ 10 %		$ 256,610.00
Mechanical Allowance @ 10 %		$ 256,610.00
Electrical Allowance @ 10 %		$ 256,610.00
Instrumentation Allowance @ 8%		$ 205,288.00
Site work Allowance @ 10%		$ 256,610.00
Subtotal		$ 3,797,828.00
Contingency @ 30 %		$ 1,139,350.00
Subtotal Construction Cost		$ 4,937,178.00
Contractor Profit @ 15%		$ 740,580.00
Engineering, legal & Admin. @ 25 %		$ 1,234,295.00
Total Project Capital Cost		$ 6,912,000.00
O&M		
Labor	(1 part-time)	$ 26,000.00
Power		$ 144,867.00
Chemical ($FeCl_3$, polymer, methanol)		$ 559,167.00
Total Project O&M Cost (Annual)		$ 730,000.00

TABLE 4-19
CAPITAL COSTS

Alternative	Capital Cost (millions)	$/gal (capital)	O & M Annual (thousands)
1	$1.9	$1.9/gal	$57
2	$.8	$.80/gal	$56
3	$5.4	$5.4/gal	$167
4	$5.5	$5.5/gal	$354
5	$8.9	$8.9/gal	$645 (1)
6	$6.9	$6.9/gal	$730

(1) does not include concentrate disposal

pumping the concentrate to the Central Regional WWP (Virginia Key). This would entail great expense (__ miles of pipeline) and shifting the burden of treating the concentrate constituents to a different facility.

- Conversion of the existing South District WWTP treatment process would entail a significant expansion of the process tankage yard piping modifications, and a overall disruption of the current process. Due to the expense involved it was decided at the PDT level that the nitrification/denitrification process should be an add on tertiary process.

- Based on results from operating facilities effluent phosphorus levels utilizing RO would be in the range of 0.008 mg/L. Results from EHRC or microfiltration plants have been able to achieve concentrations below 0.01 mg/L. Therefore, the additional cost of RO is not justified based on additional expense of concentrate disposal.

- Although, there is data from the facilities that demonstrates that EHRC can meet a phosphorus limit of 0.01 mg/L or lower, the PDT requested that microfiltration be used in place of the ERHC units and disk filtration to develop full scale costs. This would basically be a hybrid of Alternatives 3 and 4. As discussed in section 4.7.1 this decision should be verified in the pilot plant stage. It is anticipated that a full scale process utilizing EHRC units will be operational at the East Central Regional WWTP (West Palm Beach) at which time the performance of these units can be evaluated.

4.9.2 Description of the Process

This process is identical to the process described in Alternative 6 with the exception that the enhanced high rate clarification and disk filters are replaced with microfiltration MBR tank (similar to the pre-treatment step shown in Alternative 5). At the full scale, backwash (assumed to be 10-15 percent of plant flow) returned to the head of the plant will be an issue. Alternate treatment of the backwash (in lieu of sending to the head of the plant) should be evaluated at the pilot scale. To reduce the 15 to 20 MGD of backwash water, a separate microfiltration system will used to reduce the backwash stream to a more manageable flow. Permeate from the backwash treatment system should meet the effluent criteria. The facilities have been sized to accommodate a peaking factor to 2.0 and off-line equalization storage has been induced to accommodate the diurnal flow variation during the day.

The process and instrumentation diagram for this facility is presented in **Figure 4-7**.

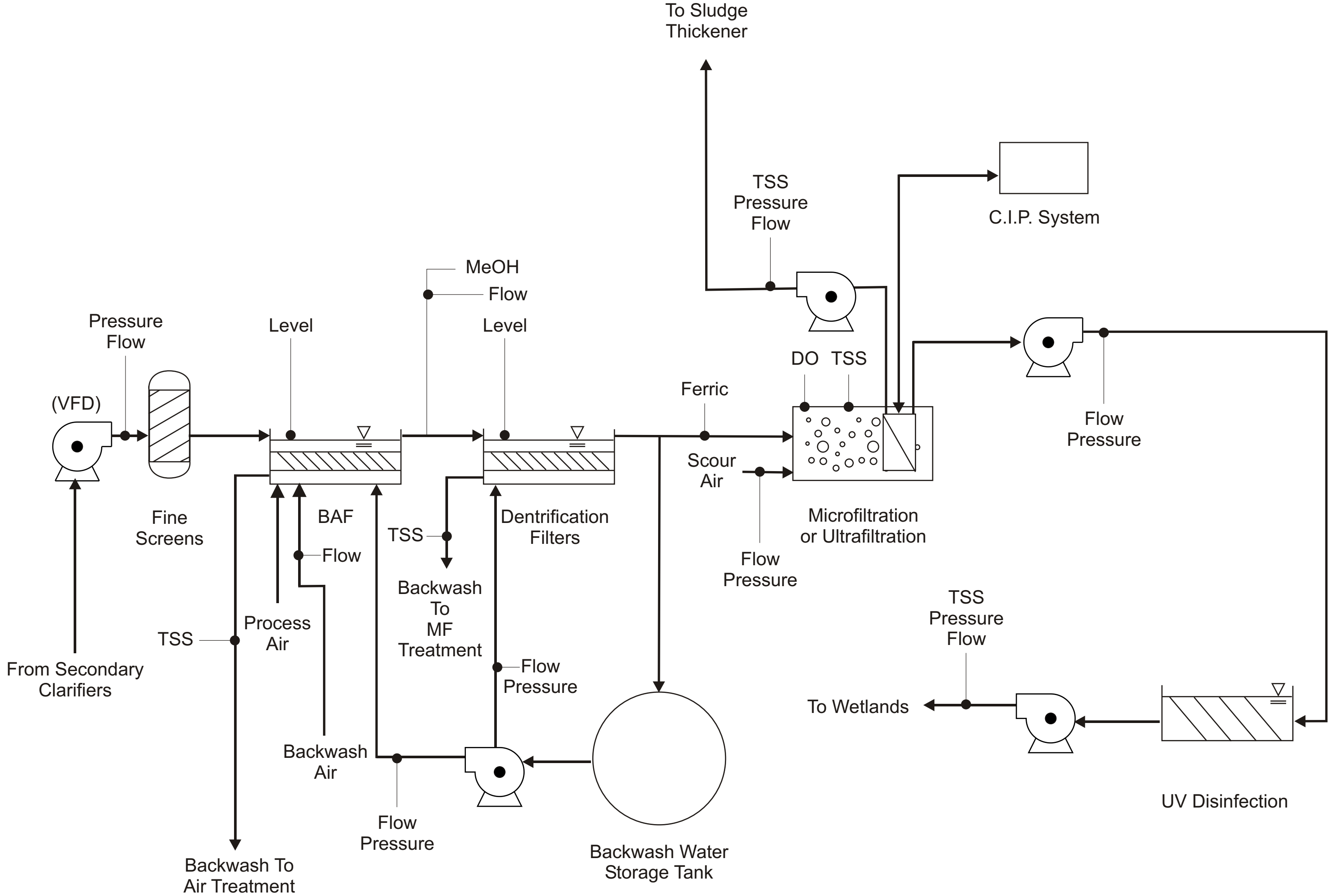
4.9.3 Coordination with On-Going Projects

The full scale facility will need to be coordinated with the high level disinfection (HLD) project currently being undertaken by MDWASD. These items will need to be revisited based on MDWASD work:

- Disinfection - This estimate include the use of UV. It is assumed that by the time this full scale reuse facility is under design, MDWASD will have its HLD process in place. These facilities could be used to disinfect the reuse facilities effluent and should be integrated into the overall design of the reuse plant.

- Reject Storage – The HLD project will produce an effluent that meets primary drinking water standards for disposal through the deep well injection system. The reuse project will provide an effluent to meet the strict anti-degradation limits for Biscayne Bay. It is anticipated that a reject management system will be a part of the improvements designed as part the HLD project. Because the reuse project will treat a majority of the flow (130 MGD/131 MGD 2010 ADF), it is assumed that any water that does not meet the reuse quality will meet the HLD standards or be routed through the HLD reject management system.

- Pollutant Limits – Based on the data available at the time of this report the microfiltration process will only be able to reduce the total phosphorus concentration to a level below 0.01 mg/L. The criteria that was established by the PDT was 0.005 mg/L. At this time it may not be possible to reach that limit. In addition to phosphorus, other pollutants of concern such as: metals, pharmaceuticals, and pesticides should be monitored at the pilot scale to determine their expected effective concentrations in the full-scale effluent.



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Full Scale Implementation: NBAF, Dentrification Filters, Microfiltration (MF) followed by UV Disinfection

Figure 4-7

4.9.4 Cost Estimates

Conceptual level estimates of both capital and operating costs were developed for each treatment alternative at a peak wet-weather flow peaking factor of 2.0 based on August 2004 values (ENR CCI= 7188).

A number of assumptions were used to develop the conceptual design and costs. The capital cost assumptions are listed in **Table 4-20**, and the operating cost assumptions are listed in **Table 4-21**. In general, installation costs were assumed to be 40 percent of the equipment cost.

TABLE 4-20
CAPITAL COST ASSUMPTIONS

Cost Item	Capital Cost
Equalization tanks (pre-stressed concrete)	$0.35/gal (installed)
Biological aerated filters (including all associated equipment)	$1,500/ft^2 (installed)
Denitrification filters (including all associated equipment)	$1,000/ft^2 (installed)
Buildings	$150/ft^2 (installed)
Microfiltration	$0.54/gal (installed)
UV equipment	$0.06/gpd
Electrical	15% of capital cost
Instrumentation	8% of capital cost
Site work	10% of capital cost
Yard piping	10% of capital cost
Contingency (construction)	25% of capital cost

TABLE 4-21
OPERATING COST ASSUMPTIONS

Cost Item	Value
Electrical power	$0.07/kWh
Labor (with overhead)	$30.0/hr
Methanol	$1.00/gal
Ferric chloride	$700/ton
Interest rate	8%
Repair and replacement	2% equipment cost/year
Fuel cost	$4.80/million BTUs

Costs for site work, yard piping, electrical work, and instrumentation and controls were estimated as percentages of the estimated capital costs for the unit treatment processes.

A construction contingency of 25 percent was applied due to the conceptual, or order-of-magnitude, nature of these cost estimates. Order-of-magnitude cost estimates are estimates made without detailed engineering data. Examples of this type of cost estimate include those made from cost-capacity curves, and estimates made using scale-up or scale-down factors and approximate ratio estimates from bid prices for similar facilities. It is normally expected that an estimates of this type are accurate within +50% to –30%.

Capital costs for wastewater treatment projects include both the construction cost and other project related costs. Project costs typically include engineering, legal and financial services such as engineering design services, surveying, geotechnical investigation, resident inspection, construction administrative services, start-up services, and interest during construction. The magnitude of these costs will vary with the size and complexity of the individual project and will typically range from approximately 15 to 25 % of the construction cost.

Estimates of annual operating costs were derived from estimates of power, labor, chemical and replacement and repair requirements for each unit treatment process, and assumptions for expected unit costs for these items.

The estimated capital cost for the full scale facility is summarized in **Table 4-22**. The tertiary treatment costs for the existing South District WWTP facility, assumed to handle the 2020 of ADF of 130 mgd are presented.

TABLE 4-22
FULL-SCALE TREATMENT ALTERNATIVE NO. 6A CAPITAL COSTS AT FLOW PEAKING FACTOR OF 2

Item/Description	Estimated Capital Cost
	130 mgd
Equalization Basins	$7,200,000
BAF Influent Pump Station	$3,600,000
Fine Screens	$1,400,000
Biological Aerated Filters	$77,500,000
Backwash Clearwell	$3,600,000
Waste Backwash Recycle Storage Tank	$3,900,000
MF Membrane Treatment for Backwash Water	$8,900,000
Biological Denitrification Filters	$30,000,000
2-Stage MF Membrane Treatment	$72,000,000
UV Disinfection	$11,700,000
Subtotal 1	$219,800,000
Electrical Allowance @ 15%	$32,970,000
Instrumentation Allowance @ 8%	$17,500,000
Site Work Allowance @ 10%	$21,980,000
Yard piping @ 10%	$21,980,000
Subtotal 2	$314,300,000
General Conditions (Mob./Demob., bonds, insurance, permits, licenses, overhead, profit, etc.) @ 25%	$78,580,000
Subtotal Estimated Construction Cost	$392,880,000
Contingency @ 25%	$98,220,000
Related Technical & Other Services @ 20%	$78,580,000
Total Project Cost Treatment Alt. No. 6A	$569,680,000

Operation and maintenance costs are shown in **Table 4-23**.

TABLE 4-23
FULL-SCALE TREATMENT ALTERNATIVE 6A ANNUAL OPERATING COSTS

Cost Item	Annual Cost
	131 mgd
Power	$ 14,300,000
Chemicals	$ 15,100,000
Membranes	$ 1,200,000
Repair & replacement	$ 5,800,000
Labor	$ 4,900,000
Total	$ 41,300,000
Unit cost ($/1000 gal)	0.86

Section 5
Conclusions and Recommendations for Implementation of Pilot-Scale Project

As noted in this report, reliable and commercially available technologies can potentially be employed to treat secondary effluent to high water quality standards. However, technical information currently available is insufficient for demonstrating that antidegradation targets for extremely sensitive tidal waters of Biscayne National Park can be met for all critical constituents.

Based on the information currently available and presented in this report the following are conclusions and recommendations for the pilot project offered by the Technology Task Group (TTG) (a group formed by the WWRPP PDT Technology sub-team members, experts in the field, consultants and other stakeholders):

5.1 Conclusions

1. The main objective of the Wastewater Reuse Technology Pilot Project is to studydetermine the feasibility for the of implementing a full-scale implementation ofproject, under the Comprehensive Everglades Restoration Plan (CERP), whose advanced treatment of secondary wastewater treatment technologies that can produce a high quality effluent (is capable of producing reuse water), for discharge under the Comprehensive Everglades Restoration Plan (CERP), that does not violate the surface water criterion of Chapter 62-302, Florida Administrative Code (F.A.C.) including the Class III and Outstanding Florida Waters (OFW) anti-degradation regulation requirements for Biscayne Bay (as well as, including associated wetlands and other surface waters), and Biscayne National .Park . In addition to this objective, the pilot project plans to investigate the presence and possible impacts to the receiving waters from EPOCs and other non-regulated constituents

2. There is an added concern for impacts to ecoreceptors from micropollutants (e.g. emerging pollutants of concern or EPOCs) and other constituents that may not currently be in the ecosystem but that may be present in the treated reuse wastewater. These compounds are not generally regulated under existing Water Quality standards and EPA rules. However, their potential effects to the ecosystem are not understood and may be chronic. For these reasons this process has to focus on these constituents and their feasibility of removal in addition to the removal of other regulated compounds such as nutrients, trace metals, and other toxic compounds.

3. The report grouped the ability of existing treatment facilities and technologies to meet three categories: Class III/OFW, Reuse, and Wetlands Application. The Class III / OFW category stems from Florida's surface water quality standards contained in Chapter 62-302, F.A.C. The Reuse and Wetlands Application categories reflect FDEP's domestic wastewater rules, which contain specific effluent requirements designed to ensure that permitted discharges achieve

compliance with the surface water quality standards in Chapter 62-302, F.A.C. These include Chapter 62-610, F.A.C., which regulates the reuse of reclaimed water (Reuse), and Chapter 62-611, F.A.C., which regulates the discharge of domestic wastewater to wetlands (Wetlands Application).

4. It is important to note that a distinction exists between the surface water quality standards in Chapter 62-302, F.A.C., and the effluent requirements contained in the domestic wastewater rules described above designed to achieve compliance with those standards, particularly with respect to nutrients. At present, the Class III water quality criterion for nutrients is narrative, rather than numeric, and is based on an affected imbalance of flora and fauna. It has been determined that if the pilot project's effluent is to be discharged to Receiving Wetlands, it will likely be permitted under Rule 62-611, F.A.C., Wastewater to Wetlands, which specifies numeric effluent limits for a limited number of the parameters, including total nitrogen and total phosphorus (Table 2.1). This rule incorporates the surface water quality standards rule (Chapter 62-302, F.A.C.), which contains an extensive list of numerical criteria for other constituents, by reference. The permitted discharge will have to, at a minimum, meet the numerical and narrative requirements contained in both rules. In addition, the OFW requirements discussed in this report will have to be met regardless of whether or not the effluent is discharged through lands subject to the Rule 62-611, F.A.C. requirements..

5. Florida's surface water quality standards also contain additional protection for OFW, a designation which prohibits the degradation of the ambient surface water quality from permitted sources, as described in Section 62-302.700, F.A.C. The team established anti-degradation targets based on existing water quality data, including numeric targets for nutrients. The permitted discharge will have to meet these targets to meet the OFW anti-degradation regulation requirements for Biscayne Bay, including associated wetlands and other surface waters, and Biscayne National Park, in addition to any specifically required by the rules described above. .

6. Section 2 of this report describes a number of large size (>10 MGD) reliable advanced wastewater treatment reclamation facilities that produce effluent with high water quality and that have been in operation for some time.

7. There is not sufficient or conclusive data presented in the report to confirm that any of the referenced sites is meeting the Class III and OFW water quality and antidegradation targets for Biscayne Bay (as shown in Table 2.1). or all of the Class III Surface Water Standards listed in Chapter 62-302, F.A.C. Pilot-scale documentation of nutrient and contaminant removal performance is required to expand upon and substantiate the limited existing database and ensure that these standards are met at the reference sites.

8. The recommended alternative is a treatment train that will be an add-on to the existing facility. This would minimize disruption to the existing plant operations during the construction of the new improvements.

9. Based on the potential to meet the desired water quality, it was concluded that Alternative 6A would be preferred over Alternative 6 to be tested in the pilot project.

10. The recommended treatment train for testing in the pilot plant (Alternative 6A) consisting of a nitrification/denitrification filter followed by chemical addition, microfiltration and UV disinfection) removes metals, organic chemicals, and pathogens, and it further has the potential for removal of emerging pollutants of concern (EPOCs), as well as various forms of inorganic nutrients, to the extent necessary to meet water quality goals.

11. The estimated capital cost for the full scale facility as determined in Alternative 6A is $569,680,000 including $314,300,000 for equipment including equalization tank for hydraulic and organic daily variations (electrical allowance @ 15%; instrumentation allowance @ 8%; site work allowance @ 10%; and yard piping @ 10%).; $78,580,000 for general conditions (mob./demob., bonds, insurance, permits, licenses, overhead, profit, etc.) @ 25%); $98,220,000 for contingency @ 25% and $78,580,000 related technical & other services @ 20%.

12. Estimates of annual operating costs were derived from estimates of power, labor, chemical and replacement and repair requirements for each unit treatment process, and assumptions for expected unit costs for these items.

13. The most promising treatment technologies for removing a spectrum of EPOCs include Reverse Osmosis, UV, activated carbon, advanced oxidation process like ozonization and membrane technologies like microfiltration and ultrafiltration. Studies will be conducted to document pilot-scale EPOC removal performance as required to expand upon and substantiate the limited existing database.

14. Reverse Osmosis (RO) membranes are currently used by several plants to produce very high quality water to recharge potable wells and to create salinity barriers. Though RO can reduce the concentration of many trace impurities in secondary effluent to levels that are below detection limits there are three problems created by the use of RO. These are: 1) concentrate disposal, 2) stability of the finished water, and 3) cost.

15. As an alternative to RO membranes, it has been suggested by the Technology Task Force team that other processes such as sand ballasted flocculation, microfiltration or ultrafiltration with chemical addition can reduce phosphorus levels significantly (based on recent pilot testing at the Everglades Agricultural area). BAF and denitrification media filtration can also provide nitrogen removal, thereby leading to the desired nutrient water quality. These potential alternatives

to RO may not individually provide a comparable level of treatment for some EPOCs , metals, pathogens, or organics that may be present. The efficacy of these treatment methodologies and their combination will be evaluated by the pilot plant study.

16. The use of UV, though energy intensive, eliminates the formation of toxic compounds formed due to chlorination, known as disinfection by-products, including tri-halomethanes and N-nitrosodimethylamine. Further reduction of microcontaminants can be accomplished through the addition/modification of the disinfection process using commercially available/emerging technologies, whether incorporating hydrogen peroxide (H_2O_2) with UV (at higher UV doses), utilizing ozone and H_2O_2, and/or incorporating low pressure biologically active reductive membranes. Such modifications to the treatment process could be done in the future as a response to emerging pollutants of concern. UV, as well as any other High Level Disinfection process selected by MDWSA for full scale implementation will be evaluated in the pilot project.

17. A review of literature for various wastewater treatment facilities indicates that activated carbon, (advanced) oxidation processes and membrane filtration are showing promising results for efficient removal of many non-regulated organic compounds during treatment.

18. There is limited information on effectiveness of technologies for removing metals, organics and other non-regulated compounds (e.g. EPOCs). This data gap will need to be addressed by the pilot project or obtained from other Environmental Organizations (such as EPA and USGS) as the research evolves.

19. The process performance monitoring program must account for diurnal water quality variability by correlating influent and effluent sampling events, and should account for hydraulic retention times in the unit process allowing for proper calculation of the percent removals of all parameters.

20. Abundant data are available on the presence of non-regulated compounds (EPOCS) in sewage effluent, surface water, and to a lesser extent in groundwater and drinking water. Further development of standardized analytical methods for detection of commonly occurring trace contaminants or non-regulated compound is required to improve performance characteristics.

21. A clearly defined list of monitoring parameters and target levels will be developed for the pilot project. Analytical methods used for various EPOC studies found in the literature will be compared and standardized where possible.

22. The pilot study should yield valuable information related to the removal efficiencies of a rather wide range of parameters that will be of value for a number of reuse activities.

5.2 Recommendations

1. The current version of the Master Implementation Schedule Plan indicates that the water reuse pilot project will be halted in 2004 and resumed in 2010. The TTG team recommends that the CERP Reuse Pilot Study continue with its original schedule, without interruption. Delaying this project until 2010 will not only delay the determination of whether water supply through reuse is feasible for areas near Biscayne Bay, but could also compromise the feasibility of a full-scale implementation of the reuse project as the remaining undeveloped lands in the area become unavailable. Specific needs for land acquisition will not likely be determined prior to a successful pilot project demonstration and a subsequent full-scale project feasibility analysis. However, in order to connect the source of the full-scale reuse water to the Biscayne Bay Coastal Wetland Project (BBCW) project, significant land acquisition may be needed in the area bounded by C-1 (Black Creek) canal to the north, the Old South Dade Landfill and the current South Dade Landfill to the east, the Florida Turnpike to the west, and the C-102 (Princeton) canal to the south. It should also be noted that the BBCW alternatives developed to date do not provide significant lands in this area to support the reuse project, nor do any of these BBCW alternatives include a specific wastewater reuse component or connection to the South Dade WWTP. This area is under intense development pressure and a large portion of the area could be permitted for development and/or developed before the water reuse pilot would even resume under the Master Implementation Schedule noted above. Therefore, if the reuse pilot project is delayed and the necessary lands are not quickly acquired (well before 2010), the opportunity to distribute the reuse water may be compromised if not lost entirely.

2. The TTG team recommends that specific comments on the technology report be addressed, and the pilot study continues without delay. This project will determine the feasibility of a full scale reuse project which is one of few CERP project that will produce “new water”.

3. Conversion of the existing South District WWTP treatment process would entail a significant expansion of the process tankage yard piping modifications, and an overall disruption of the current process. Due to the expense involved, the TTG has decided that any advanced water treatment process <u>should be an add-on process</u> to the existing facilities and that the treatment process will be reevaluated as necessary, pending the results of Miami-Dade HLD pilot studies.

4. The goal of the pilot project shall be to identify and monitor the optimum add-on treatment train technology capable of producing the water quality that will meet antidegradation targets for Biscayne Bay as established in the Treatment Objectives report. The pilot project will focus on maximizing the removal of regulatory as well as non-regulated compounds, including nutrients, pathogens, metals and organic chemicals, and on evaluating the short term and long term risks of discharging reclaimed water into the Biscayne Bay area for the purpose of

environmental restoration. Monitoring will be conducted a various stages of the process to determine achievement of all applicable standards.

5. If the pilot project is delayed, the EPOC monitoring of the South Dade WWTP secondary effluent and the HLD pilot studies should continue as planned.

6. Based on the monitoring results (i.e. type and concentrations of EPOCs occurring in the effluent), treatment processes or a combination of treatment processes should be selected for the advanced water treatment that will provide the highest degree of treatment for the South District WWTP effluent EPOC profile and also will optimize achieving antidegradation targets for nutrients, pathogens, metals, and organic chemicals for discharge to Biscayne Bay.

7. The selection of the regulated and non-regulated compounds (e.g. EPOCs) for monitoring and analysis during the pilot project is a complicated issue that should be discussed in depth pursuant to the recommendations below.

8. In order to control the monitoring costs for the pilot plant, surrogate chemicals should be selected for monitoring that will represent those constituents, including toxics and EPOCs considered representing the greatest ecological risks. These chemicals should then be monitored during the pilot plant operation using appropriate analytical methods that provide sufficiently low detection limits to verify adequate removal in the pilot plant.

9. With the current knowledge concerning regulated and non-regulated compounds, it is not possible to make a proper estimate of the ecotoxicological risk of these compounds to the environment. Better data on a wide range of species in studies that are relevant to reclaimed water are required. These can be best achieved by research conducted by EPA, USGS, and other research organizations.

10. More information is needed on the removal efficacy of non-regulated compounds during various advanced treatment processes, including membrane filtration, activated carbon filtration, ozonization, chemical addition and Cl2- and UV-disinfection.

11. A better understanding is needed of EPOC removal processes in wastewater treatment and methods to improve their efficiency. The pilot plant should be used to verify that EPOCs present at ppb or even ppt levels will be removed to the extent necessary to meet the OFW non-degradation requirements. In the event that the proposed treatment process does not remove EPOCs to the desired level, more information is needed on the removal efficacy of EPOCs through advanced treatment processes, including membrane filtration, activated carbon filtration, and advanced oxidation.

12. The pilot plant shall address a mass balance between input, output, adsorption on sludge, degradation, and evaporation to evaluate the relative contribution of the

different mechanisms of removal of all contaminants. Rigorous testing will be needed to adequately deal with the mass balance and may allow for future full-scale treatment process optimization.

13. A comprehensive and clearly defined list of monitoring parameters and target levels is needed during the design phase to prevent the omission of any necessary components in the proposed treatment train.

EVALUATE REMOVAL TECHNOLOGIES FOR EMERGING POLLUTANTS OF CONCERN- A LITERATURE REVIEW

PREPARED FOR

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EXECUTIVE SUMMARY

Many states in the U.S. are actively promoting wastewater reclamation because of state specific water needs. States with high population densities and heavy irrigation needs are steadily depleting their ground water resources without enough replenishment. In coastal areas this often results in saltwater intrusion into the aquifer. In the state of Florida, heavy rains are not efficiently tapped for future use due to high run-off and evaporation rates. In contrast, states with arid climates such as California, Arizona and west Texas, receive low rainfall resulting in the fast depletion of ground water resources. Given this situation, recycled water seems to be a good alternative to add to the supply.

Wastewater reuse is governed by stringent regulations to protect public health against waterborne diseases and any other adverse environmental effects. Conventional wastewater treatment plants employing secondary treatment are designed to remove nutrients, and are not designed for microcontaminant reduction. Due to ever increasing consumption of man-made chemicals and their various pathways to reach the wastewater treatment plants, a closer look is given to the various advanced water and wastewater treatment techniques and their removal efficiencies on several groups of chemical compounds.

Emerging Pollutants of Concern (EPOC) is the general name given to these classes of chemical compounds that have the potential to cause harmful effects or alter natural functions in humans and other forms of life. Hormones, prescription and non-prescription pharmaceuticals, human and veterinary antibiotics, personal care products (PCPs), industrial and household chemicals and disinfection byproducts (DBPs) from wastewater treatment are some of the classes of compounds collectively referred to as EPOC. EPOC, however, does not include all of the unregulated microcontaminant like pathogens and trace metals.

This study is aimed at determining the type and level of advanced treatment needed for effective treatment of EPOCs by reviewing available literature on the subject. Several of the Florida Department of Environmental Protection’s (FDEP) water quality standards including Reuse of Reclaimed Water and Land Application (Chapter 62-610, F.A.C.), Wetlands Application (Chapter 62-611, F.A.C.) and Outstanding Florida Waters (Chapter 62-302.700, F.A.C.) have no guidelines for EPOC removal, so an understanding of the highest degree of treatment that could be achieved is desirable.

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1.0 INTRODUCTION

1.1 Purpose

Barnes, Ferland and Associates, Inc. (BFA) was authorized by the South Florida Water Management District (SFWMD or District) to carry out a literature review to evaluate the effectiveness of various advanced wastewater treatment techniques to treat EPOCs. The results from this study will be integrated with another study undertaken by Camp, Dresser and McKee (CDM), which looks at cost effective treatment technology that will provide the desired water quality for freshwater wetlands that discharge to Biscayne Bay from the South Dade Wastewater Treatment facility (130 million gallons per day [mgd]). The results from this study will be used for the Wastewater Reuse Pilot Project, which is a component of the Comprehensive Everglades Restoration Program (CERP).

1.2 Definition of Terms

Explanation of some of some key terms that are frequently used in this study:

Emerging Pollutants of Concern (EPOC): The name given to classes of chemical compounds including hormones, prescription and non-prescription pharmaceuticals, human and veterinary antibiotics, PCPs, industrial and household chemicals and DBPs from wastewater treatment.

Endocrine Disrupting Chemical (EDC): Man-made industrial chemicals that might interfere with the normal functioning of human and wildlife endocrine systems. These chemicals comprise of a wide range of substances such as pesticides, surfactants, plasticizers and organohalogens.

Pharmaceuticals and Personal Care Products (PPCP): A wide variety of micropollutants that gain entry to the environment by way of their usage in human and veterinary medicine as well as agriculture. PPCPs comprise a very broad, diverse collection of thousands of chemical substances, including prescription and over-the-counter therapeutic drugs, fragrances, cosmetics, sun-screen agents, diagnostic agents and many others. PPCPs and their metabolites are excreted and washed into sewage and waterways. Expired or unwanted medications are also directly disposed to toilets and trash.

Quantitative Structure-Activity Relationship (QSAR): Quantitative structure-activity relationships (QSAR) represent an attempt to correlate structural or property descriptors of compounds with activities. These physicochemical descriptors, which include parameters to account for hydrophobicity, topology, electronic properties and steric effects, are determined empirically or by computational methods. Activities used in QSAR include chemical measurements and biological assays. QSAR currently are applied in many disciplines, with many pertaining to drug design and environmental risk assessment.

1.3 Scope

1.3.1 Categories of EPOCs evaluated

Since there could potentially be hundreds of EPOCs in the wastewater, it was decided to select a few representative compounds that could cover a range of chemicals by structural similarity, toxic potency etc. The categories of EPOC that were studied are:

- Steroids and Hormones: Estriol(E3), Estradiol(E2), Estrone(E1), Ethinylestradiol(EE2)
- Veterinary and human antibiotics: Ceftriaxone sodium, penicillin VK, enrofloxacin
- Prescription drugs: Gemfibrozil, ranitidine
- Non-prescription drugs: Ibuprofen
- Other wastewater derived compounds: Phenols, chlorobenzene (ClBz)

A detailed list of all the EPOCs that were examined is shown in **Table 9-2.**

1.3.2 Categories of advanced treatment technologies evaluated

Many of the Advanced Wastewater Treatment (AWT) technologies were evaluated for the treatment of EPOCs with considerations to advantages and limitations. The actual choice or recommendation of a process will depend on its removal efficiency given a concentration range for the influent. Following are the processes that were evaluated:

- Reverse Osmosis
- UV disinfection
- Membrane Filtration (micro, ultra)
- Ozone
- Activated Carbon (Powdered or granulated)
- Irradiation
- Combination of any of the above techniques

In addition to advanced treatment techniques, secondary treatment was 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.

1.3.3 Scope of the Literature Search

While there are several studies focused on gathering information and data for sources, occurrence in waste water treatment effluents and the environmental fate and toxic effects of EPOCs, the scope of this literature review is primarily to evaluate treatment efficiencies. The other related data on source, occurrence, fate and toxicity will be included in the overview section of this report. Also, the cost of the various technologies was outside the scope of this study. Cost estimates are addressed in a related study done by CDM which was contracted by the U.S. Army Corps of Engineers (USACE).

1.4 Approach

The Technology Task Force members for the Wastewater Reuse Technology Pilot project determined the structure and approach of the literature search at the treatment technology kick-off meeting on April 27, 2004 for the Wastewater Reuse Technology Pilot Project. The following outline provides the approach that was discussed:

- Removal efficiency will be evaluated for each category of EPOCs and each technology of interest, and then in various appropriate combinations.
- EPOCs will be organized by structural, physical-chemical, and treatability similarities, taking advantage of Quantitative Structure-Activity Relationship (QSARs).
- The treatability profile will take into account observed working concentration range and maximum sustainable loading rate.
- Potential for a treatment technology to synthesize new EPOCs will also be considered.
- Cross-checking of relevant literature from related disciplines (e.g., infer treatability potential from analytical clean-up protocols; photochemical fate literature) will be performed.

In addition, a study and results hierarchy was proposed, and is discussed in detail in Section 3.

2.0 OVERVIEW

2.1 EPOC sources in wastewater

Chemical compounds can reach the wastewater treatment plants from homes, industries and agriculture. The EPOCs may include human and veterinary drugs and antibiotics, hormones, detergents, disinfectants, plasticizers, fire retardants, insecticides, and antioxidants. Some EPOCs are DBPs from the treatment processes in the wastewater plants themselves. The figure below illustrates the possible pathways for EPOC to end up in sewage treatment plants and subsequently in the drinking water.

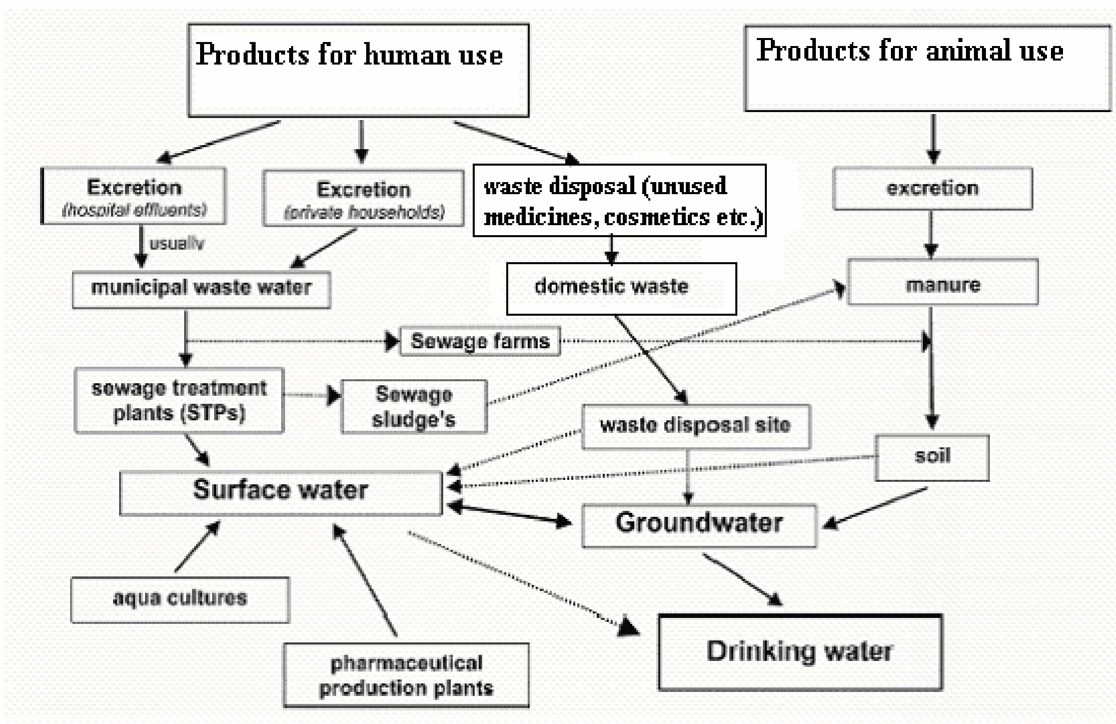

Figure 1. Scheme showing possible sources and pathways for the occurrence of EPOCs in the aquatic environment. Adapted from T. Heberer, Toxicology Letters 131 (2003): 5-17.

2.2 EPOC treatability by conventional secondary, tertiary, and advanced wastewater treatment technologies

In order the augment the sources of high quality drinking water, a lot of interest is being given to the reuse of domestic wastewater effluents. Organic micropollutants that can persist through (or which are formed during) wastewater treatment (Kimura et al., 2003) and that are associated with potential human health effects are of concern in implementing indirect potable reuse projects. Treatment of disinfection by-products (DBPs), endocrine disrupting compounds (EDCs) and pharmaceutically active compounds (PhACs) is receiving increasing attention. This study looks at several of the viable technologies to treat such EPOCs. Treatment efficiencies achieved by means of conventional activated sludge process, tertiary and advanced treatment processes and any combination of processes were reviewed.

Baronti et al. (2000) reported that as much as 95% removal could be achieved for some hormones by using activated sludge treatment alone. In contrast very low removal of 22% is reported by L.D. Nghiem et al. (2002) for a hormone (Estrone) by secondary treatment in his study. Treatment technologies like activated carbon, Reverse Osmosis (RO) and Ultra-Violet (UV) disinfection have proven to provide high percentages of EPOC removal in many studies and will be discussed in Sections 6 and 7. Also, seasonal variations in treatment efficiencies have been reported in Japanese Sewage Treatment Plants (STPs) by Nasu et al. (2000).

The goal is to identify the optimum add-on treatment technology to conventional, secondary, tertiary or AWT that would encompass a wide variety of EPOCs. Finding one ‘blanket’ treatment that will cover all possible EPOCs is highly unlikely considering the broad range of physiochemical properties of micropollutants that are known to be present in routinely treated residential sewage.

2.3 EPOC fate and transport in the environment

Purdom et al. (1994) first reported estrogenic effects in fish exposed downstream from wastewater treatment plants (WWTPs) in the United Kingdom. Since then, much effort has been made to identify and understand the compounds potentially interfering with the normal bodily functions of animals and humans.

The U.S. Geological Survey (U.S.G.S.) did an extensive national reconnaissance of pharmaceuticals, hormones and other organic wastewater contaminants (OWCs) during 1999–2000 to measure 95 OWCs across 139 streams spread over 30 states in the U.S. Kolpin et al. (2002) published their findings, and reported that one or more of OWCs were found in 80% of the streams. The compounds found represented a wide range of residential, industrial and agricultural origins.

There are various pathways for EPOCs to enter and persist in the environment. Household chemicals, pharmaceuticals and hormones are not completely metabolized (in the case of drugs) in humans and are directly released to the environment. Pesticides are applied to land and could easily find ways to groundwater, surface run-offs, etc. Industrial by products are released to the water and air through various unregulated and regulated ways. Wastewater treatment plants themselves could contribute to the list of microcontaminants in the form of DBPs.

Until recently, little was known about the extent of occurrence, transport and ultimately the fate of EPOCs due to the lack of effective analytical methods which could measure these EPOCs at very low concentrations. Advancement in analytical techniques has played a pivotal role in detecting and, as a result, quantifying the presence of EPOCs. The focus of this report is the treatment efficiency aspect of the EPOCs and detailed discussion about fate and transport is outside the scope as noted in Section 1.3.3.

2.4 EPOC occurrence in the environment

EPOCs are found in trace amounts in the environment, in the range of ppb to ppt. Several attempts were made to characterize the nature and amount of EPOCs present in wastewater, surface water, groundwater, and drinking water. Frequency of detection of EDCs and PPCPs in U.S. streams could be found in Kolpin et al. (2002). Some compounds like Coprostanol (estrogen), N-N-diethyltoluamide (mosquito repellent) and caffeine (stimulant) are found almost 80% of the time. The following are a few examples of EPOCs present in different media:

***Groundwater*:** Contamination of a groundwater supply was investigated near a landfill in Florida, which received wastes from a naval base hospital. Medicinal compounds like pentobarbital, meprobamate, and phensuximide were found in a 21-year-old ground water plume (Eckel et al., 1993). As a common practice during that time, waste from pharmaceutical industries was disposed in landfills without proper leachate collection systems.

***Drinking water*:** Contamination of tap water in Berlin was investigated by Stan et al. (1994). The presence of clofibric acid (metabolite of a blood lipid regulator in human medical care) was found, with a concentration range between 10–165 ηg/L. Also found was the persistence of clofibric acid in surface water samples across Berlin. In later studies, Heberer et al. (1998) and Ternes et al. (1999) found the presence of carbamapezine (anti-epileptic) and Ibuprofen (analgesic) in German drinking water.

***Wastewater*:** The U.S.G.S. is sampling the influent and effluent in the South District Wastewater Treatment Plant in Miami-Dade County for the presence of EPOCs. The sampling is done for 95 compounds which are comprised of antibiotics, prescription and non-prescription drugs, hormones and wastewater-related compounds. The presence of any such compounds in the aforementioned wastewater plant could of special interest for future studies as treatment of such EPOCs (which might be present) could be addressed.

Presence of EPOCs in other media such as sediment, ocean and river water has also been looked at by other studies.

2.5 EPOC toxic effects at ultra-trace concentrations

Persistent Organic Pollutants (POPs) have been shown to exhibit potentially harmful effects to man, animals and microorganisms. Environmental samples are usually polluted with a variety of compounds, and it is difficult to characterize the toxic effects of each contaminant present due to the limitations of analytical procedures. The U.S. Environmental Protection Agency (U.S.E.P.A.) maintains a database called ECOTOX which provides chemical toxicity information for aquatic and terrestrial life. It is a useful tool to provide information about the environmental impact of chemicals.

Guillete et al. (1995) observed in a study in Lake Apopka, Florida that a population of juvenile alligators exhibit significantly smaller penis size (24-percent average decrease) and lower plasma concentrations of testosterone (70-percent lower concentrations) when compared to animals of similar size on Lake Woodruff. Lake Apopka has a history of a major pesticide spill.

Lowest Observable Effect Concentrations (LOECs) have been employed by researchers to study the behavioral effects to a toxic chemical exposure. A great deal of literature exists to assess the harmful effects of anthropogenic chemicals to the environment.

2.6 Byproduct formation from EPOC treatment

Valid concerns have been raised by scientists, researchers and engineers about the inadvertent synthesis of possibly more toxic, bioaccumulative and persistent byproduct formation of compounds after being treated in wastewater plants. Hu et al. (2003) reported 13 products and six kinds of polychlorinated phenoxyphenols (PCPPs) as a result of the chlorination of Bisphenol-A (BPA). The same study also reported from an estrogen receptor binding assay that the binding affinity of the chlorinated aqueous BPA at 60 minutes was 24 times greater than before chlorination. Photocatalytic degradation of carbamazepine, clofibric acid, iomeprol and iopromide has been shown to be very effective (Frimmel et al., 2004), but byproducts during and after the treatment seem to be unavoidable. Therefore, identification of possible formation of highly toxic compounds even at low concentrations is essential for selection of a treatment technique.

3.0 SCHEME OF THE IDENTIFICATION AND RANKING OF RELEVANT LITERATURE

One can find extensive literature on the subject of EPOCs, which deals with fate and transport, analytical methods for measurement, risk assessment and regulatory needs. Such information may be used as a relevant subject matter to provide background information, but the focus is to determine the appropriate treatment needed in wastewater treatment plants to remove EPOCs. A scheme was proposed to identify and rank literature of interest in the treatment technology kick-off meeting on April 27, 2004. The study and results hierarchy described below sums up the approach that was followed. The literature was collected and then reviewed in two phases. In Phase I, abstracts and methods were reviewed and the literature ranked according to the criteria set forth below. In the second phase, papers that convey relevant information in terms of treatment and EPOC (mostly rank one and two papers) were read and summarized in detail. The summary of those papers is listed in Section 6. Some of the key considerations about the importance of a literature are as below:

Type of Operation

1. Full-scale facility
2. Demo facility
3. Pilot Plant
4. Bench top model
5. Mathematical model

Study design Criteria

1. Multi season sampling and analysis
2. One time with mass budget (liquid, solid, gas)
3. In and Out concentrations with statistical basis for study design
4. In and Out concentrations without statistical basis for study design
5. Without accounting for potential artifacts (radio-labeled tracer)

By-product formation

1. Consideration of inadvertent synthesis of toxic byproducts
2. No such consideration

Waste Management

1. Consideration of solids residuals management and costs
2. No such consideration

Based on these criteria, the ideal study involved multi-season sampling with mass budget measurements and tracers with a statistical basis for study design to quantify a true difference between the inflow and outflow, with a resolving power of ± 20% at the 95%-percentile confidence level.

It must be noted that to find a study which has the best of criteria in all aspects is very difficult. Therefore, a relative ranking system based on the scheme described above was developed which would enable giving a confidence level for a particular study.

4.0 LITERATURE SEARCH STRATEGY

The project manager (a SFWMD employee) and the contractor (a BFA employee) involved in this project formulated a plan which would enable them to identify the best possible literature available for the given task.

EPOC removal could be considered a new field, with research being done in various parts of the world to determine the appropriate treatment needed to remove EPOCs. Most of the existing relevant literature is from the last five years. A goal of 150 total papers, reports, conference proceedings, agency databases, etc. was set to ensure sufficient coverage to meet the objectives of the project. The selection criteria took into account the quality of the journal (or any other sources), the author, whether the item was peer reviewed or not, and the rigorousness of design.

The first step in the literature search strategy was to identify the topics that should be addressed in the paper. The major objective for this work was the EPOC removal efficiencies of select technologies, and the next step was to determine where to search for such articles. Traditional and non-traditional methods were employed to search relevant material. Traditional methods were comprised of library search and contacting people working in the same or related fields. Non-traditional electronic search methods included databases, journals, conference proceedings, and websites.

To focus the effort on the key literature it is important to determine:

1. The degree to which the publication is within the scope of the study
2. The relevancy to peer-reviewed, regulatory, and commercially sponsored literature

After a satisfactory amount of literature was gathered, a bibliography table was prepared, and each paper and report was ranked according to its relevance based on quantitative rigor and reliability. A wide variety of literature was collected that covered a wide range of topics and many treatment technologies.

5.0 LIST OF SOURCES SEARCHED AND LITERATURE ACCESSED

The list of sources searched was extensive, covering many journals, agencies, organizations, databases, and conference proceedings. The following is the list of sources that were searched:

JOURNALS
Adsorption
Advances in Environmental Research
Analytical Chemistry
Biosource Technology
Chemical Research in Toxicology
Chemosphere
Desalination
Ecotoxicology and Environmental Safety
Ecotoxicology
Environmental Chemistry Letters
Environmental Engineering Science
Environmental Science and Technology
Environmental Pollution
Environmental Toxicology
Groundwater Monitoring and Remediation
Journal of Physical Chemistry
Journal of Biological Chemistry
Journal of Environmental Engineering
Journal of Membrane Science
Journal of Photochemistry and Photobiology
Process Biochemistry
Radiation Physical Chemistry
Science of the Total Environment
Separation and Purification Technology
Toxicology Letters
Transport in Porous Media
Trends in Analytical Chemistry
Ultrasonics Sonochemistry
Waste Management
Water Research
Water Science and Technology
Water, Air, and Soil Pollution

AGENCIES AND ORGANIZATIONS
U.S. Environmental Protection Agency
- Office of Research and Development (National Exposure Research Laboratory)
- http://www.epa.gov/nerlesd1/chemistry/pharma/

American Water Works Association Research Foundation (AWWARF)
U.S. Geological Survey
EU- Project Poseidon
California Water Environment Association (CWEA)

CONFERENCES
U.S.E.P.A. Emerging Pollutants Workshop
CWEA Specialty Conference
USGS Pharmaceuticals and Emerging Organic Contaminants Annual Meeting
Endocrine/ Estrogen Conference
National Groundwater Association, 3rd International conference on Pharmaceuticals and EDCs in Water

Most of the resources mentioned above were accessed and found to have valuable information. A majority of good work directly related to this study came from journals such as Environmental Science and Technology, Water Research, and Science of the Total Environmental.

For a detailed description of the articles and reports accessed, please refer to the references section of this report.

6.0 SUMMARY OF KEY LITERATURE

The results from the key literature are summarized in tables outlining the EPOC compounds, concentration range and the treatment efficiency achieved. The treatment techniques under investigation are secondary, reverse osmosis, membrane, ozone, activated carbon and irradiation. Hybrid techniques and technologies not falling in the aforementioned categories are termed as "Other". The studies are also assigned confidence values which is explained in Appendix 9-1.

Table 6-1. Treatment table showing treatment efficiencies of secondary treatment on various EPOC compounds

EPOC Compound	Concentration Range	Removal Efficiency	Confidence	Reference
Hormones: (1) Estriol (E3), (2) Estradiol (E2), (3) Estrone (E1), (4) Ethynylestradiol (EE2)	4 mo. Avg: 80,12, 52, 3 for 1, 2, 3 and 4	95, 87, 85, 61% removals for 1, 2, 3 and 4 respectively by Activated sludge process	1	9
Phenols: (1) Methylcatechol, (2) hydroxytyrosol, (3) catechol, (4) m-tyrosol	0.3–0.9 mM	100, 70, 70, 35% removals for 1, 2, 3 and 4	4	21
Hormone: Estrone	15–100 ηg/L	22.3% @ 15 ηg/L	3	34
Antibiotic: Penicillin G	40–1060 mg/L	61.1% @ 35° C and 72 mg/L by activated sludge	4	3
2 cosmetic ingredients (galaxolide, tonalide), 8 pharmaceuticals (carbamazepine, diazepam, diclofenac, ibuprofen, naproxen, roxithromycin, sulfamethoxazole andiopromide) and 3 hormones (estrone, 17β-estradiol and 17α-ethinylestradiol)	0.6–6.6 µg/L	70–90% for fragrances, 40–65 for anti-inflammatories, 65 for 17β-estradiol, 60 % for sulfamethoxazole, 0 for iopromide	3	6
Hormones: 17 α-ethynylestradiol (EE2), 17β-estradiol (E2), estrone (E1)	8.6,17.8,157.1 ηg/L for EE2, E2 and E1 resp.	76, 94, 92% for EE2, E2 and E1	3	52
17β-Estradiol, 4-t-Octylphenol, sum 4- Nonylphenol, BisphenolA, 2-Hydroxybiphenyl, 4-chloro-3-methylphenol, 3-t-Butyl-4-hydroxyanisole	40–70ηg/L	90, 96, 40, 91,100,100, 72% removals	2	30
Estradiol equivalent (EEQ)	66.4, 56.2, 52.9, 45.3, 67.5 ηg/L on different sampling days	96.5, 98.8, 98.7, 98.5, 99% removals by biological followed by ultrafiltration	2	14
Non-ionic surfactants, pharmaceuticals, antiseptics, pesticides	Data compiled from various studies	alkylphenol ethoxylates: 90–99, ibuprofen: 65–90, carbamazepine:7, triclosan: 44–92% removal rates	6	41
(1) Clofibric acid, (2) diclofenac, (3) ibuprofen	10 µg/L	AST: > 95% for 1 and 2, 40% for 3 BioFilm Reactor(BFR): 96-99% for 1 and 2 and 30–36% for 3	3	51
BisphenolA (BPA), 17β-Estradiol (E2), 17α-ethynyl estradiol	0.5 µM	Cl: 92–99% for BPA, > 99% for E2 and EE2	5	5
EDCs: Nonylphenol (NP), nonylphenol mono and diethoxylates (NP_1EO and NP_2EO), nonylphenol carboxylates (NP_1EC and NP_2EC) and their brominated and chlorinated derivatives	8–22 µg/L	Prechlorination removal: 25–35% for NPEC and NPEO, 90% for NP; settling and flocculation followed by rapid sand : 7%	2	42

Table 6-2. Treatment efficiency of Reverse Osmosis (RO) on various EPOC compounds

EPOC Compound	Concentration Range	Removal Efficiency	Confidence	Reference
Antibiotic: oxytetracycline (OTC)	1000 mg/L	> 92%	4	32
Antibiotics: carbadox, sulfachlorpyridazine, sulfadimethoxine, sulfamerazine, sulfamethazine, sulfathiazole, and trimethoprim	50 µg/L for each compound	> 99% with 3 RO units in series	4	2
Estrone	15–100 ηg/L	95–99% depending on pH @ 100 ηg/L	3	34
9-ACA, Salicylic acid, DCAA, TCAA, Diclofenac, 2-Naphthol, Bisphenol-A, Phenacetine, Primidone	2-Naphthol: 110 µg/L, TCAA: 100 µg/L	96, 92, 95, 96, 95, 43, 99, 71, 84 resp. by RO-XLE for a 24 hour test	4	29
Estradiol equivalent (EEQ)	66.4, 56.2, 52.9, 45.3, 67.5 ηg/L on different sampling days	97.6, 97.7, 97.2, 98.3, 99% removals. Estrogenicity detected after RO but not after AC	2	14
NDMA, 1, 4-Dioxane, pharmaceuticals	47, 200, 4600,1800, 2300 ηg/L for ketoprofen, diclofenac, gemfibrozil, naproxen, ibuprofen resp.	Pharmaceuticals: Non-detect after treatment	4	15

Table 6-3. Treatment efficiency of UV on some EPOC compounds

EPOC Compound	Concentration Range	Removal Efficiency	Confidence	Reference
Bisphenol A (BPA)	10 mg/L	100% degradation after 9 min with H2O2 and Fe (II), also called photo-fenton process	3	28
Clofibric acid, carbamazepine, iomeprol	clofibric acid: 0.94 mmol/L ; iomeprol:0.012 mmol/L ; carbamazepine: $2.3*10^{\wedge-5}$ mol/L	29% and 33% for clofibric acid and iomeprol resp. for simulated solar UV-light	6	19
Pharmaceutical: Diclofenac	$1*10^{-3}$ M	84% removal by UV with H_2O_2 in terms of chlorine to chloride ions conversion	4	6
Chlorobenzene (ClBz), 1,4-dichlorobenzene (1, 4-DCilBz), 1-chloronaphthalene (ClNt)	200, 300 and 40 µM resp.	92.5, 93.3 and 94.5% removals resp.	11	27
Bromacil	0.38 mM	95% @ 1.25 mM DO, 84% @ 0.25 mM DO. Exp time: 5s	4	1
NDMA, 1, 4-Dioxane, pharmaceuticals	47, 200, 4600,1800, 2300 ηg/L for ketoprofen, diclofenac, gemfibrozil, naproxen, ibuprofen resp.	UV with H_2O_2: effectively treat for CA standards	4	15

Table 6-4. Treatment efficiency of membrane filtration on some EPOC compounds

EPOC Compound	Concentration Range	Removal Efficiency	Confidence	Reference
17β-estradiol (E2)	1 µg/L	~100% removal after 36 hours coupling time by porous hollow-fiber membrane	3	37
Estradiol, estrone, testosterone, progesterone	100 ηg/L	~100% removal by NF-90 and NF-270 membrane initially but declines to 95% after filtration time exceeds 400 minutes.	2	36
EDCs: Nonylphenol (NP), BisphenolA(BPA)	150 µg/L NP, 8000 µg/L BPA from landfill leachate	> 90%	2	47
Phenols, 4-chlorophenol, 2, 4-dichlorophenol, 4-notrophenol, p-cresol, hydroquinone	8-10 g/L: total conc. of all phenols, typically > 200mg/L in WWTPs	> 94% using Membrane Aromatic Recovery System(MARS)	3	22
9-ACA, Salicylic acid, DCAA, TCAA, Diclofenac, 2-Naphthol, Bisphenol-A, Phenacetine, Primidone	2-Naphthol: 110 µg/L, TCAA: 100 µg/L	93, 92, 91, 94, 93, 12, 45, 19, 87 respectively by NF; ESNA (product name) for a 24-hour test	4	29
Gemfibrozil, clofibric acid, fenofibrate, carbamazepine,primidone, diclofenac, ibuprofen,ketoprofen,naproxen, fenoprofen, propyphenazone, meclofenamic acid,tolfenamic acid	Up to 1200ηg/L after secondary	MF: > 98%	4	16
Estrone, estradiol	100 ηg/L	NF: 75–95%	3	35
Benzylpenicillin (PenG), erythromycin, medmycin	9000-27000 U/mL	UF: 86–93%	4	31

Table 6-5. Treatment efficiency of Ozone on some EPOC compounds

EPOC Compound	Concentration Range	Removal Efficiency	Confidence	Reference
BisphenolA (BPA), 17β-Estradiol (E2), 17α-ethynyl estradiol	0.5 μM	~100%	5	5
Antibiotics: carbadox, sulfachlorpyridazine, sulfadimethoxine, sulfamerazine, sulfamethazine, sulfathiazole, and trimethoprim	50 μg/L for each compound	> 95%	4	2
Clofibric acid, ibuprofen, diclofenac	2 μg/L	> 98% with 3.7mg/L of O3 and 1.8mg/L of H2O2	3	17
Pentachlorophenol (PCP)	10 μg/L	100% after 10 min.	3	23
Antibiotics: ceftriaxone sodium, penicillin VK, enrofloxacin	250 mg/L as COD	71–82% as COD removal	4	8
Paracetamol	$5*10^{-3}$ mol/L	75–97% as T.O.C removal depending on reaction time	4	7
EDCs: Nonylphenol(NP),nonylphenol mono and diethoxylates(NP_1EO and NP_2EO), nonylphenol carboxylates (NP_1EC and NP_2EC) and their brominated and chlorinated derivatives	8–22 μg/L	87% after secondary removal	2	42
Pharmaceuticals: benzafibrate, carbamazepine, diclofenac, ethinylestradiol, sulfamethoxazole	10–40μg/L	95% for O3 dose of > 0.2mg/L and < 80 % for O3 dose of < 0.2mg/L	3	26
Pharmaceutical: Diclofenac	$1*10^{-3}$ M	97% removal in terms of chlorine to chloride ions conversion	4	6
5 antibiotics, 1 antiepileptic, 4 antiphlogistics, 2 lipid regulators, 5 betablockers, 2 musk fragrances, Estrone, caffeine, 4 ICMs	0.1–5.2 μg/L	All below Limit of Quantitation (LOQ) except 4 Iodinated x-ray contrast media (ICM)	3	45
Pharmaceuticals: bezafibrate, clofibric acid, carbamazepine, diclofenac	1–8μg/L	carbamazepine,diclofenac > 97%, < 40% for clofibric acid, bezafibrate > 50 %	3	46

Table 6-6. Treatment efficiency of Activated Carbon on some EPOC compounds

EPOC Compound	Concentration Range	Removal Efficiency	Confidence	Reference
17 α-ethynylestradiol (EE2)	15000 ηg/L	99.80%	2	43
(1) Bisphenol A, (2) Nonylphenol, (3) Octylphenol, (4) Estradiol (ELISA)	(1) 0.13 μg/L, (2) 2.8 μg/L, (3) n.d*, (4) 0.005 μg/L * n.d < 0.03 μg/L	(1) > 96% (2) > 98% (3) Non-detect (4) > 80% removals	3	10
Bisphenol A (BPA), 17β-estradiol (E2), 17α-ethynyl estradiol (EE2)	500 ηg/L	> 99% for PAC dosage of 15mg/L	3	50
17 β-estradiol	1–100 ηg/L	49–81% depending on influent conc.	2	20
Bromoform, 2-Chloropyridine, trichlororbenzenes, terbuthylazine, polyethoxylated nonylphenols, bromo ployethoxylated nonylphenols	4–60 ηg/L	57, 90, 96, 86, 47, 91% respectively for column 'A' compounds	3	11
Antibiotics: carbadox, sulfachlorpyridazine, sulfadimethoxine, sulfamerazine, sulfamethazine, sulfathiazole, and trimethoprim	50 μg/L for each compound	57–97% and 81–98% for PAC dosages of 10mg/L and 20 mg/L resp.	4	2
Penicillin G	40–1060 mg/L	64.4% @ 35°C and 177mg/L	4	3
EDCs: Nonylphenol (NP),nonylphenol mono and diethoxylates (NP_1EO and NP_2EO), nonylphenol carboxylates (NP_1EC and NP_2EC) and their brominated and chlorinated derivatives	8–22 μg/L	73% after O3	2	42
Pharmaceuticals: bezafibrate, clofibric acid, carbamazepine, diclofenac	1–8μg/L	75–99% for carbamazepine, diclofenac, bezafibrate, and 20% for clofibric acid	3	46
Progesterone	$8.98*10^{-5}$ M	77% by Merck GAC	4	12
Estrone	15–100 ηg/L	95% at 50mg/L of PAC @ 15ηg/L	3	34
Estradiol equivalent (EEQ)	66.4, 56.2, 52.9, 45.3, 67.5 ηg/L on different sampling days	98.9, 98.8, 98.7, 98.5 after column secondary treatment	2	14

Table 6-7. Treatment efficiency of Electron Beam/ Radiation on EPOC compounds

EPOC Compound	**Concentration Range**	**Removal Efficiency**	**Confidence**	**Reference**
Phenol, chlorofom, tetrachloroethylene (PCE), carbon tetrachloride, trichloroethylene (TCE), 1,1- dechloroethane, dichloromethane, benzene, toluene, xilene	3–10 μg/L for benzene, toluene, xilene, phenol ; 1000–10000 μg/L for PCE, CH_3Cl, TCE, dichloromethane, carbontetrachloride; 80000 μg/L for 1, 1-dichloroethane	> 90% for all compounds	3	44
(1) Phenol, (2) 2-cholorophenol, (3) 3, 4-dichlorophenol and (4) sodium dodecylbenzene sulfonate (SDBS)	0.1 g/L	4 < 20%. 1: 25% and 45%, 2: 38% and 85%, 3: < 20% for both with (1) Low frequency (20 kHz) ultrasonic irradiation (US), and (2) US + Fe^{2+} respectively	4	40
Tetrachloroethylene (PCE)	$2.5*10^{-4}$ –$9.2 *10^{-6}$ mol/L	95% @ 1.5 kGy/h of ^{60}Co-gamma rays	4	33
Iomeprol (1), clofibric acid (2), 4-chlorophenol (3), hydroquinone, isobutyric acid	(1) 0.0055 mmol/L, (2) 0.9 mmol/L, (3) 0.8 mmol/L	Simulated solar light with TiO2 materials: 72 % for iomeprol after 180 minutes, 70 % for clofibric acid, 35–40 % for 4-chlorophenol, hydroquinone and isobutyric acid in DOC reduction after 40 minutes.	4	19

Table 6-8. Treatment efficiency of 'Other' techniques on some EPOC compounds

EPOC Compound	Concentration Range	Removal Efficiency	Confidence	Reference
17β-Estradiol	10^{-6}M	~100% photocatalytic degradation by TiO_2	2	38
5 antibiotics, 1 antiepileptic, 4 antiphlogistics, 2 lipid regulators, 5 betablockers, 2 musk fragrances, Estrone, caffeine, 4 ICMs	0.1–5.2 µg/L	25–89% with H_2O_2/O3 and 36–90% with O3/UV for the 4 ICMs	3	45
Procaine Penicillin G (PPG)	PPG formulation effluent (COD_o = 600 mg/l; BOD_5 =53 mg/l; TOC_o = 450 mg/l)	56% COD and 42% TOC removal by photo-Fenton-like (Fe3+/H2O2/UV-A) processes and 44% COD and 35 % TOC removal by Fenton-like (Fe3+/H2O2) process @ [Fe3+] = 1.5mM and [H2O2] = 25 mM	5	4
Antibiotics: ceftriaxone sodium, penicillin VK, enrofloxacin	250 mg/L as COD	75–99% for COD removal with H_2O_2/O3 process	4	8
Penicillin G	40–1060 mg/L	78.3% @ 35^{o}C and 69 mg/L by R.arrhizus (a fungus)	4	3
Paracetamol	5*10^{-3} mol/L	87% as T.O.C removal with H2O2/O3 process	4	7
Naphthalene, anthraquinone-sulphonic acids	naphthalene sulphonic acid: 26 mg/l, aminoanthraquino-ne: 24.6 mg/l, phenol 16.5 mg/l	87% by Eltectrogenerated Fenton's Reagent	4	39
(1) Phenol, (2) 2-cholorophenol, (3) 3,4-dichlorophenol and (4) sodium dodecylbenzene sulfonate (SDBS)	0.1 g/L	Phenol: 65% and 90%, CP: 80% and 90%, DCP: 75% and 90% with (1) US+Fenton, and (2) Fenton resp.	4	40
17 α-ethynylestradiol (EE2)	15000 ηg/L	Sand: 17.3% and MnO_2: 81.7%	2	43

7.0 KEY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Secondary Treatment

It was found that secondary treatment alone could generate high removals for some EPOCs. It was reported by Baronti et al. (2000) that for a variety of hormonal compounds, high treatment efficiency was achieved by six Italian sewage treatment plants employing activated sludge process. But this result cannot be considered as typical since there are other studies (Nghiem et al., 2002) which suggest low removals for some of the same hormonal compounds (for example, estrone) examined in the aforementioned study. The discrepancy in outcomes could be caused by several factors in the treatment system such as food to microorganisms ratio, hydraulic retention time (HRT), solids retention time (SRT), temperature and concentration range.

Advanced Treatment Technologies

Studying Tables 6-2 through 6-8, a generalization can be reached that all the advanced treatment methods show high treatment efficiencies for most of the EPOC compounds under investigation.

UV alone or UV with H_2O_2 can effectively treat many EPOC compounds. Jiang et al. (2002) found greater than 90% removals for chlorobenzene (ClBz), 1,4-dichlorobenzene (1,4-DCilBz)and 1-chloronaphthalene (ClNt). 95% disinfection efficiency (Acher et al., 1997) was found in two experimental pilot plants for a wastewater polluted with bromacil. The Photo-Fenton process, which is the combination of UV with H_2O_2 and Fe (II), has shown 100 % removal of a very frequently studied EPOC, bisphenolA (BPA).

Reverse Osmosis (RO) has shown very high removal rates (mostly > 90%) across a variety of EPOC categories such as antibiotics, pharmaceuticals, hormones and industrial chemicals (Schafer et al., 2000; Coors et al., 2003; Adams et al., 2002; Kimura et al., 2003; Li et al., 2004). Nanofiltration and RO was found to be most effective at treating a variety of pharmaceutical compounds (Heberer et al., 2002) in a study that examined activated sludge process, trickling filters and RO at full-scale facilities in Arizona and California.

In a study done by the USEPA (EPA/625/R-00/015) to evaluate the removal of endocrine disruptor chemicals (EDCs) using drinking water treatment processes, it identified granular activated carbon (GAC) as the treatment option. The EDCs that were studied are pesticide residues, highly chlorinated compounds, alkylphenols and alkylphenol ethoxylates and plastic additives.

Sometimes a combination of techniques has advantages over a single treatment option. In a pilot plant that received sewage water from a German STP, ozone (O_3) by itself effectively treated (below limit of quantitation) all of the five antibiotics, one antiepileptic, four antiphlogistics, two lipid regulators, five betablockers, two musk fragrances, estrone, and caffeine except four iodinated X-ray contrast media (ICM) (Ternes et al., 2003). Removal efficiency improved for the four ICMs to 25–89% with O_3/H_2O_2 and 36–90% with O_3/UV.

Of interest are the studies that compare different advanced treatment technologies for the same EPOC compound or category. Schafer et al. (2002) reported 22% removal for the hormone Estrone (E1) by secondary treatment, 95–99% removal depending on the pH by RO, and 95% removal by powdered activated carbon at a dosage of 50 mg/L. For the pharmaceutical diclofenac 84% removal (Andreozzi et al., 2004) by UV with H_2O_2 was obtained in terms of chlorine to chloride ions conversion whereas ozone was more effective at 97%.

Conclusions

A combination of UV-O_3 and RO-carbon filtration should be considered best available treatment technology for a wide variety of EPOCs. The treatment costs to achieve > 99% removal at parts per trillion (ppt) concentrations at 130 mgd throughout are probably prohibitive at present. As the cost of these technologies decline with expanded use and experience, this conclusion should be revisited. However, the cost of these technologies was outside the scope of this study but is addressed in a separate study done by CDM for the USACE (Corps Contract No. DACW 17-01-D-00B).

Recommendations

Revision of this report should occur after the final results from the USGS study are made available.

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9.0 APPENDICES

Appendix 9-1. Table showing confidence values based on study design criteria

Confidence Value	Study Design
1	Mass Budget and Radioactive Tracers
2	Mass Budget OR Radioactive Tracers
3	In/Out Conc. in the relevant concentration range
4	In/Out Conc. in the extreme concentration range
5	Inferred from fate data in surface water in the relevant concentration range
6	Inferred from fate data in groundwater in the relevant concentration range
7	Inferred from fate data in soil in the relevant concentration range
8	Inferred from fate data in surface water in the extreme concentration range
9	Inferred from fate data in groundwater in the extreme concentration range
10	Inferred from fate data in soil in the extreme concentration range
11	Analytical method within the relevant concentration range
12	Analytical method in the extreme concentration range

Appendix 9-2. Listing of all the literature collected with their ranks.

Title	Author(s)	Source	Compound(s)	Technologies	Rank
17β-Estradiol Degradation by TiO2 Photocatalysis as a Means of Reducing Estrogenic Activity	Y. Ohko, K. I. Iuchi, C. Niwa, T. Tatsuma, T. Nakashima, T. Iguchi, Y. Kubota, A. Fijishima	Environ. Sci. Technol., Vol 36 (2002), 4175-4181	17β -estradiol	TiO_2 photocatalysis	1
3rd International conference on pharmaceuticals and EDCs in water	Proceedings of conference (2003)	National Groundwater Association	pharmaceuticals and EDCs	general	4
A case study of long-term RO plant operation without chemical pretreatment	V. J. Shah, C. V. Devmurari, S. V. Joshi, J. J. Trivedi, A. Prakash Rao, P. K. Ghosh	Desalination , Vol. 161 (2004), 137–144	general	RO	2
A pilot scale evaluation of removal of mercury from pharmaceutical wastewater using granular activated carbon	Rominder P.S. Suri, Patrick J. Cyr, Edward D. Helmig	Water Research, Vol. 36 (2002), 4725–4734	Hg in pharmaceuticals, phenol, Cu	GAC	1
Adsorption isotherms of 17β-estradiol on GAC	Maria Fuerhacker, Astrid Durauer, Alois Jungbauer	Chemosphere, Vol 44 (2001), 1573–1579	17β-estradiol	GAC	1
Adsorption of trace steroid estrogens to hydrophobic hollow fibre membranes	Sheng Chang, T. David Waite, Andrea I. Schsfer, Anthony G. Fane	Desalination, Vol. 146 (2002), 381–386	Estrone	Membrane	1
Adsorptive interactions between membranes and trace contaminants	L. D. Nghiem, A. I. Schafer, T. D. Waite	Desalination, Vol. 147 (2002), 269–274	estrone	RO	1
Advanced oxidation of the pharmaceutical drug diclofenac with UV/H2O2 and ozone	D. Andreozzi, David Vogna, Raffaele Marotta, Alessandra Napolitano, Marco D'Iscia	Water research, Vol 38 (2004), 414–422	diclofenac	UV/H2O2 and ozone	1
Advanced water treatment with manganese oxide for the removal of EE2	J. de Rudder, T. Van de Wiele, Willem Dhooge, Frank Comhaire, Willy Verstraete	Water Research, Vol 38 (2004), 184–192	EE2	GAC with MnO2	1
Alkylphenol ethoxylate degradation products in land-applied sewage suldge(biosolids)	M. J. La Guardia et al.	Environ. Sci. Technol., Vol. 35 (2001), 4798–4804	phenols	degradation	3
An Analytical Solution of Tetrachloroethylene Transport and Biodegradation	Yunwei Sun, Xinjian Lu, James N. Petersen, Thomas A. Buscheck	Transport in Porous Media ,Vol. 55 (2004), 301–308	TCE, PCE, 1, 2-DCE	Analytical model of degradation	3
Analysis and occurrence of estrogenic hormones and their glucuronides in surface water and waste water in the Netherlands	A. C. Belfroid, A. Van der Horst, A. D. Vethaak, A. J. Schafer, G. B. J. Rijs, J. Wegener, W. P. Cofino	Science of the Total Environment, Vol. 225 (1999), 101–108	estrone, 17β-estradiol, 17α-estradoil and 17α-ethynyl estradoil	analysis	3
Analysis and removal of emerging contaminants in wastewater and drinking water	Mira Petrovic, Susana Gonzalez, Damia Barcelo	Trends in Analytical Chemistry, Vol. 22 (2003), 685–696	pharmaceuticals	membrane, AOPs	1
Analysis of endocrine disrupting steroids: Investigation of their release into the environment and their behaviour during bank filtration	Sebastian Zuehlke, Uwe Duennbier, Thomas Heberer, and Birgit Fritz	Ground Water Monitoring and Remediation, Vol. 24 (2004), 78–85	E1, E2, EE2	secondary treatment, bank filtration	1
Application of biosorption for penicillin G removal: comparison with activated carbon	Zumriye Aksu, Ozlem Tunc	Process Biochemistry (2004), in press	Penicillin G	secondary, AC, fungus	2
Application of pervaporation and adsorption to the phenol removal from wastewater	Wojciech Kujawski, Andrzej Warszawski, Wlodzimierz Ratajczak, Tadeusz Porebski, Wieslaw	Separation and Purification Technol., 2004, Article in Press	phenols	Membrane	1

Title	Author(s)	Source	Compound(s)	Technologies	Rank
	Capala, Izabela Ostrowska				
Application of ultrafiltration to improve the extraction of antibiotics	S.Z. Li , X.Y. Li , Z.F. Cui , D.Z. Wang	Separation and Purification Technology, Vol. 34 (2004), 115–123	antibiotics	ultrafiltration	2
Aquatic ecotoxicology of fluoxetine	B W Brooks, Christy M Foran, Sean M Richards, James Weston, Philip K Turner, Jacob K Stanley, Keith R Solomon, Marc Slattery, Thomas W LaPoint	Toxicology Letters, Vol. 142 (2003), 169-183	fluoxetine	risk assessment	3
Assessing the environmental fate of chemicals of emerging concern: a case study of PBDE	Donald Mackay, Anna Palm, Ian T. Cousins, Mats Tysklind, Chris Metcalfe, Mehran Alaee	Environmental Pollution, Vol. 117 (2002), 195–213	polybrominated dipheyl ethers	Fate lit.	2
Assessment on the removal of organic chemicals from raw and drinking water at a Llobregat river water works plant using GAC	J. Caixach, F. Paune, I. Espadaler, J. Om, J. Rivera	Water Research, Vol. 32 (1998), 3313–3324	THM, bromoform, terbutyllazine, molinate, surfactants, plasticizers etc	GAC	1
Attenuation of two estrogen compounds in aquifer materials supplemented with sewage effluent	Guang-guo Ying, Rai S Kookana, Peter Dillon	Ground Water Monitoring and Remediation, Vol 24(2004), 102–107	E2, EE2	Fate lit.	3
Behaviour and occurrence of estrogens in municipal sewage treatment plants-I Investigations in Germany, Canada and Brazil	T. A. Ternes, M Stumpf, J. Mueller, K. Haberer, R. D. Wilken, M. Servos	Science of the Total Environment, Vol 225(1999), 81–90	EDCs	degradation in STPs	2
Behaviour and occurrence of estrogens in municipal sewage treatment plants-II aerobic batch experiments with activated sludge	T. A. Ternes, P. Kreckel, J Mueller	Science of the Total Environment, Vol. 225(1999), 91–99	EDCs	degradation in activated sludge plant	2
Behaviour of pharmaceuticals, cosmetics and hormones in a sewage treatment plant	Marta Carballaa, Francisco Omila, Juan M. Lemaa, Marıa Llompartb, Carmen Garc!ıa-Jaresb, Isaac Rodr!ıguezb, Mariano Go´ mezc, Thomas Ternes	Water Research , Vol. 38 (2004), 2918–2926	Two cosmetic ingredients (galaxolide, tonalide), eight pharmaceuticals (carbamazepine, diazepam, diclofenac, ibuprofen, naproxen, roxithromycin, sulfamethoxazole andiopromid e) andthree hormones (estrone, 17b-estradiol and 17a-ethinylestradiol)	secondary treatment	2
Biodegradability of some antibiotics, elimination of the genotoxicity and affection of wastewater bacteria in a simple test	K. Kummerer, A. Al-Ahmad, V Mersch-Sundermann	Chemosphere, Vol 40 (2000), 701–710	antibiotics-ciprofloxacin, ofloxacin, metronidazole	Biodegradabil-ity	2
Biodegradation of anthracene and fluoranthene by fungi isolated from an experimental constructed wetland for wastewater treatment	F. Giraud, P. Guiraud, M. Kadri, G. Balke, R. Steiman	Water Research, Vol 35(2001), 4126–4136	fluoranthene (PAHs)	wetland	3
Biodegradation of tetrachloroethylene in upflow anaerobic sludge blanket reactor	S. K. Gupta, S. M. Prakash	Biosource Technology, Vol 72 (2000), 47–54	PCE, TCE	UASB	2

Title	Author(s)	Source	Compound(s)	Technologies	Rank
Biological and physical attenuation of endocrine disruptors and pharmaceuticals: Implications for water reuse	Shane A Snyder, Paul Westerhoff, Yeomin Yoon, Joseph Leising, Brett Vanderford	Ground Water Monitoring and Remediation, Vol. 24 (2004), 108-118	several EDCs and PhACs	ASR study	4
Carbamazepine as a possible anthropogenic marker in the aquatic environment: investigations on the behaviour of carbamazepine in wastewater treatment and during groundwater infiltration	M Clara, B Strenn, N Kreuzinger	Water Research, Vol 38(2004), 947-954	Carbamazepine	degradation	3
Case history: Pharmaceutical wastewater treatment plant upgrade, SmithKline Beecham Pharmaceuticals Company	Antonio Garcia, Hector M. Rivas, Jorge L. Figueroa, Alex L. Monroe	Desalination, Vol. 102 (2004), 225–263	general	RO	3
Chemical Oxidation of trichloroethylene with potassium permanganate in a porous medium	Kun Chang Huang, George E Hoag, Pradeep Chheda, Bernard A Woody, Gregory M Dobbs	Advances in Environmental Research, Vol. 7 (2002), 217–229	TCE	Oxidation	2
Concentration of 17β-estradiol using an immunoaffinity porous hollo-fiber membrane	S. Nishiyama, A. Goto, K. Saito, K. Sugita, M. tamada, T. Sugo, T. Funami, Y. Goda, S. Fujimoto	Anal. Chem., Vol. 74 (2002), 4933–4936	E2	membrane	1
Degradation of pentachlorophenol by ozone generated by pulsed power corona discharge	Kil-Hwan Hong, Suk-Jung Oh and Seung-Hyeon Moon	Water, Air, and Soil Pollution 145: 187–203, 2003.	pentachloropheno l (PCP)	ozone	1
Degradation pf bisphenol A in water by the photo-Fenton reaction	Hideyuki Katsumata, Shinsuke Kawabe, Satoshi Kaneco, Tohru Suzuki, Kiyohisa Ohta	Journal of Photochemistry and Photobiology, Vol. 162 (2004), 297–305	BPA	photo-Fenton process	2
Determination of sex hormones and nonylphenol ethoxylates in the aqueous matrices of two pilot scale municipal wastewater treatment plants	USEPA, Univ. of Cincinnati, Shaw Env. & Infrastructure, Inc.	NRMRL	7 hormones, phenols, ethoxylates	GC/MS analysis	2
Development of a sensitive e-screen assay for quantitative analysis of estrogenic activity in municipal sewage plant effluents	Wolfgang Korner, Volker Hanf, Winfried Schuller, Christoph Kempter, Jorg Metzger, Hanspaul Hagenmaier	Science of the Total Environment , Vol 225 (1999), 33–48	17β-estradiol, estrogenic compounds	analysis	2
Ecologically Friendly wastewater disinfection techniques	A. Acher, E. Fischer, Roni Turheim, Y. Manor	Water Research, Vol 31 (1997), 1398–1404	DBPs	UV	2
Ecotoxicological impact of pharmaceuticals found in treated wastewaters: study of carbamazepine, clofibirc acid, and diclofenac	Jeanne Garric, Benoit Ferrari, Nicklas Paxeus, Roberto Lo Giudice, Antonino Pollio	Ecotoxicology and Environmental Safety, Vol 55 (2003), 359–370	carbamazepine, clofibirc acid, and diclofenac	risk assessment	2
Effects of chlorine on the decrease of estrogenic chemicals	Byoung-cheun Lee, Motoyuki Kamata, Yasushi Akatsuka, Makoto Takeda, Koichi Ohno, Tasuku Kamei, Yasumoto Magara	Water Research, Vol 38(2004), 733-739	17β-estradiol, nonylphenol, bis-phenol A	chlorination	1
Effects of dissolved organic matter surrogates on the partitioning of 17β-estradiol and p-Nonylphenol between synthetic membrane vesicles and water	Hiroshi Yamamoto, Howard M Liljestrand, Yoshihisa Shimizu	Environ. Sci. Technol. , Vol 38(2004), 2351–2358	E2, NP	fate model	2
Elimination of COD, microorganisms and pharmaceuticals from sewage by trickling through sandy soil below	Claudia Gallert, Jianmin Hua, Pinglin An, Josef Gallert	Water Research, Vol 37 (2003), 4395–4404	benzafibrate, clofibric acid, diclofenac,	sand filter	2

Title	Author(s)	Source	Compound(s)	Technologies	Rank
leaking sewers			ibuprofen, naproxen, iopromide, iomeprol etc		
Emerging contaminant removal using RO and UV for the groundwater replenishment system	S. S. Deshmukh, M. V. Patel, W. R. Everest, J. L. Daugherty	Membrane technology conference, AWWA (2003)	N-nitrosodimethylamine(NDMA), 1, 4-Dioxane,several pharmaceuticals	RO, UV	1
Emerging pollutants in water analysis	Editorial	Trends in Analytical Chemistry, Vol. 22 (2003)	general	GC/MS analysis	3
Endocrine disruptor removal from wastewater using membrane bioreactor and nanofiltration technology	Thomas Wintgens, Martin Gallenkemper, Thomas Melin	Desalination, Vol 146 (2002), 387–391	EDCs	membrane bioreactors, NF	2
Endocrine disruptors and pharmaceutically active compounds: US regulations and research	Dr Shane Snyder	South Nevada Water Authority	EDCs, PhACs	general	3
Endocrine disruptors in wastewater: Is there a cause for concern?	Matthew Davis, Chris Cleveland & Mike Sharar	Water Environment Federation Proceedings 1999	EDCs	general	4
Endocrine/Estrogen Conference Report		E/E letter (2002)	EDCs	general	4
Estimating steroid oestrogen inputs into activated sludge treatment works and observation on their removal from the effluent	A C Johnson, A Belfroid, A Di Corcia	Science of the Total Environment, Vol 256(2000), 163-173	E2, E1, EE2, E3	estrogen input model	2
Estrogen receptor agonist fate during wastewater and biosolids treatment processes: a mass balance analysis	R David Holbrook, John T Novak, Thomas J Grizzard, Nancy G Love	Environ. Sci. Technol. , Vol. 36(2002), 4533–4539	estrogenic compounds	fate	2
Estrogenic and dioxin-like in each step of a controlled landfill leachate treatment plant in Japan	Peter A Behnisch, Kenji Fujii, Ken Shiozaki, Isamu Kawakami, Shin-ichi Sakai	Chemosphere, Vol. 43(2001), 977–984	Bisphenol A, Nonylphenol, Octylphenol, Estradiol (ELISA)	GAC	2
Evaluation of biokinetic parameters for pharmaceutical wastewater using aerobic oxidation integrated with chemical treatment	D Samuel Suman Raj, Y. Anjaneyulu	Process Biochemistry (2004), in press	general	pretreatment	3
Expanding the applicability of multimedia fate models to polar organic chemicals	Knut Breivik, Frank Wania	Environ. Sci. Technol. , Vol. 37(2003), 4934–4943	organic chemicals	fate and transport model	3
Fate and transport of testosterone in agricultural soils	Francis X. M. Casey, Heldur Hakk, Jiri Simunek, Gerald L. Larsen	Environ. Sci. Technol. , Vol 38(2004), 790–798	testosterone	Fate and transport	3
Fate of estrogens in a municipal sewage treatment plant	Henrik Andersen, Hansruedi Siegrist, Bent Halling-Sorensen, Thomas A Ternes	Environ. Sci. Technol. , Vol. 37(2003), 4021–4026	estrone, 17β-estradiol, and 17α-ethynyl estradoil	fate	2
Fate of pharmaceuticals-photodegradation of simulated solar UV-light	F. H. Frimmel, Tusnelda E. Doll	Chemosphere, Vol. 52 (2003), 1757–1769	pharmaceuticals	UV	1
Fate of pharmeceuticals during indirect potable reuse	J. E. Drewes, T. Heberer, K Reddersen	Water Science and Technology, Vol. 46 (2002), 73–80	pharmaceuticals	fate	2
Fate of selected pharmaceuticals during additional steps of wastewater treatment and in the groundwater after infiltration af the treated wastewater	Dr. Norbert Kreuzinger	Project Poseidon presentation	10 pharmaceuticals	general	4
Fate of steroidal hormones during	Jessica Mansell, J.E.	Ground Water	E2, estriol,	soil aquifer	3

Title	Author(s)	Source	Compound(s)	Technologies	Rank
soil aquifer treatment	Drewes	Monitoring and Remediation, Vol 24(2004), 94-101	testosterone	treatment	
Field studies on the fate and transport of pharmaceutical residues in bank filtration	Thomas Heberer, Andy Mechlinski, Britta Fanck, Andrea Knappe, Gudrun Massmann, Asaf Pekdeger, Birgit Fritz	Ground Water Monitoring and Rremediation, Vol 24 (2004), 70–77	PhACs	bank filtration	3
Groundwater recharge with reclaimed municipal wastewater: health and regulatoy considerations	Takashi Asano, Joseph A. Cotruvo	Water Research, Vol 38 (2004), 1941–1951	various	risk assessment	2
H2O2/VisUV photo-oxidation process for treatment of waterborne hazardous substances-reaction mechanism,rate model, and data for tubular flow and flow stirred tank reactors	Steven Shimoda, H. William Prengle Jr, James M. Symons	Waste Management, Vol. 17(1997), 507–515	Benzene, dichlorobenzene, TCE, TCA, CTC	H2O2/VisUV	1
HPLC-fluorescence detection and adsorption of BPA, 17β-estradiol, and 17α-ethynyl estradoil on powdered activated carbon	Yeomin Yoon, Paul Westerhoff, Shane A. Snyder, Mario Esparza	Water Research, Vol 37 (2003), 3530–3537	BPA, 17β-estradiol, and 17α-ethynyl estradoil	powdered activated carbon	1
Influence of the structural diversity of data sets on the statistical quality of 3 dimensional QSAR models: predicting the estrogenic activity of xenoestrogens	Seong Jae Yu, Susan N. Keenam, Weida Tong, William J Welsh	Chem. Res. Toxicol., Vol. 15 (2002), 1229–1234	EDCs	QSAR	2
Input/output balance of estrogenic active compounds in a major municipal sewage plant in Germany	W. Korner, Ulrike Bolz, Wolfgang Submuth, Georg Hiller, Winfred Schuller, Volker Hanf, Hanspaul Hagenmaier	Chemosphere, Vol. 40 (2000), 1131–1142	4-t-Octylphenol, Sum 4-Nonylphenol, Bisphenol A, 2-hydroxybipheyl, 4-chloro-3-methylphenol, 3-t-butyl-4-hydroxyanisole	Analysis	1
Kinetic study of photocatalytic degradation of carbamazepine, clofibric acid, iomeprol and iopromide assisted by different TiO2 materials-determination of intermediates and reaction pathways	F. H. Frimmel, Tusnelda E. Doll	Water Research, Vol. 38(2004), 955-964	carbamazepine, clofibric acid, iomeprol and iopromide	photocatalytic degradation	1
Kinetics and mechanisms of ultrasonic degradation of volatile chlorinated aromatics in aqueous solutions	Yi Jiang, Chriatian Petrier, T. David Waite	Ultrasonics Sonochemistry, Vol 9 (2002), 317–323	chlorobenzene, 1,4-dichlorobenzene, 1-chloronaphthalene	decomposition processes	3
MARS- a new membrane process for the recovery of phenols from wastewaters	Shejiao Han, Frederico Castelo Ferreira, Andrew Livingston	Journal of Membrane Science, Vol. 118 (2001), 219–233	phenols	Membrane aromatic recovery system (MARS)	1
Membrane filtration (RO-UF) for antibiotic wastewater treatment and recovery of antibiotics	Shi-zhong Li, Xiao-yan Li, Dian-zuo Wang	Separation and purification Technol., Vol 34(2004), 109–114	oxytetracycline	RO, UF	2
Membrane filtration in water recycling: removal of natural hormones	L. D. Nghiem, A. I. Schafer, T. D. Waite	Water Sci. & Technol., Vol. 3 (2003), 155–160	estrone, estradiol	nanofiltration	1
Microfiltration of a dental wastewater for Hg removal: clinic demonstration	Brain E Reed, Michael D. Bagby, Ronald L. Vaughan, Jr.	Journal Of Environmental Engineering, Vol. 130 (2004), 12–16	Hg	Hollow fiber and tubular membrane	1
Modelling of pharmaceuticals residues in Australian sewage by quantities of use and fugacity	Stuart J khan, Jerry E. Ongerth	Chemosphere, Vol. 54 (2004), 355–367	50 "top" Australian pharmaceutical	Modeling	3

Title	Author(s)	Source	Compound(s)	Technologies	Rank
calculations			compounds		
Monitoring natural and synthetic estrogens at activated sludge sewage treatment plants and in a receiving river water	Chiara Baronti, Roberta Curini, Giuseppe D'Ascenzo, Antonio Di Corcia, Alessandra Gentili, and Roberto Samperi	Environ. Sci. Technol., Vol. 34 (2000), 5059–5066	estrone, estroil, estradoil and ethynyl estradoil	Activated sludge	2
Monte Carlo analysis of uncertainty attached to microbial pollutant degradation rates	Pierre Goovaerts, Jeremy Semrau, Sonny Lontoh	Environ. Sci. Technol., Vol. 35 (2001), 3924–3930	Vinyl chloride, halogenated hydrocarbons	Statistical model	4
Occurrence and Environmental Behaviour of the bactericide Triclosan and its Methyl derivative in surface waters and in wastewater	Anton Lindstorm	Environ. Sci. Technol., Vol. 36 (2002), 2322–2329	Triclosan	occurrence data	3
Occurrence and fate of macrolide antibiotics in wastewater treatment plants and in the Glatt valley watershed, Switzerland	Christa S McArdell, Eva Molnar, Marc J. F. Suter, Walter Giger	Environ. Sci. Technol., Vol .37 (2003), 5479–5486	erythromycin and its degradation products	Analysis using LC/MS	2
Occurrence and removal of estrogenic short-chain ethoxy nonylphenolic compounds and their halogenated derivatives during drinking water production	Mira Petrovic, Alfredo Diaz, Francesc Ventura, Damia Barcelo	Environ. Sci. Technol., Vol. 37 (2003), 4442–4448	Nonylphenol, Nonylphenol mono and diethoxylates, Nonylphenol carboxylates and their brominated and chlorinated derivates	Flocculation followed by rapid sand filtration, ozonation, GAC, Cl disinfection	1
Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: a review of recent research data	Thomas Heberer	Toxicology letters, Vol. 131 (2002), 5–17	> 80 PhACs	fate	1
Oestrogens and oestrogenic activity in raw and treated water in severn trent water	J K Fawell, D Sheahan, H A James, M Hurst, S Scott	Water Research, Vol. 35 (2001), 1240–1244	steroids, phthalates, nonylphenol, BPA, bisphenol F	bioassay study	3
On-site tertiary treatment using Ecomax systems	Martin Bowman	Desalination, Vol. 106 (1996), 305–310	general	Metals, typical ww effluents	3
Oxidation of bisphenol A, 17β-estradiol,and 17α-ethynyl estradoil and byproduct estrogenicity	Absar Alum, Yeomin Yoon, Paul Westerhoff, Morteza Abbaszadegan	Environmental Toxicology, Vol. 19 (2004), 257–264	BPA, E2, EE2	ozonation, chlorination	1
Oxidation of Pharmaceuticals during Ozonation and Advanced Oxidation Processes	Marc M. Huber, Silvio Canonica, Gun-Young Park, and Urs von Gunten	Environment Science &Technology, Vol. 37 (2002), 1016–1024	bezafibrate, carbamazepine, diclofenac, enthinylestradiol, sulfamethoxazole, diazepam, ipromide, ibuprofen	ozonation & AOPs	1
Oxidative transformation of phenols in aqueous mixtures	L Gianfreda, F Sannino, M A Rao, J M Bollag	Water Research, Vol . 37 (2003), 3205–3215	phenols	oxidation	2
Oxidative treatment of pharmaceuticals in water	F. H. Frimmel, C. Zwiener	Water Research, Vol. 34 (2000), 1881–1885	clofibric acids, ibuprofen, diclofenac	Oxidation	1
Ozonation: a tool for removal of pharmaceuticals, contrast media and musk fragrances from wasewater?	T A Ternes, Jeannette Stuber, Nadine Herrmann, Derek McDowell, Achim Ried, Martin Kampmann, Bernhard Teiser	Water Research, Vol. 37 (2003), 1976–1982	pharmaceuticals, contrast media and musk fragrances	Ozonation, UV	1
Ozone treatment degrades endocrine disruptors in pharmaceutical wastewater. (Technologies & Products).	Article A106648386	Water and Waste Water International, Feb 2003 v18 i1 p60 (1)	pharmaceuticals EDCs	Ozone	4

Title	Author(s)	Source	Compound(s)	Technologies	Rank
Paracetamol oxidation from aqueous solutions by means of ozonation and H2O2/UV	R. Andreozzi, Vincenzo Caprio, Raffaele Marotta, david Vogna	Water Research, Vol 37 (2003), 993–1004	paracetamol	ozonation and H2O2/UV	1
Particle interactions and removal of trace contaminants from water and wastewaters	A. I. Schafer, M. Mastrup, R. Lund Jensen	Desalination, Vol. 147 (2002), 243–250	estrone, estradiol	MF, UF	1
Pharmaceutical and other organic wastewater contaminants within a leachate plume downgradient of a municipal landfill	Kimberlee K. Barnes, Scott C. Christenson, Dana W. Kolpin, Michale J. Focazio, Edward T. Furlong, Steven D. Zaugg, Michael T. Meyer, Larry B. barber	Ground Water Monitoring and Remediation, Vol. 24 (2004), 108–118	76 compounds	Analysis	4
Pharmaceuticals and health care products in wastewater effluents: the example of carbamazepine	K. Stamatelatou, C. Frouda, M. S. Fountoulakis, P. Drillia, M. Kornaros, G. Lyberatos	Water Sci. & Technol., Vol. 3 (2003), 131–137	CBZ	Fate	2
Pharmaceuticals and PPCPs in surface water and treated waters of Louisiana, USA and Ontario, Canada	Glen R Boyd, Helge Reemtsma, Deborah A Grimm, Siddharta Mitra	Science of the Total Environment, Vol. 311 (2003), 135–149	naproxen, ibuprofen, estrone, 17β-estradiol, BPA, chlorophene,triclo san, fluoxetine, and clofibric acid	analysis	3
Pharmaceuticals, hormones, and other organic wastewater contaminants in US streams	USGS Fact Sheet, FS-027-02 (2002)	USGS	general	occurrence data	3
Pharmaceuticals, personal care products, and endocrine disruptors in water: Implications for the water industry	Shane A. Snyder, Paul Westerhoff, Yeomin Yoon, David L. Sedlak	Environ. Engg. Sci., Vol. 20 (2003), 449–469	EDC, PPCP	Oxidation, chlorination, ClO_2, ozonation, UV, membrane, biotransformat ion	2
Phenolic xenoestrogens in surface water, sediments, and sewage sludge from Baden-Wurttemberg, south-west Germany	U. Bolz, H. Hagenmaier, W. Korner	Environmental Pollution, Vol. 115 (2001), 291-301	Phenolic compounds	analysis	2
Photo-Fenton-like and photo-fenton-like oxidation of Procaine Penicillin G formulation effluent	I. Arslan-Alaton, F. Gurses	Journal of Photochemistry and Photobiology A: Chemistry, Vol 165 (2004), 165–175	Procaine Penicillin G (PPG)	Fenton-like (Fe3+/H2O2) and UV-A light assisted Fenton-like (Fe3+/H2O2/ UV-A)	1
Phototransformation and ecotoxicity of the drug Naproxen-Na	M. DellaGreca, M. Brigante, M. Isidori, A. Nardelli, L. Previtera, F. Temussi	Environ Chem Lett (2004), 237–241	naproxen Na	Irradiation	2
Polar drug residues in sewage and natural waters in the state of Rio de Janeiro, Brazil	Marcus Stumpf, Thomas A. Ternes, Rolf-Dieter Wilken, Silvana Vianna Rodrigues, Wolfram Baumann	Science of the Total Environment, Vol. 225 (1999), 135–141	human and veterinarary drugs	removal from STP	2
PPCPs as environmental pollutants	American College of Toxicology 21st Annual Meeting (2000)	NRMRL	pharmaceuticals	general	4
Primary biodegradation of veterinary antibiotics in aerobic and anaerobic surface water simulation systems	F. Ingerslev, Lars Torang, Marie-Louise Loke, Bent Halling Sorensen, Niels	Chemosphere, Vol 44 (2001), 865–872	antibiotics: OLA, MET, TYL, OTC	Biodegradabil-ity	2

Title	Author(s)	Source	Compound(s)	Technologies	Rank
	Nyholm				
Priority lists for persistent organic pollutants and emerging contaminants based on their relative toxic potency in environmental samples	E. Eljarrat, D. Barcelo	Trends in Analytical Chemistry, Vol. 22(2003), 655-665	DLC, PCDDs, PCDFs, PCBs, PCNs, PAHs	Toxicity	2
Products of aqueous chlorination of 17β-estradiol and their estrogenic activities	Jianying Hu, Shuijie Cheng, Takako Aizawa, Yoshiyasu Terrao, Shoichi Kunikane	Environ. Sci. Technol., Vol . 37 (2003), 5665–5670	17 β-estradiol and their products	estrogenicity and degradation products	3
QSAR for estrogen receptor binding affinity of phenolic chemicals	Jian Ying Hu, Takako Aizawa	Water Research, Vol. 37 (2003), 1213–1222	phenols, phytoestrogens, steroids	QSAR	2
Radiation dechlorination of PCE in aqueous solutions under various conditions	V. Mucka, B. Lizalova, M. Pospisil, R. Silber, D. Polakova, B. Bartonicek	Radiat. Phys. Chem., Vol. 67 (2003), 539–544	PCE	Irradiation	2
Rejection of organic micropollutants (DBPs, EDCs, PACs) by NF/RO membranes	Katsuki Kimura, Gary Amy, J.E. Drewes, Thomas Heberer, Tae-Uk Kim, Yoshimasa Watanabe	Journal of Membrane Science, Vol. 227 (2003), 113–121	DBPs, EDCs, PACs	NF, RO	2
Remotion of organic compounds of actual industrial effluents by electron beam irradiation	M. H. O. Sampa, C L Duarte, P. R. Rela, E. S. R. Somessari, C. G. Silveira, A. L. Azevedo	Radiat. Phys. Chem., Vol. 52 (1998), 365–369	phenol, chlorofom, PCE, carbon tetrachloride, TCE, 1,1-dichloromethane, benzene, toulene, xilene	electron beam	1
Removal of antibiotics from surface and distilled water in conventional water treatment processes	C. Adams, Y. wang, K. Loftin, M. Meyer	Journal of Environmental Engineering, Vol. 128 (2002), 253–260	antibiotics-barbadox, sulfachlorpyridazine, sulfadimethoxine, sulfamerazine, sulfamethazine, sulfathiazole, trimethoprim	activated carbon, RO, Oxidation with Cl and ozone	1
Removal of chlorophenols using industrial wastes	Ajay K. Jain, Vinod K. Gupta, Shubi Jain, Suhas	Environ. Sci. Technol. , Vol. 38 (2004), 1195–1200	phenol, 2-chlorophenol, 4-chlorophenol, 2,4-dichlorophenol	carbonaceous adsorbent	2
Removal of EDCs using drinking water treatment processes	EPA/625/R-00/015 (2001)	ORD, USEPA	EDCs	GAC, various	2
Removal of endocrine disruptors in advanced treatment-the Australian approach	A. I. Schafer, T. D. Waite	University of New South Wales	EDCs	particle addition, membranes	1
Removal of endocrine-disrupting chemicals in activated sludge treatment works	A. C. Johnson, John P. Sumpter	Environ. Sci. Technol., Vol. 35 (2001), 4697–4703	EDCs	degradation in activated sludge plant	2
Removal of Estrogenic Activity from Municipal Waste Landfill Leachate Assessed with a Bioassay Based on Reporter Gene Expression	Anja Coors, Paul D. Jones, John P. Giesy, And Hans Toni Ratte	Environ. Sci. Technol., Vol. 37 (2003), 3430–3434	Estradiol equivalent (EEQ)	Biological with ultrafiltration, activated carbon, RO	1
Removal of estrogenicity in swedish municipal sewage treatment plants	Anders Svenson, Ann-Sofie Allard, Mats Ek	Water Research, Vol. 37 (2003), 4433–4443	E1, E2,E3,EE2	comparative at different plants	1
Removal of natural hormones by nanofiltration membranes: measurement, modeling, and mechanisms	Long D. Nghiem, Andrea I Schafer, Menachem Elimelech	Environ. Sci. Technol., Vol. 38 (2004), 1888–1896	estradiol, estrone, testosterone, and progesterone	Nanofiltration	1
Removal of Organic pollutants from industrial wastewater by electrogenerated fenton's reagent	Marco Panizza, Giacomo Cerisola	Water Research, Vol. 35 (2001), 3987–3992	naphthalene, anthraquinone-sulphonic acids	Electrochemi-cal	3

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Removal of pharmaceuticals during drinking water treatment	Thomas A. Ternes, Martin Meisenheimer, derek Mc Dowell, Frank Sacher, Heinz-Jurgen Brauch, Brigittehaist-Gulde, Gudrunpreuss, Uwe Wilme, Ninette Zulei-Seiberts	Environ. Sci. Technol., Vol. 36 (2002), 3855–3863	Bezafibrate, clofibric acid, carbamazepine, diclofenac	Flocculation, ozonation, activated carbon	1
Removal of phenolic compounds from synthetic wastewater using soybean peroxidase	Nicole Caza, J. K. Bewtra, N Biswas, K. E. Taylor	Water Research, Vol. 33 (1999), 3012–3018	phenols	SBP (an enzyme based treatment)	3
Removal of some substituted phenols by activated carbon obtained from agricultural waste	A. A. M. Daifullah, B. S. Girgis	Water Research (J) Vol. 32, No 4, p 1169–1177	phenols	Activated carbon, RO, Oxidation with Cl and ozone	1
Retention of Progesterone by an Activated Carbon: Study of the Adsorption Kinetics	Cristobal Valenzuela-Calahorro, Antonio Navarrette-Guijosa, Mostafa Stitou, Eduardo M. Cuerda-Correa	Adsorption, Vol. 10, 2004. 19–28	progesterone	GAC	2
Reusable adsorbents for dilute solution separation 6. Batch and continuous reactors for the adsorption and degradation of 1,2-dichlorobenzene from dilute wastewater streams using titania as a photocatalyst	K. T. Valsaraj, Hong Fei Lin, R. Ravikrishna	Separation and Purification Technol., Vol 28(2002), 87-102	1,2-dichlorobenzene and degradation products	photoreaction	2
Short term tests with a pilot sewage plant and biofilm reactors for the biological degradation of the pharmaceutical compounds clofibric acids, ibuprofen, and diclofenac	C. Zwiener, F. H. Frimmel	Science of the Total Environment , Vol. 309(2003), 201-211	clofibric acids, ibuprofen, diclofenac	Biodegradabil-ity	2
Some researches into problems of molecular structure and chemical reactivity	Sidney W. Benson	J. Phys. Chem., Vol. 85 (1981), 3375–3385	Hydrocarbons	general	3
Sonocatalytic oxidation processes for the removal of contaminants containing aromatic rings from aqueous effluents	M. Papadaki, Richard J Emery, Mohd A. Abu-Hassan, Alex Diaz Bustos, Ian S. Metcalfe, Dionissios Mantzavinos	Separation and Purification Technol, Vol. 34 (2004), 35–42	sodium dodecylbenzene sulfonate (SDBS), phenol, 2-chlorophenol and 3,4-dichlorophenol	UV	1
Sorption and degradation of selected five endocrine disrupting chemicals in aquifer material	Guang-guo Ying, Rai S. Kookana, Peter Dillon	Water Research, Vol. 37 (2003), 3785–3791	BPA, E2 ,EE2, 4-t-OP, 4-n-NP	Biodegradabil-ity	3
Sorption and dissipation of testosterone, estrogens, and their primary transformation products in soils and sediments	Linda S. Lee, Troy J .Strock, Ajit K. Sarmah, P. Suresh Rao	Environ. Sci. Technol. , Vol. 37 (2003), 4098–4105	testosterone, 17β-estradiol, and 17α-ethynyl estradoil	Analysis	2
Sorption of 17β-estradiol and 17α-ethinylestradiol by colloidal organic carbon derived from biological wastewater treatment systems	R. David Holbrook, John T. Novak, Nancy G. Love	Environ. Sci. Technol., Vol. 38 (2004), 3322–3329	17β-estradiol and 17α-ethinylestradiol	carbon	3
Special report on environmental endocrine disruption: an effects assessment and analysis	report	USEPA	general	risk assessment	4
Structural Features of alkylphenolic chemicals associated with estrogenic activity	E. J. Routledge, John P. Sumpter	Journal of Biol. Chem., Vol. 272 (1997), 3280–3288	EDCs	QSAR	2
The endocrine disruptor screening program developed by the USEPA	Penelope A. Fenner-Crisp, Anthiny F. Maciorowski, Gary E. Timm	Ecotoxicology, Vol. 9 (2000), 85–91	EDCs	regulatory	3
The potential for oestrogenic effects of pesticides in headwater streams in	M. R. Hurst, David A. Sheahan	Science of the Total Environment, Vol	26 agricultural compounds	bioassay study	3

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the UK		301 (2003), 87–96			
Treatment of pharmaceutical wastewater containing antibiotics by O_3 and O_3/ H2O2 processes	Isil Akmehmet Balcioglu, Merih Otker	Chemosphere, Vol. 50 (2003), 85–95	antibiotics	ozonation	1
Triclosan in a sewage treatment process-balances and monitoring data	K Bester	Water Research, Vol. 37 (2003), 3891–3896	Triclosan	mass balance	2
Triclosan: Occurrence and fate of a widely used biocide in the aquatic environment: field measurements in wastewater treatment plants surface waters, and lake sediments	Heinz Singer, Stephen Muller, Celine Tixier, Laurent Pillonel	Environ. Sci. Technol. , Vol. 36 (2002), 4998–5004	Triclosan	Analysis	3
Urban contribution of pharmaceuticals and other organic wastewater contaminants to streams during differing flow conditions	Dana W. Kolpin, Mary Skopec, Michael T. Meyer, Edward T. Furlong, Steven D. Zaugg	Science of the Total Environment, 2004, article in press	105 compounds including metolachlor, cholesterol, caffeine , beta-sitosterol, 1,7-dimethylxanthine etc.	Analysis by LC/MS	3
UV-Irradiated DNA Matrixes Selectively Bind Endocrine Disruptors with a Planar Structure	M. Yamada, K. Kato, M. Nomizu, K. Ohkawa, H. Yamamoto, N. Nishi	Environ. Sci. Technol., Vol .36 (2002), 949–954	Bisphenol A, diethylstybestrol, dioxin, dibenzofuran, biphenyl, benzo[a]pyrene, ethidium bromide, acridine orange	DNA-columns	1
Veterinary pharmaceuticals: potential environmental impact and treatment techniques	John L. Cicmanec	Emerging Pollutants Workshop	veterinary pharmaceuticals	general	4