WATER DESALINATION CONCENTRATE MANAGEMENT AND PILOTING

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

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Prepared By

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South Florida Water Management District

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- Lee County Utilities
- Manalapan WTP
- Martin County Utilities
- Palm Beach County
- Port St. Lucie Utilities
- Town of Jupiter Water Utilities

EXECUTIVE SUMMARY

ES.1 Purpose

South Florida Water Management District (SFWMD) selected Carollo Engineers (Carollo) to perform a Water Desalination Concentrate Management and Piloting study. The overall goal of the study was to evaluate alternatives for concentrate minimization in South Florida and provide recommendations through identification of affordable and sustainable treatment technologies.

ES.2 Background

Several public water utilities in South Florida have turned to alternative sources of water as the region's increasing demand for potable water continues and development of additional fresh water sources is limited. This includes use of the Floridan Aquifer, which is brackish in South Florida, as an alternative source of water. Desalination with reverse osmosis (RO) has been used to treat the brackish Floridan Aquifer water. Some regions are even considering seawater desalination as part of their water resource portfolio.

The typical range of efficiency or "recovery" for brackish water RO plants depends on the source water characteristics and is typically between 65 to 85 percent for brackish waters. For seawater, the recovery is much lower and typically ranges from 30 to 60 percent. Water that is not recovered as product or "permeate" is lost as "reject" or concentrate. Thus, the concentrate ranges from 15 to 35 percent of the feed stream for brackish water RO, to as much as 40 to 70 percent of the feed stream for seawater RO. Although small concentrate streams may be disposed of by dilution in wastewater collection systems, most concentrate streams are larger and require costly disposal through deep injection wells or surface water outfalls. The significant challenges with cost and permitting of concentrate management are limiting additional use of alternative water sources in inland communities.

Currently, there are 31 operating desalination facilities in the SFWMD with a total capacity of 206 million gallons per day (mgd). By 2012, the number of facilities is projected to increase to 38 including existing plant expansions that will increase the water desalination capacity to about 253 mgd. By 2025, the desalination capacity projected in the District is 540 mgd. Affordable and sustainable concentrate management will be needed. Minimizing concentrate disposal via additional treatment, and thus increasing overall process recovery efficiencies from the current average of 75 percent to about 95 percent, will make over 140 mgd of water available by waste minimization. The actual increase in recovery for a specific facility would depend on its specific raw water quality characteristics and the concentrate treatment technology selected. This study was intended to address the testing and affordability of concentrate management via established and mature treatment technologies.

ES.3 Project Components

The study included two phases. Phase 1 constituted several desktop evaluations of four concentrate minimization methods and several representative RO treatment plants in the SFWMD region. Phase 2 included further evaluation through pilot testing of one concentrate minimization method at one representative brackish water RO plant site, both of which were selected based on Phase 1 evaluations.

The key components of the project included: (1) initial screening for 18 RO water plants and source water modeling and characterization for 14 plants consisting of 12 inland, brackish water plants and two seawater facilities; (2) characterization of treatment schemes for four representative RO plants, followed by evaluation of four promising concentrate minimization methods; (3) examination of technical, permitting, and implementation factors; (4) estimation of costs and benefits of implementing the recommended improvements; and (5) pilot study at one representative site to demonstrate technology feasibility and provide data to establish order-of-magnitude costs.

ES.4 Results and Recommendation

The key results and conclusions from the study are summarized as follows.

<u>Water Quality Characterization</u>

Eighteen RO plants were initially screened. Water quality data required for process modeling were available from 14 plants, consisting of 12 brackish water RO plants and two seawater RO facilities. These data were collected for the 14 RO plants, and analyzed through process modeling to determine the recovery limiting salts in the concentrate.

The recovery limiting salts identified from the simulations were used to group the various concentrate water qualities into four representative categories -- three for inland brackish water RO and the fourth for seawater RO. The majority of the inland brackish water RO plants evaluated (i.e., 9 of 12 plants) were found to be limited in recovery due to the potential to form $CaCO_3$, $BaSO_4$, and $SrSO_4$ scales and were grouped under Category 1. The remaining 3 brackish water RO plants were characterized by the potential to additionally form $CaSO_4$ scale. However, one of these three plants utilizes a unique feed stream, comprising a blend of brackish groundwater and nanofiltration (NF) concentrate. Thus, two of these plants were grouped under Category 2, and the third plant with the unique feed stream was classified under Category 3. The recovery of the RO systems at the two seawater facilities was limited by pressure, and not the solubility of limiting salts.

Four representative RO plants were then selected for further concentrate management evaluations, with one plant each corresponding to one of the four representative water quality categories. Due to the similarity of the recovery limiting salts at most of the inland brackish water plants in the District, a common solution to concentrate management/ minimization can likely be applied at multiple plants.

Concentrate Minimization Technologies

The existing treatment schemes for the four representative RO plants were evaluated and four promising approaches for concentrate minimization were broadly evaluated for the plants in terms of several economic and non-economic criteria. The concentrate minimization approaches that were evaluated included: 1) dual RO system with intermediate chemical precipitation; 2) brine concentrator and evaporation ponds; 3) brine concentrator and crystallizer; and 4) salt recovery and extraction. Table ES.1 summarizes the broad-based comparison of the four technologies.

Table ES.1 Broad-Based Comparison of Concentrate Minimization Technologies

Item	Dual Reverse Osmosis with Intermediate Chemical Precipitation	Brine Concentrator and Evaporation Pond	Brine Concentrator and Brine Crystallizer	Salt Extraction and Recovery
Production efficiency (recovery)	High	Moderate[1]	Very High	High
Product water quality	High	Very High	Very High	High
Footprint	Moderate	Large (for pond)	Small	Moderate
Energy consumption	Moderate	High	Very High	Moderate
Chemical consumption	Moderate-High[2]	Low	Low	Moderate-High[2]
O&M considerations	Sludge Disposal	High Energy Use	High Energy Use	Marketability of Salts
Overall costs	Moderate	Very High	Very High	Moderate-High
Concentrate management	Final concentrate disposal; sludge disposal	Regular sludge disposal from pond or capping at end of life	Disposal of crystalline solids	Marketing of saleable products and final disposal of concentrate
Permitting Complexity[3]	Low-Moderate for final concentrate and sludge disposal	Moderate for evaporation pond	Low-Moderate for disposal of concentrate solids[3]	Low-Moderate for final concentrate disposal; use of recovered salts

Notes:

1. Due to the water lost in the evaporation pond.
2. Will depend on the water quality characteristics of the concentrate stream being treated.
3. Permitting complexity will be higher in a scenario where constituents are concentrated to a level that classify the final concentrate or solids to be disposed of as ‘hazardous’.

The first approach uses intermediate chemical precipitation to make the concentrate stream amenable to a second RO treatment step - resulting in a relatively low energy process for concentrate treatment. The second and third approaches both avoid the chemical treatment of concentrate and instead use a thermal process (i.e. brine concentrator) to further concentrate the stream to a slurry while recovering additional product water. However, this results in a comparatively high energy, high cost process. In the second approach the brine concentrator is followed by an evaporation pond and in the third approach it is followed by a thermal crystallizer. In both approaches, the second step converts the slurry to solids, resulting in zero liquid discharge. The fourth approach views desalination concentrate streams as potential mineral resources and uses selective salt recovery to generate specific salts as products. The sale of recovered salt products is essential to support the added capital expense of salt recovery. A practical market for coproduced salts from water treatment plants has yet to emerge in North America.

Examination of Technical, Permitting, and Implementation Factors

The concentrate constituents were characterized and compared with hazardous substances, and risks associated with increased recovery were identified in terms of increased concentrations and possible implications on operations and cost. Treatment of RO concentrate for recovery of additional water will reduce the volume of liquid waste while increasing the concentration of many contaminants in the liquid waste. Depending on the specific source water characteristics and the allowable ‘non-hazardous’ concentrations implied by the local/federal regulatory guidelines, the practical increase in recovery via concentrate treatment can be limited to a certain level. In each site-specific case, this limitation could simply be to avoid increases in recovery and hence concentrations that result in potentially classifying the concentrate as ‘hazardous’.

Some treatment technologies may also generate a solid waste. Zero liquid discharge technologies such as brine crystallizers would eliminate the liquid waste and only produce a solid waste. Depending on the source water characteristics, solid wastes generated through enhanced recovery can contain increased levels of radionuclides, restricting where the solid waste may be disposed. Key observations from the examination of technical, permitting, and implementation factors include:

- FDEP prohibits deep well injection of hazardous waste; however, water injected by deep well injection is not required to meet primary or secondary drinking water regulations.
- For the representative plants evaluated, most of the parameters in the concentrate predicted to exceed the primary and secondary drinking water regulations at 95 to 80 percent).
- The major hazardous characteristic displayed by RO concentrate is toxicity due to low dissolved oxygen and high hydrogen sulfide. These conditions can be treated by pH adjustment and aeration.

- Enhanced concentrate recovery will produce a concentrate of increased density and reduced volume. The associated decrease in injectate buoyancy and reduced injection pressures needed for deep well injection suggest that concentrate recovery may actually reduce the risk for a vertical migration of water into an underground source of drinking water (USDW).

Cost Opinions

An order-of-magnitude economic analysis of the two most promising concentrate minimization technologies for three of the representative desalination plants was performed, excluding the seawater plant. Because the recovery of the RO systems at the two seawater facilities was limited by pressure and not by the solubility of limiting salts, the representative seawater facility was not included in the economic analysis for concentrate minimization. Based on the evaluations performed in the previous tasks, the two most promising technologies were selected to be the dual RO system with intermediate chemical precipitation, and the brine concentrator. Although a brine crystallizer was also discussed along with the brine concentrator in the previous discussions, a crystallizer is only required to be included in the case of a zero-liquid-discharge (ZLD) facility. For the purposes of the economic analysis, the brine concentrator alone was considered as the second concentrate minimization alternative.

Order of magnitude capital costs, operations and maintenance costs, and annual treatment costs were developed for the two concentrate minimization technologies by sizing individual components for each candidate site. Table ES.2 summarizes the total treatment costs in terms of $/kgal of product water generated from concentrate treatment.

Table ES.2 Order of Magnitude Cost Opinions for Concentrate Treatment

Treatment Alternative	North Miami Beach WTP	Hollywood WTP	Deerfield Beach WTP
Design Flow (mgd) (1)	2.00	1.00	1.00
Operating Flow (mgd) (2)	1.33	0.67	0.67
Probable Total Unit Treatment Cost:			
Softening/Filtration/Secondary RO ($/kgal)	9.63	12.28	15.09
Brine Concentrator ($/kgal)	18.92	23.71	22.28

Notes:
1. Concentrate flow to be treated; used as basis for developing capital cost opinion.
2. Concentrate flow to be treated; used as basis for developing O&M cost opinion.

Due mostly to the high energy needs and costs associated with the currently available brine concentrator systems, the dual RO process with intermediate chemical precipitation was selected as the preferred approach for concentrate minimization for inland desalination plants within the SFWMD. The total treatment cost with this approach was estimated to be about half that of product water generated with a brine concentrator approach.

Pilot Testing

Phase 2 of the project included further evaluation through pilot testing of one concentrate minimization method at one representative brackish water RO plant site, both of which were selected based on the Phase 1 evaluations. The Phase 1 evaluations determined the dual RO system with intermediate chemical precipitation as the most promising method for further evaluation at pilot scale. Compared to the other alternatives, the capital cost and energy use, along with implementation factors associated with this option, were more attractive.

The purpose of the pilot test was to demonstrate the feasibility of the selected concentrate minimization methodology and evaluate its conceptual performance. The pilot study was undertaken at the City of North Miami Beach Norwood-Oeffler Water Treatment Plant (WTP). The testing began in August 2009 and was completed in November 2009. The pilot plant treated the concentrate from the full-scale primary RO system at the WTP. The pilot unit processes included chemical softening with lime and soda-ash, media filtration, followed by secondary RO.

The pilot plant demonstrated stable performance, effectively increasing the overall system recovery from 75 to 88 percent under conservative operating conditions for the secondary RO, implying an increase of 13 percent in production efficiency. Even higher recoveries might be possible under less conservative operating conditions, which can be evaluated in subsequent testing. The process was shown to be viable for a representative South Florida brackish water. Due to the observed similarity of the salts limiting RO recovery in South Florida brackish waters evaluated in this study, this concentrate treatment approach may be applicable at many brackish desalting plants within the District.

Recommendation

This study provided a systematic evaluation of a concentrate minimization approach, and demonstrated its feasibility for a representative brackish water source in South Florida. The desktop evaluations were comprehensive, and the small-scale pilot that was employed demonstrated stable performance. The key recommendation from this study is to further optimize the key process and operational parameters for this approach in a subsequent study. This subsequent study should be conducted at a larger pilot/demonstration scale and operated over a longer duration to capture any size-related scale-up effects, and seasonal variability.

WATER DESALINATION CONCENTRATE MANAGEMENT AND PILOTING

1.0 INTRODUCTION

1.1 Purpose

South Florida Water Management District (SFWMD) selected Carollo Engineers (Carollo) to perform a Water Desalination Concentrate Management and Piloting study. The overall goal of the study was to evaluate alternatives for concentrate minimization in South Florida and provide recommendations through identification of affordable and sustainable treatment technologies.

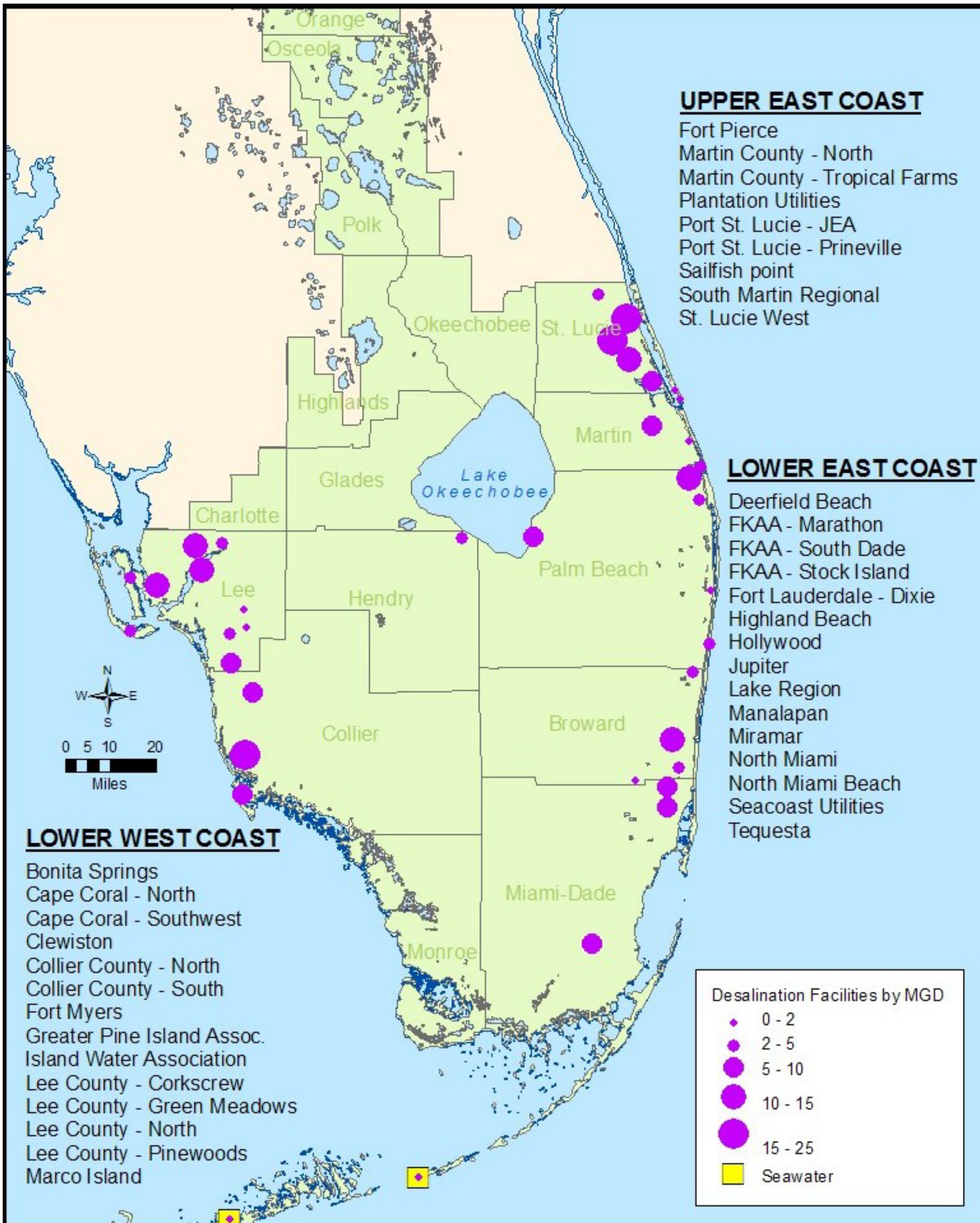
The study included two phases. Phase 1 constituted several desktop evaluations of four concentrate minimization methods and several representative reverse osmosis (RO) treatment plants in the SFWMD region. Phase 2 included further evaluation through pilot testing of one concentrate minimization method at one representative brackish water RO plant site, both of which were selected based on Phase 1 evaluations.

1.2 Background

In South Florida, greater than 90 percent of water used in homes and businesses comes from groundwater sources. The remainder comes from surface waters. As the region’s increasing demand for potable water continues and development of fresh water sources is maximized, several public water utilities in South Florida have turned to the deeper, brackish Floridan Aquifer as an alternative source of water. Some regions are even considering seawater desalination as part of their water resource portfolio. Because the Floridan Aquifer is brackish in South Florida, it typically requires treatment by RO technology.

Using RO provides utilities with an alternative source of water, but at increasingly higher treatment costs when compared to treatment of fresh water sources. Furthermore, the RO technology also generates a reject or concentrate stream that needs to be managed and disposed of appropriately. Although small concentrate streams may be disposed of by dilution in wastewater collection systems, most concentrate streams are larger and require costly disposal through deep injection wells or surface water outfalls. The significant challenges with cost and permitting of concentrate management are limiting additional use of alternative water sources in inland communities.

Currently, there are 31 operating desalination facilities in the SFWMD with a total capacity of 206 million gallons per day (mgd). By 2012, the number of facilities is projected to increase to 38 (Figure 1.1) including existing plant expansions that will increase the water desalination capacity to about 253 mgd.



South Florida Water Management District
Water Desalination Concentrate Management and Piloting

Desalination Facilities in the South Florida Water Management District (Source: Akpoji, 2008).

FIGURE 1.1

By 2025, the desalination capacity projected in the District is 540 mgd. Affordable and sustainable concentrate management will be needed. Minimizing concentrate disposal via additional treatment, and thus increasing overall process recovery efficiencies from the current average of 75 percent to about 95 percent, will make over 140 mgd of water available by waste minimization. The actual increase in recovery for a specific facility would depend on its specific raw water quality characteristics and the concentrate treatment technology selected. This study was intended to address the testing and affordability of concentrate management via established and mature treatment technologies.

1.3 Reverse Osmosis Technology

The reverse osmosis (RO) process uses semi-permeable membranes and a driving force of hydraulic pressure to remove dissolved solids from brackish water or seawater. The RO membranes are capable of rejecting contaminants as small as 0.0001 μm. The process can be described as diffusion controlled as the mass-transfer of ions through the RO membranes is by the process of diffusion. Consequently, RO can remove dissolved salts, hardness, TDS, synthetic organic chemicals (SOCs), and disinfection by-product (DBP) precursors.

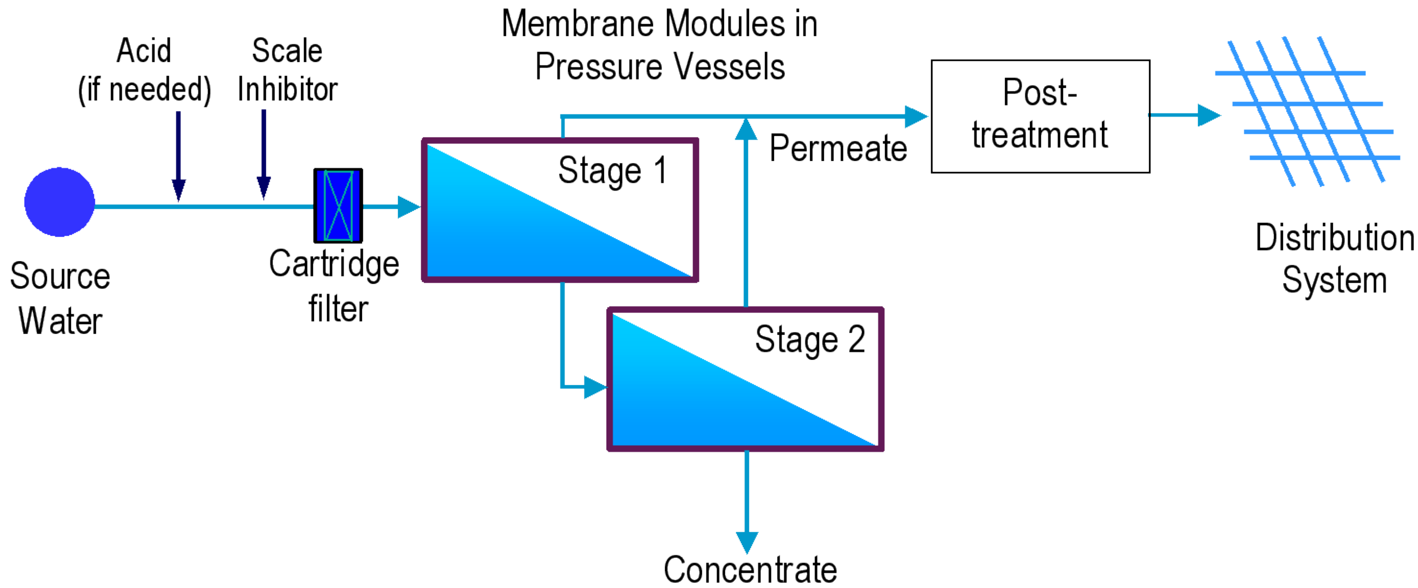
The water molecules that diffuse through the membrane, along with a small amount of ions that are not rejected, constitute the purified product stream or "permeate." The recovery of the system is the volume ratio of the permeate stream to the feed stream. The rejected contaminants are concentrated on the feed side of the membrane and are ultimately flushed out of the process along with the non-permeated water as the "concentrate stream."

The schematic in Figure 1.2 depicts the layout of a typical membrane treatment process for a brackish groundwater source. In the case of a brackish surface water source, an additional pretreatment (e.g. filtration) is typically required to reduce the loading of suspended solids to the RO process, since a high loading of suspended solids and particulates can foul the RO membranes.

A membrane "element" packs a large surface area of the membrane and the associated feed and permeate channels around a permeate tube. Spiral wound membrane elements are the most common configuration in practical use. Hollow fine fiber elements are also available but are less common. Each spiral wound membrane element recovers about 5 to 15 percent of the feed water flow by converting it into the permeate stream. Multiple membrane elements are housed in series inside a pressure vessel. A stage of membranes consists of multiple pressure vessels in parallel. Most brackish water RO desalination facilities operate with two-stages of pressure vessels, as shown in Figure 1.2. A membrane array refers to a collection of pressure vessels over two or more stages.

Schematic of Typical Membrane Treatment Process for Brackish Groundwater Desalination.

FIGURE 1.2



Note: Additional pretreatment (e.g. filtration) is typically required in case of a brackish surface water source.

The productivity of an RO membrane can decline over time if fouling or scaling occurs. Fouling occurs when suspended solids and particulates, such as metal oxides, colloids, or bacteria, deposit on the membrane surface and/or the feed channel, reducing the flow of water. Scaling occurs when dissolved solutes precipitate on the membrane surface and/or the feed channel and decrease the flow of water. If not properly controlled, scaling most commonly occurs in the last elements of the final stage, where the feed stream is the most concentrated. Pretreatment is provided before RO membranes to control fouling and scaling. Cartridge filters serve as the minimal/final barrier for protection of the membranes against suspended solids in the feed stream, reducing the potential for membrane fouling. While cartridge filters are typically sufficient for addressing suspended solids in the case of a brackish groundwater source, for waters with relatively higher loading of suspended solids (i.e. brackish surface waters) an additional filtration step is required as part of the pretreatment. This additional filtration step typically used is conventional filtration or membrane filtration (i.e. microfiltration or ultrafiltration).

Brackish water RO system recovery and concentrate volume is determined by the scaling propensity of sparingly soluble salts such as calcium carbonate, calcium-, barium-, and strontium sulfates, and silica. In practice, the scaling propensity of such compounds is typically controlled via addition of scale inhibitor (or antiscalant) chemicals and/or acid, which allows the RO process to operate with supersaturated levels of such salts in the concentrate. The allowable supersaturation concentration depends on the salt and the type of antiscalant. Several varieties of proprietary antiscalants are available. Most inhibit the precipitation of supersaturated salts by complexing divalent cations in solution (e.g. Ca^{2+}, Ba^{2+}, and Sr^{2+}), or by disrupting the crystallization of the salt. Antiscalant alone can be used if sulfate salts and/or silica are of concern, and calcium carbonate precipitation is either not of concern or the levels of calcium and carbonate ions are relatively low such that control of calcium carbonate precipitation via antiscalant alone will be sufficient. Acid can be used alone to lower the pH and control the scaling if calcium carbonate is the only sparingly soluble salt of concern, or it can be used in combination with antiscalant if the levels of calcium and carbonate ions are relatively high such that control of calcium carbonate precipitation via antiscalant alone will not be sufficient.

The typical range of recovery for brackish water RO plants depends on the source water characteristics and is between 65 to 85 percent for a two-stage RO process. As discussed above, antiscalant and/or acid are often added to reduce scaling at higher recoveries. Beyond approximately 85 percent, even if the saturation levels of the sparingly soluble salts can be controlled via addition of chemicals, the hydraulic limitations of the process would require either a recycle configuration of concentrate in a two-stage process, or the addition of a third RO stage. For seawater RO recovery is typically limited by the permissible driving pressure, and ranges from 30 to 60 percent.

Water that is not recovered as permeate is lost as concentrate, which ranges from 15 to 35 percent of the feed stream for brackish water RO, to as much as 40 to 70 percent of the feed stream for seawater RO. Identifying effective concentrate management processes for water desalination will expand the useful supply of alternative water sources, by reducing total concentrate disposal costs and maximizing the water recovered.

2.0 SOURCE WATER AND CONCENTRATE DATA COLLECTION

2.1 Purpose

The RO process requires the appropriate concentrate treatment methodology to maximize the efficiency of the process and to reduce the volume of the concentrate. Understanding the source water quality and range of potential scalants for the brackish water desalination facilities in the District is essential to identifying effective concentrate treatment alternatives.

This task thus focused on the collection of available water quality data for several desalination plants located in the SFWMD, analysis of the data to determine the types of recovery limiting salts in the concentrate, and finally using these data to categorize the various concentrate water qualities into distinctive groups.

2.2 Scope

The scope for this task included collection of available and pertinent data for an initial target of up to 14 desalination facilities located in the SFWMD, identification of data gaps, and with the District's assistance, obtaining the remaining pertinent information from the appropriate desalination facilities. Information to be collected included pertinent and available data of the following parameters: source of water, location of facility, facility type (RO, NF, etc.), plant size, and available data for following types of water quality parameters: total dissolved solids (TDS), conductivity, total organic carbon, major anions and cations, radionuclides, and general parameters such as pH, alkalinity, hardness, etc. Reported concentrate water quality data made available by the facilities is also included.

The scope included classification of the plant influent as freshwater, brackish, or seawater, using a simple nomenclature as defined in the District's Water Supply Plan documents. Additionally, the data would be consolidated and characterized into groups of source water qualities (e.g. three inland brackish water categories with recovery limited by carbonate, sulfate, or silica, and one seawater/surface water category). Based on these categories, four representative desalination facilities would be selected to depict the four water quality categories, for use in the subsequent evaluations.

The data collection subtask was performed in collaboration with the District, using reports available at the District, and working with the District to identify and close data gaps where possible by contacting individual desalination plants and requesting the missing information. The various activities that were performed in this task are summarized as follows.

- A list/questionnaire was developed for obtaining available and pertinent data on facility, water quality, and selected operating parameters such as system recovery.
- Data were collected by working in collaboration with the District, with the initial target of obtaining data sets for up to 14 desalination plants located in the District.
- Data were collated, compiled, and data gaps identified and the individual desalination plants were contacted to obtain the missing data.
- Literature reviews were conducted in parallel to supplement desalination plants data.
- Source water quality data were compiled and classified data into fresh, brackish or seawater.
- Simulations were performed using one manufacturer's software to determine the percent saturation of sparingly soluble salts in the concentrate, in order to assess the salts that were impacting the recovery and hence concentrate volumes.
- Source waters and plants were classified into four water quality categories (three inland brackish groundwater categories and one seawater/surface water category) based on potential membrane scalants including $CaCO_3$, $BaSO_4$, $SrSO_4$, $CaSO_4$, and silica.

2.3 List of Water Treatment Facilities

The facilities were classified by salinity according to the scheme shown in Table 2.1. These water source quality definitions are similar to those used in the District's 2005/2006 Water Supply Plan update for the evaluation of water source options (SFWMD, 2006).

Out of the total of 31 operating desalination facilities in the District, water quality data were available and gathered for 18 RO facilities listed in Table 2.2 (the initial target was up to 14 facilities). A summary table of raw water quality data for these facilities is included in Appendix A. The District collated and provided laboratory reports on raw water quality from most of the facilities. Carollo compiled the data, with the District's assistance, and gathered additional information from publications and phone conversations with facility staff. The salinity classification corresponding to the source water quality for each desalination facility is also included in Table 2.2. Based on the salinity classification described in Table 2.1, fifteen of the facilities treat brackish groundwater, two treat surface/seawater, and one treats fresh water.

Table 2.1 Water Classification by Salinity	
Water	**TDS (mg/L)**
Fresh Water	<1,000
Slightly Saline	1,000 to 3,000
Brackish (Moderately Saline)	3,000 to 10,000
Very Saline	10,000 to 35,000
Sea Water	35,000
Brine	>> 35,000
Note: Source: SFWMD (2006)	

2.4 Water Quality and Membrane Simulations

Fourteen of the 18 facilities listed in Table 2.2 provided sufficient data to support the water quality analysis needed to identify the levels of saturation of sparingly soluble salts in the concentrate. The saturation concentrations of the sparingly soluble salts were predicted for each source water by performing simulations.

For convenience, in the initial simulations performed for all plants, software from one membrane manufacturer (Hydranautics Inc.) was used and one consistent membrane was assumed for all brackish water plants and one consistent membrane was assumed for all seawater plants. Subsequent simulations for the representative plants selected for further evaluation in the study were made using specific membranes installed at each plant (see Section 3).

The simulation software makes basic assumptions about the passage of ions through the membrane, while calculating the percent saturation of multiple salts, incorporating the effects of ionic strength. The general assumptions made for all simulations are summarized in Table 2.3. All initial simulations were run at 25°C assuming a two-stage RO system. Brackish water simulations were run assuming the ESPA2 brackish RO membrane at a flux of 15 gallons per square foot per day (gfd). Seawater simulations were run with a SWC3+ seawater RO membrane at a flux of 8 gfd. A summary of the raw water quality data for all 18 facilities is included in Appendix A. Each facility was contacted by phone, and the reported percent recovery was used in the simulation.

Table 2.4 includes the results of the membrane simulations. The source water total dissolved solids and current RO system recovery are listed for each plant. The table also lists the predicted percent saturation in the concentrate stream for the sparingly soluble salts including calcium carbonate ($CaCO_3$ as Langelier Saturation Index, LSI), calcium sulfate ($CaSO_4$), strontium sulfate ($SrSO_4$), barium sulfate ($BaSO_4$), and silica (SiO_2). A percent saturation greater than 100 percent (i.e. “supersaturation”) indicates that the water will tend to precipitate that salt, potentially scaling the membrane, unless controlled via addition of antiscalant (and/or acid in case of $CaCO_3$). Supersaturated salts are indicated in bold for each plant.

Table 2.2 Reverse Osmosis Plants Classified by Water Quality and Salinity

Facility	Salinity Classification	Source Water TDS (mg/L)	Source Water Chloride (mg/L)	Plant Capacity (mgd)
Cape Coral (Southwest)[1]	Slightly Saline	1,900	820	18
Clewiston	Brackish	3,100	1,300	3
Deerfield Beach[2]	Brackish	3,300	1,510	3
Florida Keys (Marathon)	Seawater	37,200	21,000	1
Florida Keys (Stock Island)	Seawater	37,300	22,000	2
Fort Myers	Brackish	3,700	1,920	13
Fort Pierce	Fresh Water	800	290	16
Hollywood	Brackish	4,900	2,790	4
Jupiter	Brackish	5,800	2,970	14
Lee County (North)	Slightly Saline	2,500	1,070	5
Lee County (Pinewoods)	Slightly Saline	2,800	1,000	2.1
Manalapan	Brackish	4,100	2,000	1.7
Marco Island	Brackish	6,200	2,860	6
Martin County (North County)	Slightly Saline	2,400	1,210	5.5
North Miami Beach	Brackish	4,000	1,430	6
Palm Beach County (Lake Region)	Brackish	3,200	1,400	10
Port St. Lucie (James E. Anderson)	Brackish	3,100	1,800	22
Port St. Lucie (Prineville)	Slightly Saline	2,800	1,400	11

Notes:

1. Two plants on site with (North-Under Construction) 12 mgd and (Southwest-Operating) 18 mgd capacity each. Raw water quality is same for both plants.
2. Deerfield Beach RO Plant was under construction at the time of this study.

Table 2.3 General Assumptions for the Initial Simulations			
Parameter	**Units**	**Brackish GW**	**Seawater**
Temperature	°C	25	25
Permeate Flux	Gfd	15	8
Membrane Type[1]	-	ESPA2	SWC3+
Number of Stages	#	2	1

Note:

1. A common membrane assumption was made for the initial simulations, and simulations were performed using membrane manufacturer software (Hydranautics Inc.). Subsequent simulations for the four representative plants were made using specific membranes installed at each plant (see Section 3). Inclusion of trade names does not imply endorsement of products.

For each water source, these simulations highlight the major salts and their levels in the concentrate. While in practice specific dose(s) of antiscalant and/or acid are added to control the scaling propensity of these supersaturated salts, the simulations focused on analyzing the percent saturation in the concentrate in order to identify the challenging and/or recovery limiting salts. Identifying the potential recovery limiting salts for each facility provides insight on the ions that are present in challenging or limiting concentrations; it is likely that their reduction or removal would allow for meaningful reductions in concentrate volume.

Concentrate water quality data were provided by 10 of the 18 facilities listed in Table 2.2. These data are summarized in Appendix B. These data were collected for completeness but cannot realistically be compared against the estimated concentrate data from the membrane simulations. The reasoning is that the concentrate water quality is purposely simulated in this section at specific/standardized conditions and assumptions (see Table 2.3) and without any addition of chemicals, so that the challenging/limiting salts can be identified at their “non-adjusted” (e.g. with acid and/or antiscalant) super-saturated concentrations. In a subsequent project task (Section 3), additional simulations were performed to reflect the chemical addition and other specific conditions for the four representative plants, and the simulated concentrate water quality was compared with the observed concentrate water quality data. Thus, these subsequent simulations also considered the potential for increased formation of sulfate salts when adding sulfuric acid.

Table 2.4	**Estimated Percent Saturation of Sparingly Soluble Salts at Existing Recoveries**								
#	**Facility Name**	**TDS**	**Percent Recovery**	**Percent Saturation in Concentrate[1]**					
				LSI[2]	**$CaSO_4$**	**$BaSO_4$**	**$SrSO_4$**	**SiO_2**
		mg/L	**%**	**-**	**%**	**%**	**%**	**%**
1	Cape Coral	1,900	85	**2.3**	14	**360**	**270**	66
2	Clewiston	3,100	75	**1.6**	47	**810**	**360**	37
3	Jupiter	5,800	75	**1.7**	32	**770**	**230**	45
4	Lee County (North)	2,500	75	**1.8**	37	**940**	**460**	45
5	Manalapan	4,100	75	**2.3**	38	**370**	**170**	40
6	North Miami Beach	4,000	75	**2.0**	30	**N/A[3]**	**170**	32
7	Palm Beach County (Lake Region)	3,200	80	**2.1**	66	**930**	**510**	49
8	Port. St. Lucie (Prineville)	2,800	80	**2.3**	26	**550**	**190**	39
9	Fort Myers	3,700	73	**1.8**	28	**550**	**N/A[3]**	**N/A[3]**
10	Hollywood	4,900	80	**0.7**	**100[4]**	**320**	**390**	49
11	Lee County (Pinewoods)	2,800	85	**2.5**	**100**	**2700**	**920**	75
12	Deerfield Beach[5]	3,300	75	**2.6**	**100**	**520**	**140**	91
13	Florida Keys (Marathon)	37,200	30	0.8	34	65	69	3
14	Florida Keys (Stock Island)	37,300	35	0.7	31	71	76	3

Notes:
1. Supersaturated salts are indicated in bold for each plant. Values above 100% rounded to the nearest 10%.
2. LSI = Langelier Saturation Index for $CaCO_3$ precipitation. LSI>0 indicates $CaCO_3$ supersaturation.
3. N/A = No data was available from this facility for concentration of cation and/or anion associated with this salt.
4. For Hollywood WTP, the saturation of $CaSO_4$ was simulated at 93% at recovery of 80%; with an increase to 100% saturation at a recovery of 81%. Due to its high proximity to the saturation level, and the high sensitivity with recovery, the $CaSO_4$ saturation is assumed and noted at 100% (supersaturated) in this study.
5. Water quality data for Deerfield Beach is for an RO plant under construction. Feed water represents a unique blend of brackish groundwater and nanofiltration concentrate (see Section 3). Deerfield Beach WTP simulations assume the appropriate membrane for the plant (Toray TMG20). Inclusion of trade names does not imply endorsement of products.

2.5 Water Quality Categories

The 14 simulated facilities were grouped into four water quality categories, as shown in Table 2.5, based on the results of the simulations. Based on the values of the LSI (Table 2.4), all facilities were predicted to have a concentrate saturated with $CaCO_3$ (in the absence of acid and/or antiscalant addition). All 12 brackish water facilities were predicted to have a concentrate saturated additionally with $BaSO_4$ and $SrSO_4$ (in the absence of antiscalant addition). Saturation of $CaSO_4$ was predicted for three brackish water facilities (in the absence of antiscalant addition). Finally, the two surface water/seawater facilities were predicted to be saturated with $CaCO_3$ in the concentrate (in the absence of acid and/or antiscalant addition).

2.5.1 Category 1 - $CaCO_3$, $BaSO_4$, and $SrSO_4$

Category 1 includes the nine facilities that were predicted to have a concentrate saturated with $CaCO_3$, $BaSO_4$, and $SrSO_4$. These three salts were identified as potential scalants for all the brackish RO facilities considered in this report. This indicates that the water quality for brackish groundwater RO plants within the District is largely similar. Because of this similarity, concentrate minimization solutions identified for one facility may be applicable to a broad range of brackish RO facilities within the District. North Miami Beach was unable to supply data on barium. Fort Myers was unable to supply data on strontium and silica. These data gaps are listed as “N/A” indicating no data was available.

Category 1 raw waters do not show a potential for $CaSO_4$ scaling, however addition of sulfuric acid for LSI adjustment could increase the sulfate concentrations to levels that would increase the potential for $CaSO_4$ scaling as well as scaling of $BaSO_4$ and $SrSO_4$. In practice, when addition of an acid is desired, but addition of sulfuric acid becomes limiting due to considerations of higher sulfate levels, then hydrochloric acid addition is another option that can be considered.

2.5.2 Category 2 - $CaSO_4$, $CaCO_3$, $BaSO_4$, and $SrSO_4$

The Hollywood and Lee County (Pinewoods) plants are different from the facilities in Category 1 because the concentrates are also supersaturated in $CaSO_4$ as well. This is largely because the sulfate concentration for these plants (795 mg/L and 621 mg/L, respectively) is much higher than the range of sulfate concentrations for the other brackish RO facilities (125 mg/L to 570 mg/L).

Table 2.5 Water Quality Characterization								
#	**Facility Name**	**TDS**	**Percent Recovery**	**Present in Concentrate Above Saturation Limit**				
		mg/L	**%**	**$CaCO_3$**	**$CaSO_4$**	**$BaSO_4$**	**$SrSO_4$**	**SiO_2**
	Category 1: $CaCO_3$ + $BaSO_4$ + $SrSO_4$							
1	Cape Coral	1,900	85	X		X	X	
2	Clewiston	3,000	75	X		X	X	
3	Fort Myers	3,700	73	X		X	N/A[1]	N/A[1]
4	Jupiter	5,800	75	X		X	X	
5	Lee County (North)	2,500	75	X		X	X	
6	Manalapan	4,000	75	X		X	X	
7	North Miami Beach	4,000	75	X		N/A[1]	X	
8	Palm Beach County (Lake Region)	3,200	80	X		X	X	
9	Port. St. Lucie (Prineville)	2,800	80	X		X	X	
	Category 2: $CaSO_4$ + $CaCO_3$ + $BaSO_4$ + $SrSO_4$							
10	Hollywood	4,900	80	X	X	X	X	
11	Lee County (Pinewoods)	2,800	85	X	X	X	X	
	Category 3: $CaSO_4$ + $CaCO_3$ + $BaSO_4$ + SrSO4 (Unique RO Feed Comprising Blend of Brackish Groundwater with NF Concentrate)							
12	Deerfield Beach[2]	3,300	75	X	X	X	X	
	Category 4: Surface/Sea Water							
13	Florida Keys (Marathon)	37,200	30	X				
14	Florida Keys (Stock Island)	37,300	35	X				

Notes:
1. N/A = No data was available from this facility for the concentration of cation and/or anion associated with this salt.
2. Water quality data for Deerfield Beach is for an RO plant under construction. Feed water represents a unique blend of brackish groundwater and nanofiltration concentrate (see Section 3).

2.5.3 Category 3 - $CaSO_4$, $CaCO_3$, $BaSO_4$, and $SrSO_4$ (Unique RO Feed)

The Deerfield Beach RO plant (currently under construction) has the same salts saturated in the concentrate as for the Category 2 plants. However, the feed water for the Deerfield Beach RO plant is fundamentally different from the facilities in Category 2 (or Category 1) because it comprises a unique blend of brackish groundwater with NF concentrate. In one sense, it already includes a concentrate minimization methodology, but one that is focused on the minimization of the NF concentrate. Thus, further reduction of the RO concentrate is still another key consideration for such facilities. The NF concentrate data were initially not available from the City, but were included in subsequent evaluations in the study. The super-saturated salts in the concentrate predicted in Table 2.4 assume the feed water that is comprised of a blend of brackish groundwater with NF concentrate in a 50/50 blend ratio (see Section 3 for water quality data). The blended feed water calcium (396 mg/L) and silica (36 mg/L) concentrations for Deerfield Beach WTP are the highest amongst all the brackish RO facilities considered. The feed water sulfate concentration (307 mg/L) is moderate amongst all the brackish RO facilities, for which the feed water sulfate ranges from 125 to 795 mg/L.

2.5.4 Category 4 - Surface Water/Seawater

The two facilities in the Florida Keys, the Marathon Seawater Desalination Facility and the Stock Island Seawater Desalination Facility, treat seawater through submerged intake wells. The recovery at these facilities (ranging between 30 to 40 percent) is well below that of the brackish water facilities (73 to 85 percent); hence, only calcium carbonate was predicted to be supersaturated in the concentrate (if no acid or antiscalant were added to the raw water). The percent recovery of seawater desalination by RO is limited in practice by the enormous osmotic pressures that must be overcome in the final membrane elements of the treatment train and the corresponding design limits of the pressure vessels. At seawater RO facilities, removal of boron can also be challenging given the high levels of boron in seawater and low boron rejection by most membranes at ambient pH.

2.6 Representative Facility for Each Water Quality Category

As indicated in Section 2.2, selection of four representative desalination facilities was performed, to represent the four water quality categories that were identified in Section 2.5. These representative facilities were further evaluated in subsequent project tasks. The representative facilities were selected based on discussions with the District using several selection criteria. The selected representative facilities are summarized in Table 2.6.

Table 2.6 Representative Facility for Each Water Quality Category		
Category #	**Super-Saturated Salts in Concentrate**	**Representative Facility**
Category #1	$CaCO_3$, $BaSO_4$, and $SrSO_4$	North Miami Beach WTP
Category #2	$CaCO_3$, $BaSO_4$, $SrSO_4$, and $CaSO_4$	City of Hollywood WTP
Category #3	$CaCO_3$, $BaSO_4$, $SrSO_4$, and $CaSO_4$ (unique feed comprising NF concentrate blended with brackish groundwater)	Deerfield Beach WTP
Category #4	$CaCO_3$ (surface water/seawater)	Marathon Desalination Facility

Notes:
1. Category #3 includes the same super-saturated salts as in Category #2; however, Category #3 represents a unique RO feed comprising a blend of brackish groundwater and NF concentrate.

2.7 Summary

- Water quality data were assembled and analyzed for 18 desalination facilities throughout the South Florida Water Management District, including 16 brackish groundwater facilities and two surface water/seawater facilities.
- Simulations were performed for 14 facilities with adequate data to support the simulations. While in practice specific dose(s) of antiscalant and/or acid are added to control the scaling propensity of these supersaturated salts, the simulations focused on analyzing the percent saturation in the concentrate in order to identify the challenging and/or limiting salts. In subsequent project tasks, simulations were performed including specific doses of acid and/or antiscalant where required to identify concentrate minimization and treatment possibilities. The 14 desalination facilities with adequate data for simulation were classified among four water quality categories.
- Most brackish water RO facilities (9 of 12) were classified in Category 1, with the potential to form $CaCO_3$, $BaSO_4$, and $SrSO_4$ scales. It is noted that in practice, depending on the acid type and dose used, $CaSO_4$ levels in the concentrate would change for some of these waters. The focus of the simulations was to highlight the propensity of scaling levels in the concentrate based on the source water characteristics, in order to allow characterization of the types of source water qualities. The subsequent simulations in the project allowed for calculations including specific doses of acid as used in the specific plant.
- The Hollywood and Lee County Pinewoods RO facilities were classified in Category 2, with the potential to form $CaSO_4$ scales in addition to $CaCO_3$, $BaSO_4$, and $SrSO_4$ scales.

- The Deerfield Beach RO facility (under construction) was classified as Category 3 due to its unique RO feed that will comprise a blend of brackish groundwater with NF concentrate. The blended feed for Deerfield Beach depicts the potential to form the same scales as for Category 2 facilities, i.e. the scales of $CaSO_4$, $CaCO_3$, $BaSO_4$, and $SrSO_4$.
- The two surface water/seawater desalination facilities, Marathon and Stock Island, were classified in Category 4, with the potential to form $CaCO_3$ scales.
- The similarity among predicted scales for the brackish water RO facilities suggest that concentrate minimization solutions identified for one facility may have broad applicability to other brackish RO facilities within the District.

3.0 CHARACTERIZATION OF THE EXISTING PLANT TREATMENT SCHEMES

3.1 Purpose

This section examines one representative facility from each of the four recovery limiting concentrate water quality categories that were identified in Section 2. This evaluation develops more details on the four representative facilities, investigating the entire process scheme of each plant while evaluating the potential of each plant to accomplish concentrate recovery utilizing each of four concentrate minimization technologies.

3.2 Scope

The existing water plant treatment schemes for the four representative desalination sites are discussed, defining the primary treatment scenario of each along with the process type, overall efficiency, finished water TDS, number of stages, flow rates, bypass volume, concentrate water quality, concentrate handling (sewer, deep well, ocean outfall), and operational challenges as reported by facility's operations staff. Facility owners were contacted by phone to obtain treatment details. Where available, data were collected summarizing changing water quality since operations began.

The following four concentrate handling and minimization technologies were broadly evaluated in a relative fashion in terms of both non-cost and cost factors, i.e. for their broad potential economic and environmental challenges/benefits consistent with local conditions. More detailed evaluations of the concentrate minimization technologies were performed in subsequent project tasks (see Sections 4 and 5).

1. Dual RO system approach using intermediate chemical precipitation
2. Thermal evaporation (brine concentrator) and evaporation pond
3. Thermal evaporation (brine concentrator) and brine crystallizer
4. Salt extraction and recovery

3.3 Facility Process Analysis

The characteristics of each representative facility are summarized in Table 3.1, and discussed in the following paragraphs.

Table 3.1 Summary of Reverse Osmosis Treatment Systems				
	North Miami Beach WTP	**Deerfield Beach WTP**	**Hollywood WTP**	**Marathon Desalination Facility**
Water Quality Category				
Source	Floridan Aquifer	Floridan Aquifer, 1000 ft	Floridan Aquifer, 1200 ft	Seawater, Bank Filtration
TDS (mg/L)	4,000	3,300	4,900	37,200
Design Flow (mgd)	6	3	4	1
Operating Flow (mgd)	4	Under Construction	2	Intermittent Operation
Recovery (%)	75	75	80	30
Acid Dose	None	73 mg/L H_2SO_4	70 mg/L H_2SO_4	None
Antiscalant Dose (Supplier/Type)	2.7 mg/L (AWC-102-L)	3 mg/L (GE/Betz)	2 mg/L (Nalco)	(Infrequent addition)
Other Pretreatment	Cartridge Filtration	Cartridge Filtration	Cartridge Filtration	Bank Filtration, Cartridge Filtration
Membrane Type	Hydranautics ESPA2 (Stg 1) ESPA1 (Stg 2) Polyamide	Toray TMG20-430 Polyamide	Hydranautics CPA2 Polyamide	Toyobo HOLLOSEP HB9155 Hollow Fiber Cellulose Acetate
Process Data				
Trains	3	2	2	2
Stages/Train	2	2	2	1
Vessels/Stage	36/18	26/13	37/17	110
Elements/Vessel	7	6	7	1
Flux (gsfd)	13	14.9	14.5	N/A
Area/Element (ft^2)	400	430	365	N/A
Feed Pressure (psi)	200	185	350	815
Energy Recovery	Yes	No	No	No
Concentrate Disposal	3,400 ft deep well injection - combined with nanofiltration concentrate	Deep well injection	Ocean outfall with dilution by nanofiltration concentrate and treated wastewater	Shallow wells 110-155 ft

3.3.1 City of North Miami Beach, Norwood-Oeffler Water Treatment Plant

The City of North Miami Beach's Norwood-Oeffler Water Treatment Plant (WTP) contains multiple processes for the treatment of fresh water and brackish water. Historically, the plant was a 15-mgd lime softening plant treating fresh water from the Biscayne aquifer. A 17-mgd membrane expansion was completed in early 2008.

The expansion included three nanofiltration trains (9 mgd total) treating highly organic, freshwater from the Biscayne Aquifer water and three 2-mgd reverse osmosis trains (6 mgd total) treating brackish water from the Floridan Aquifer. A schematic of the RO system at the City of North Miami Beach WTP is included in Figure 3.1, and a summary of the process is included in Table 3.1.

Typically, the RO plant operates near 4 mgd with one of the RO trains out of service. Additionally, up to 1.5 mgd of raw Biscayne water and 0.5 mgd of raw Floridan water can be microfiltered and blended with the membrane permeate streams. The plant previously added sulfuric acid and antiscalant (AWC 111-L) before cartridge filtration; however, since January 2009, it has switched to antiscalant addition only (2.7 mg/L AWC 102-L).

Each RO train contains 54 pressure vessels distributed between two stages in a 36:18 configuration. Each pressure vessel contains seven elements. The elements in the first stage are Hydranautics ESPA2 membranes, and the elements in the second stage are Hydranautics ESPA 1 membranes. The average membrane operating flux is 13 gfd. The feed pressure is about 200 psi. Each train has an energy recovery system that pressurizes the stage 2 feed using extra pressure from the stage 2 concentrate. The RO permeate is acidified and passes through air stripping before being blended with nanofiltration permeate and lime-softened water. Up to 2 mgd of RO concentrate is blended with 2.25 mgd of NF concentrate before being discharged by deep well injection to 3,400 feet.

Since startup in 2008, operations staff had not noticed any significant changes in water quality. Like Deerfield Beach and Hollywood plants, the North Miami Beach plant contains both NF and RO membrane systems on the same site. The plant has effectively treated NF concentrate for short intervals using the third RO train; however, to achieve adequate pressure to draw in the NF concentrate, both NF and RO systems must be running at full capacity above the system-wide demand. Currently there is no booster pump between the NF concentrate and RO feed. A booster pump may allow the NF concentrate to be used while operating only one or two RO trains. Otherwise, there is not adequate pressure to treat the NF concentrate. The NF concentrate also contains significant amounts of iron; however, iron fouling was not a concern because the iron was all present in the soluble ferrous form. The plant is located in the middle of a residential neighborhood. During the membrane expansion several homes near the plant were purchased to accommodate the improvements with the remaining becoming park lands. The only available space for an evaporation pond is on the park land to the northeast of the water treatment plant.

The simulation described in Section 2 was updated to include both the Hydranautics ESPA2 and ESPA1 membranes used by the North Miami Beach WTP. None of the saturations changed significantly because the ESPA2 membrane was used for the initial simulations. The simulations indicated an LSI of 1.9. The $CaSO_4$ saturation was 30 percent. The $BaSO_4$ saturation was not available (as barium data was not available). The $SrSO_4$ saturation was 170 percent. The SiO_2 saturation was 31 percent.

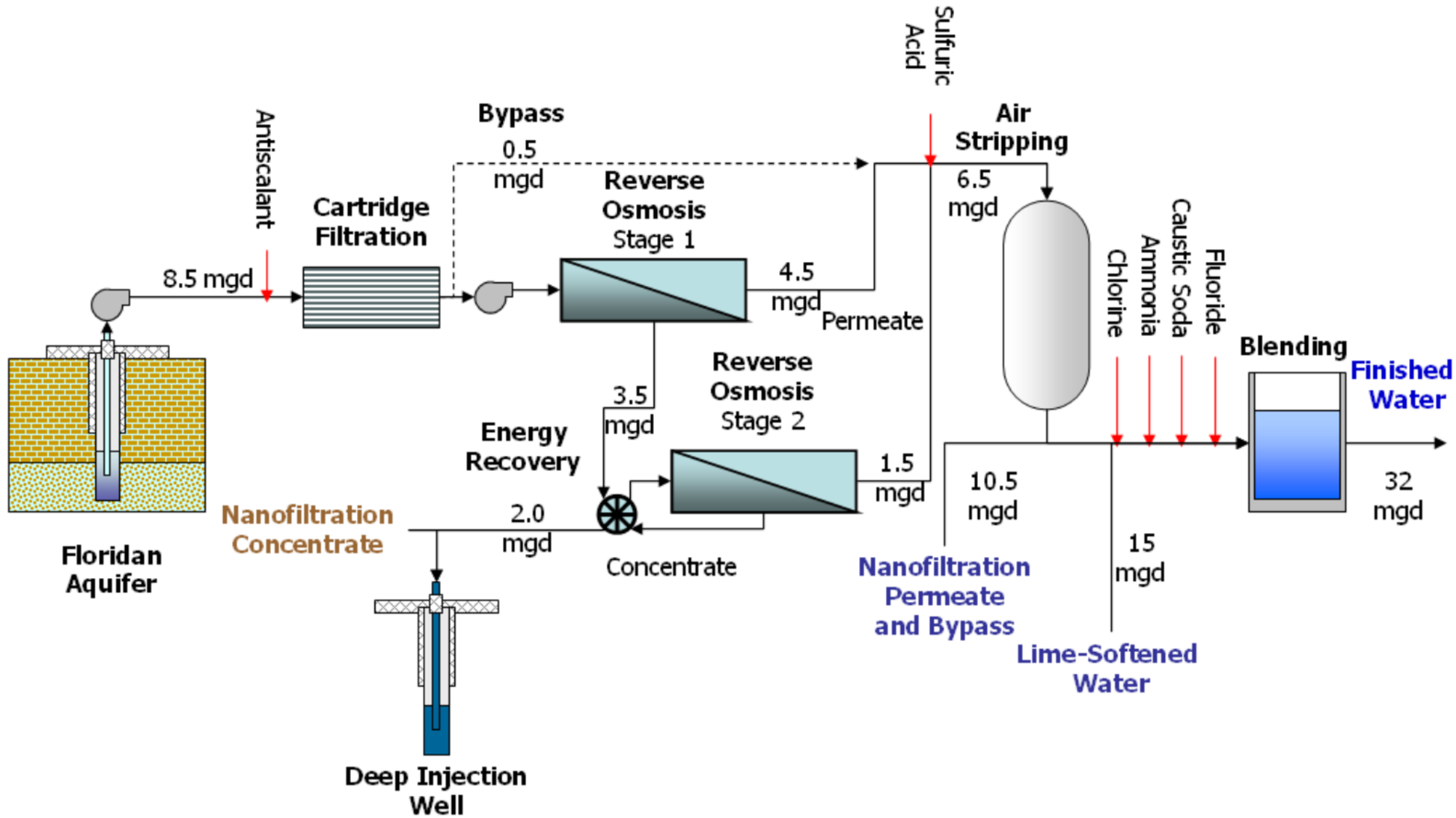
3.3.2 City of Deerfield Beach, West Water Treatment Plant

The City of Deerfield Beach is constructing a 3 mgd RO expansion at its West WTP. A schematic of the West WTP RO process is included in Figure 3.2. Currently, the plant has two parallel independent treatment trains treating fresh water from the Biscayne aquifer, including 7.5 mgd of lime softening, and 10.5 mgd of NF. There will be two 1.5 mgd RO trains with two stages per train. Each train will receive 2.0 mgd of brackish feed water and operate at 75 percent recovery, producing 1.5 mgd per train. Pretreatment includes 73 mg/L of sulfuric acid addition and 3 mg/L of GE/Betz Hypersperse antiscalant addition before cartridge filtration.

Each train will contain 39 pressure vessels distributed between two stages in a 26:13 configuration. There will be 6 elements (Toray polyamide membranes) within each pressure vessel. There will be no energy recovery device .The RO permeate will pass through air stripping before being blended in the clearwell with NF permeate and lime-softened water. The 1.0 mgd of RO concentrate will be disposed by deep well injection. There is a moderate amount of open space on the plant site; however, this may not be enough to hold an evaporation pond, as discussed in Section 3.4.2.

Before construction, three months of pilot testing had been performed, demonstrating that brackish Floridan water and nanofiltration concentrate could be blended together without rapidly fouling the RO membrane. Because NF concentrate is relatively high in organic matter, there were concerns that blending would cause an increase in membrane fouling, resulting in an increase in cleaning frequency and a decrease in membrane useful life. Pilot testing performed in previous studies at the Deerfield Beach WTP did not indicate significant fouling of the RO process when blending NF concentrate.

Under the planned blending scheme, both RO trains will receive brackish Floridan water only, or a blend of Floridan water and NF concentrate in a maximum blend ratio of 50/50. In Section 2, a membrane simulation was described for Deerfield Beach using feed water quality data for the blended feedwater scenario and the appropriate membrane (Toray TMG20). This simulation identified $CaSO_4$, $CaCO_3$, $BaSO_4$, and $SrSO_4$ as salts that would be present in the RO concentrate above the saturation limit.



City of North Miami Beach Norwood-Oeffler WTP, Reverse Osmosis System.

FIGURE 3.1

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FIGURE 3.2

City of Deerfield Beach West Water Treatment Plant, Reverse Osmosis System.

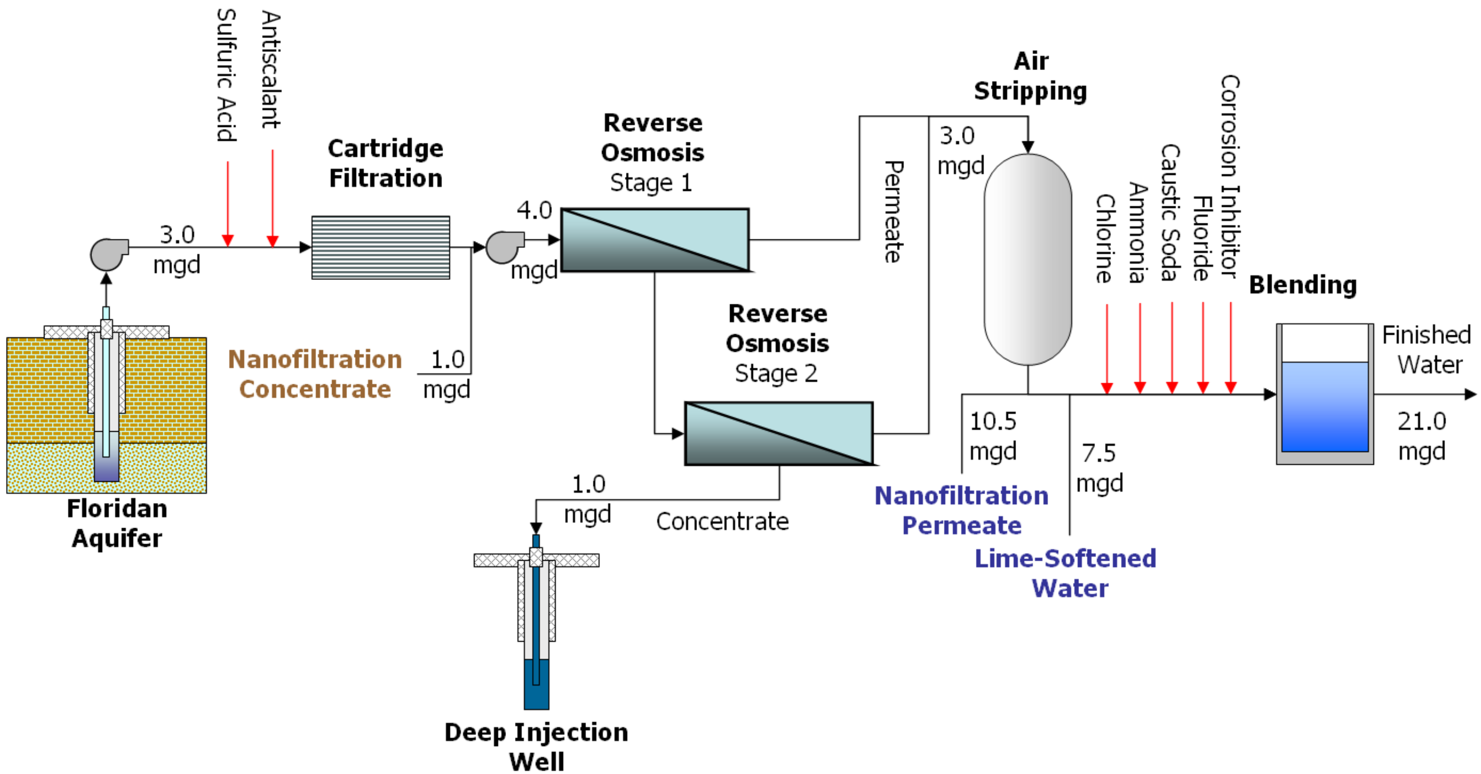

Table 3.2 summarizes the impact of blending NF concentrate on the major ions in the RO feedwater stream. Although the TDS in the NF concentrate, 2,881 mg/L, is nearly the same as the TDS in the Floridan aquifer water, 3,240 mg/L, the composition of the two streams is much different. The NF concentrate increases the calcium, alkalinity, color, and silica of the blend; however, the NF concentrate also decreases the sulfate and chloride of the blend. While the previously completed pilot tests at Deerfield Beach WTP did not identify a problem, the potential for RO fouling due to organic matter in the blend from the NF concentrate should be examined by pilot testing on a case-by-case basis.

Table 3.2 Effect of Blended Nanofiltration Concentrate on Reverse Osmosis Feed Water Quality at the Deerfield Beach West Water Treatment Plant

STREAM	**Floridan Aquifer**	**Nanofiltration Concentrate**	**RO Feedwater 50/50 Blend**
SOURCE	Water Analyses for Basis of Design	NF Plant Operating Data	Calculated
Color	0	378	189
Ca	219.0	572.1	395.6
Mg	160.0	18.1	89.1
Na	675.0	145.6	410.3
K	32.0	11.1	21.6
Sr	8	11.6	9.8
HCO_3^-	219.0	1699.8	959.4
SO_4^{2-}	400.0	214.3	307.2
Cl^-	1498.0	151.5	824.8
SiO_2 (Silica)	24.0	48.8	36.4
Sum of Ions (TDS)	3,240	2,881	3,060

Notes:
1. **Bolded** parameters are present at higher concentrations in the NF concentrate.
2. *Italicized* parameters are present at lower concentrations in the NF concentrate
3. Color of the NF concentrate was estimated in Camp, Dresser, and McKee (2008)
4. Data sources: Camp, Dresser, and McKee (2008); Hempstead, Miller, and Magenheimer, 2008.

3.3.3 City of Hollywood Water Treatment Plant

The City of Hollywood Water Treatment Plant has a 4 mgd reverse osmosis water treatment process. A schematic of the RO treatment train is shown in Figure 3.3. In addition to RO, the plant has 18 mgd of lime softening and 14 mgd of NF treating fresh water from the Biscayne aquifer. The RO process treats brackish water from wells 1200 ft deep in the Floridan aquifer. Pretreatment includes addition of sulfuric acid and antiscalant before cartridge filtration. There are two 2 mgd RO trains with two stages per train. Each train receives 2.5 mgd of feed water and operates at 80% recovery, producing 0.5 mgd of concentrate per train. As of March 2009, only one of the two trains was operating. There are plans to construct an additional 2 mgd RO train.

Each train contains 54 pressure vessels distributed between two stages in a 37:17 configuration. Each pressure vessel contains seven elements. The elements are Hydanautics CPA 2 membranes operating at a flux of 14.5 gfd. The new RO train will use Toray TM720-400 membranes. The feed pressure is about 350 psi. The RO permeate is acidified and passes through air stripping before being blended in the clearwell with 14 mgd of NF permeate and 18 mgd of lime-softened water. The 1 mgd of RO concentrate is blended with 2.5 mgd of NF concentrate and with wastewater effluent before being discharged to an ocean outfall. An injection well for concentrate disposal is being constructed onsite. There is no land available for an evaporation pond on the plant site. There is some open land and a pond to the north of the plant; however, this land is a public park.

The simulation described in Section 2 was updated to include the Hydranautics CPA2 membrane used by the Hollywood RO plant. None of the saturations changed because of the refinement to the actual membrane used at the plant, since the membrane initially assumed (ESPA2) in Section 2 is similar in rejection characteristics to the actual (CPA2) membrane used at the plant.

3.3.4 Marathon Seawater Desalination Facility

The Florida Keys Aqueduct Authority’s Marathon Seawater Desalination Facility has a 1 mgd seawater RO water treatment process. A schematic of the RO treatment train is shown in Figure 3.4. Raw water is withdrawn from onsite seawater wells. Neither acid nor antiscalant are added. The water passes through cartridge filtration and to the RO membranes. There are two 0.5 mgd RO trains with a single stage per train. Each train receives 1.7 mgd of water and operates at 30 percent recovery, producing 1.2 mgd of concentrate per train.

City of Hollywood Water Treatment Plant, Reverse Osmosis System.

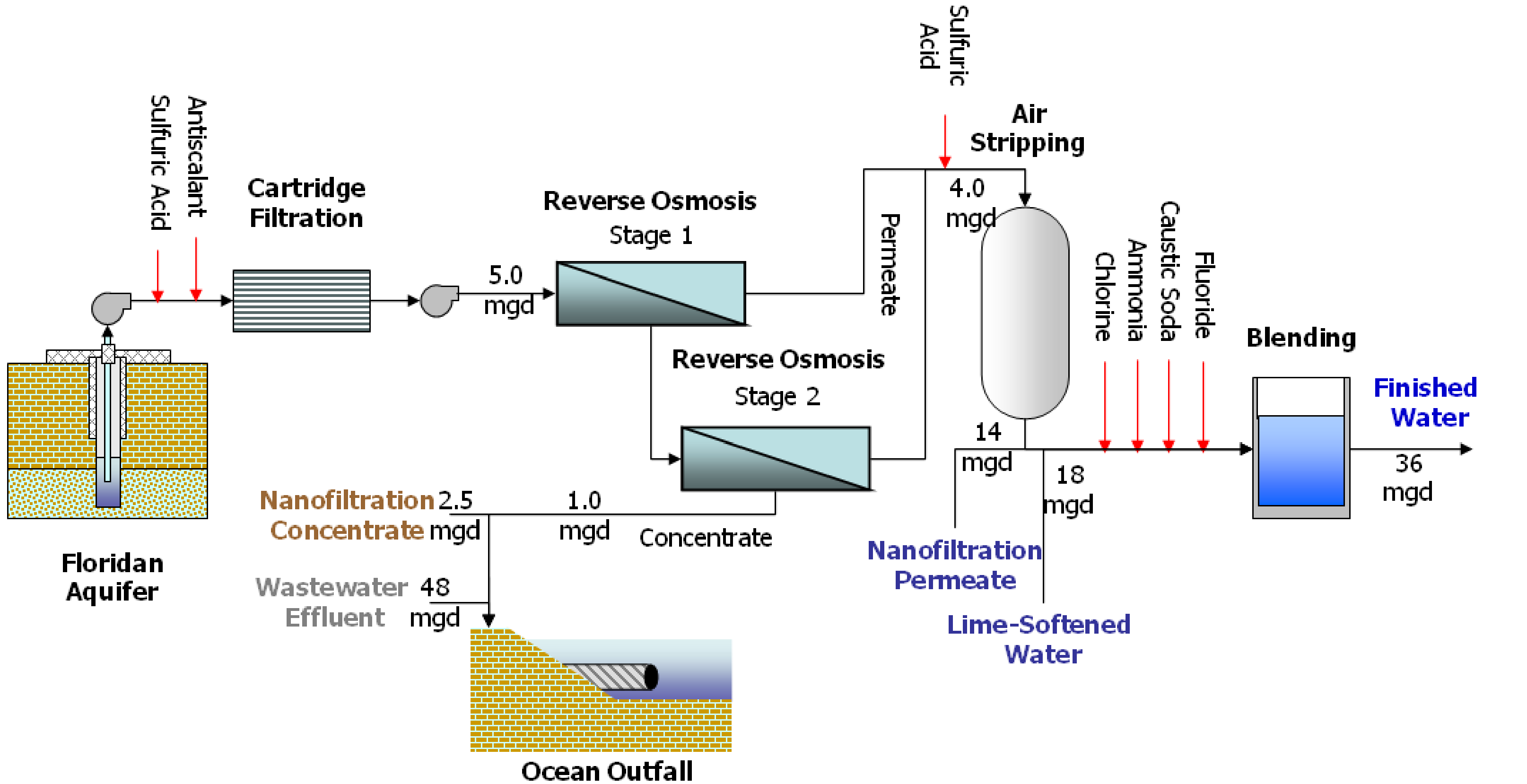

FIGURE 3.3

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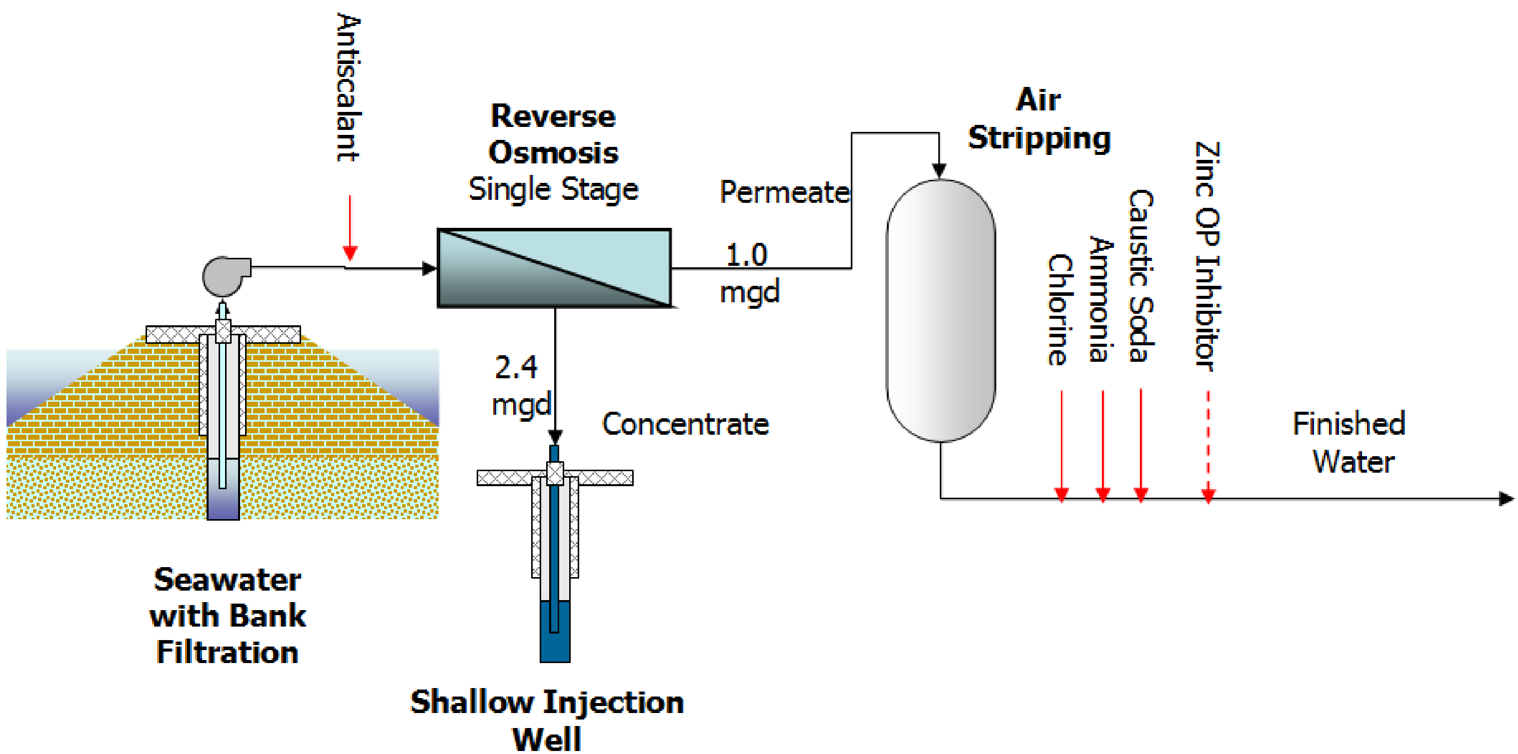

FIGURE 3.4

Florida Keys Aqueduct Authority Marathon Seawater Desalination Facility.

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Each train contains 110 pressure vessels in a single stage. Each pressure vessel contains a single element. The elements are Toyobo HOLLOSEP 9155 hollow fine fiber membranes. The feed pressure is about 815 psi. Sodium hypochlorite, sodium hydroxide, and ammonia are then added to the permeate. Zinc orthophosphate inhibitor is available, but not usually added. No acid is added before air stripping. According to the plant staff, the hydrogen sulfide removal performance of the air stripping towers is inadequate. The plant is on standby most of the time and receives only intermittent use.

The 2.4 mgd of concentrate is disposed by shallow wells near the site. Open ocean discharge was avoided because the water body next to the Marathon facility, Florida Bay, has been classified as an “Outstanding Florida Water.” There is very limited open space near the plant for an evaporation pond. Because the recovery of the RO system at the Marathon facility is limited by pressure and not the solubility of limiting salts, further simulations were not performed for the Marathon facility beyond what was described in Section 2.

3.4 Technology Feasibility Evaluation

A broad technical assessment is presented that evaluates several potential technologies that can enhance overall desalination percent recovery and minimize concentrate volume. Each technology is described and broadly evaluated for several economic, operational, and other criteria.

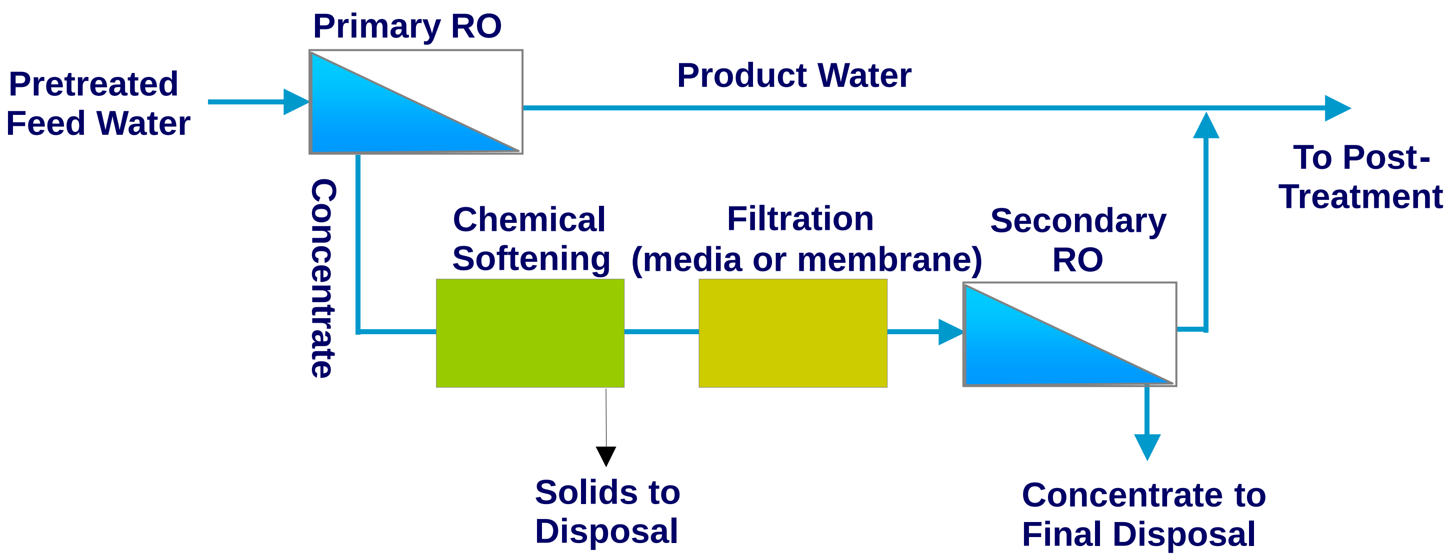
3.4.1 Dual Reverse Osmosis with Intermediate Chemical Precipitation

Dual RO with intermediate chemical precipitation is a physical-chemical approach to enhancing the recovery of a RO process through treatment and minimization of concentrate. An assessment of this technology was included in a recently completed study (Sethi et al 2009) by the Water Research Foundation (formerly AwwaRF) and is summarized herein. This approach uses established technologies such as lime soda softening and a second phase RO (Williams et al. 2002, Gabelich et al. 2007, Rahardianto et al. 2007). Figure 3.5 illustrates how this approach treats the concentrate from a primary RO system using a physical-chemical process, after which it is treated in a secondary RO system. An assessment summary for this technology is provided in Table 3.3.

The concentrate treatment step focuses on removal of cations of concern via precipitative softening to reduce the scaling potential of the concentrate. The steps involved are chemical treatment and precipitation for removal of calcium, magnesium, silica, and other sparingly soluble components, followed by filtration (e.g. media filtration or membrane filtration) for removing solids carryover from the precipitation process. As the secondary RO system will be operated at a higher TDS, it will require higher pressures compared to the primary RO system.

Process Schematic of Dual RO with Intermediate Chemical Precipitation.

FIGURE 3.5



This technology is attractive because it applies established unit processes with relatively low additional energy requirements. However, this treatment scheme has multiple costs including: additional chemical feed and storage facilities chemicals, sludge production from the chemical precipitation process, and the need for a secondary RO system . This approach has been pilot tested at the Metropolitan Water District of Southern California (Williams et al., 2002). A dual RO configuration with intermediate chemical precipitation has also been recently pilot tested at the Southern Nevada Water Authority (SNWA, 2004). The combined recovery of the process is reported to be 95 percent or greater for brackish water.

Table 3.3 Assessment Summary for Dual RO with Intermediate Chemical Precipitation

Criterion	Evaluation
Production efficiency	The overall recovery is expected to vary from 90 to 98 percent with brackish water. The recovery of the primary RO process will be similar to a BWRO system, i.e., from 60 to 85 percent. The recovery of the secondary RO system is expected to vary from 50 to 80 percent.
Product water quality	The overall TDS rejection of the two RO systems is expected to be around >94 percent, assuming >98 percent rejection in each RO system. Product water TDS would increase with recovery, as salt concentration on membrane feed side increases with recovery (which results are increased salt passage across membrane).
Infrastructure considerations	Compact and modular membrane system for the secondary RO system. Membrane process and certain associated equipment (feed pumps, clean-in-place system, instruments and controls, and electrical) need to be housed inside building. Additional area requirement for intermediate chemical precipitation step and associated filtration step before secondary RO. Plant footprint would thus be greater compared to brackish water RO (BWRO) without concentrate recovery.
Energy consumption	Energy consumption is estimated to range from 4 to 20 kWh/1000 gal of concentrate treated. Energy usage includes softening process, filtration, and reverse osmosis treatment of a high salinity concentrate. Energy recovery should be possible for the secondary RO system.
Chemical consumption	Lime or caustic (and possibly soda ash) for chemical precipitation. Polymer for filtration. Acid, caustic, and detergent for membrane cleaning. Antiscalant, acid, and disinfectant for control of fouling and scaling. Reducing agent to remove oxidant/disinfectant before membranes. Caustic for corrosion control. Alkalinity may not be required, as the secondary RO would produce a comparatively higher TDS product, which might provide adequate alkalinity in the combined product after blending with the product from the primary RO system.
Life cycle	About 20 years. Major replacement needs include membrane replacement about every 3 to 7 years.

Table 3.3 Assessment Summary for Dual RO with Intermediate Chemical Precipitation	
Criterion	**Evaluation**
O&M considerations	O&M needs would be relatively more complex compared to BWRO due to the addition of the chemical softening step. Automated monitoring/control system is required including pH, temperature, conductivity, flow rate, pressure and chemical dosing. Cleaning frequency for membrane system is expected to be similar to BWRO.
Overall costs	A pilot study for treatment of 1 mgd concentrate from the Eastern Municipal Water District in California identified a total cost of approximately $3.25/1000 gal of concentrate. The total capital cost was $14.75/gpd of concentrate capacity and the annual operating cost was $0.97/gpd of concentrate capacity.
Pre-and post treatment	Post filtration is required to suspended solids before the secondary RO system. Also, acid and antiscalant feed before the secondary RO system may be required.
Concentrate management	Concentrate treatment includes chemical precipitation, filtration (i.e. media or microfiltration), followed by a secondary RO system. The liquid concentrate from the secondary RO system will be highly concentrated, and may require reevaluation before discharge to existing concentrate disposal systems.
Permitting	Disposal of concentrate solids may require regulatory approval. Handling of highly concentrated brine from the secondary RO may require a reevaluation of concentrate disposal at the plant for potentially hazardous levels of brine constituents. Depending on sludge composition, permitting could also restrict sludge disposal options.
Adapted from Sethi. et al. 2009	

3.4.2 Thermal Evaporation (Brine Concentration) and Evaporation Pond

This concentrate treatment train consists of a brine concentration step and final concentrate disposal to an evaporation pond. It is capable of providing zero liquid discharge (ZLD), and a recoverable mixed salt product; however, the acreage required for evaporation ponds along with climate conditions makes this treatment train impractical for many desalination facilities in South Florida. An assessment summary for this technology is provided in Table 3.4.

Table 3.4 Assessment Summary for Thermal Evaporation and Evaporation Pond	
Criterion	**Evaluation**
Production efficiency	Brine concentrator recovery is 90-99 percent. Evaporation ponds are only a concentrate disposal technology. All water entering a pond is evaporated and hence “lost” to the atmosphere.
Product water quality	Brine concentrator distillate is typically very pure with a TDS as low as 10 mg/L.
Infrastructure considerations	Brine concentrator is located outdoors for heat dissipation. Evaporation ponds have large land area requirements; with an expected loading rate in Florida of about 1 gpm/acre. Clay or synthetic liners are required. Monitoring wells or boreholes are required.
Energy consumption	Energy usage is very high due the thermal concentrate treatment processes, estimated to be about 85 to 135 kWh/1000 gal of concentrate treated. The only energy required for the evaporation pond is to pump the concentrate out to the pond.
Chemical consumption	Scale inhibitor may be added before the brine concentrator and heat exchanger. No chemicals are required for the evaporation pond unless pH adjustment is necessary.
Life cycle	The brine concentrator is constructed of corrosion resistant metal alloys and has a design life of about 20 years. The evaporation pond should be designed to have a life similar to the projected life of the desalting facility.
O&M considerations	Scale control in the brine concentrator and heat exchanger must be maintained. The brine concentrator is energy intensive and will have high energy operating costs. Requirements are minimal for the evaporation pond. The only mechanical equipment used is pumps. Other items may include liner repairs and monitoring.
Overall costs	Costs vary with feed water salinity, plant capacity and site-specific factors. However, in general costs are due to the high capital and energy costs associated with the thermal processes Typical total product costs are greater than $3/kgal. The capital costs for evaporation ponds are highly variable and dependent on location. There is little economy of scale and method is most competitive for small flows. Capital costs are high and in general range from $40/gpd to $160/gpd. O&M costs are approximately 0.5 percent of capital costs.
Pre-and post treatment	Scale inhibitor may be added before the brine concentrator and heat exchanger to prevent scaling of the interior walls. For the evaporation pond, no pre/post treatment is required except for sludge disposal if pond has been designed for periodic sludge removal (hazardous sludge would require proper handling, treatment, and disposal according to RCRA).
Concentrate management	Concentrate treatment includes brine concentration and may also typically include pH adjustment. Pond may be designed for either sludge accumulation throughout life of ponds with capping at the end of useful life, or for periodic sludge removal and disposal.
Permitting	The brine concentrator will increase the concentration of constituents in the RO concentrate by a factor of 10 to 100. Handling of highly concentrated brine will require a reevaluation of concentrate disposal at the plant for potentially hazardous levels of brine constituents. The evaporation pond will require permitting and continual monitoring for leakage. Depending on sludge composition, permitting could also restrict sludge disposal options.
Adapted from Sethi. et al. 2009	

Thermal Evaporation

A brine concentrator is a thermal desalination process that concentrates a saline feed stream through distillation and vapor compression. The brine concentrator shown in

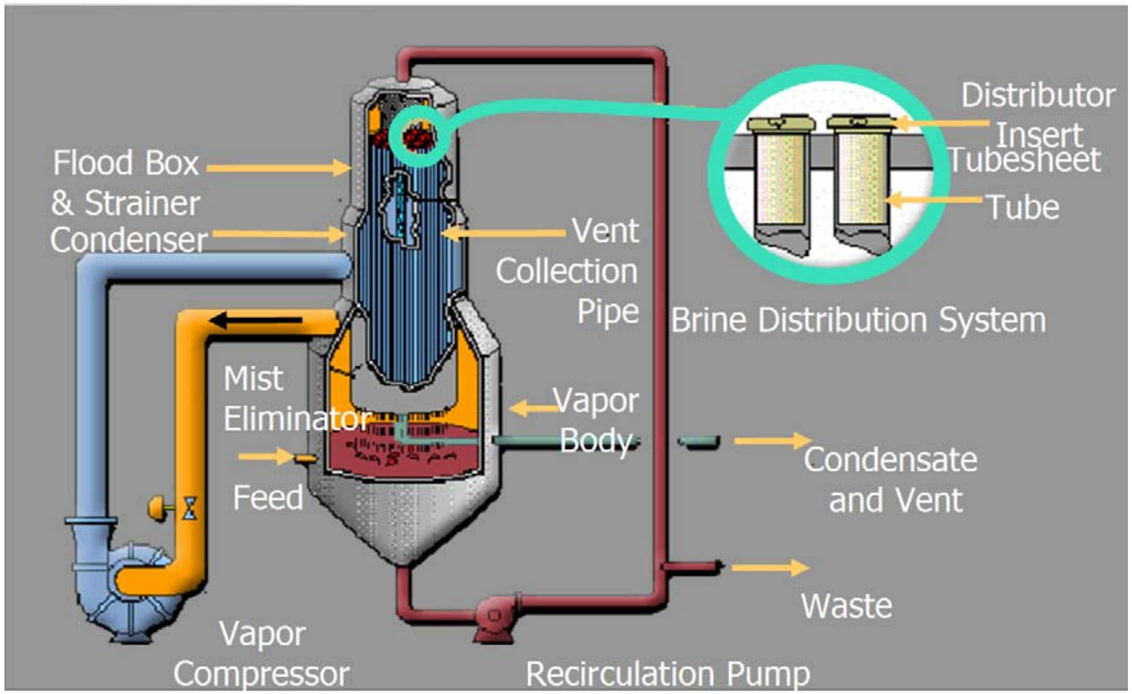
Figure 3.6 is one example of this configuration that employs a vertical tube, thin film evaporator.

Before entering the concentrator, the feed stream passes through a heat exchanger (not shown) with the distillate and a deaerator (not shown) that removes non-condensable gases such as carbon dioxide and oxygen. A scale inhibitor is added to prevent scaling in the heat exchanger and evaporation chamber. Once in the concentrate sump, the feed is pumped up and falls by gravity in a thin film down the inside of two-inch heat transfer film. A small portion of the liquid evaporates and the rest falls back to the sump to be recirculated. The vapor passes is drawn out of the sump chamber and is pressurized by a vapor compressor. The vapor condenses on the outside surface of the heat transfer tubes and is collected and drawn off. Salinity of the distillate can be less than 10 mg/L TDS. At the same time, a small portion of concentrated brine stream is continually drawn off to waste. The brine concentrator typically recovers 95 percent of the concentrated feed stream as distillate, reducing the volume and increasing the salinity of the concentrate by a factor of 20.

Evaporation Pond

Brine concentration relies on a separate unit operation for solids recovery such as an evaporation pond or brine crystallizer. Use of an evaporation pond can allow a plant to achieve true zero liquid discharge; however, the water that evaporates is lost. An evaporation pond is typically a shallow lined pond where concentrate evaporates naturally using solar energy. Over the life of the pond, as the water evaporates, a salt sludge accumulates that is either left in place or removed and hauled offsite for disposal. This disposal method can be expensive due to the large surface area required and the associated land and impermeable liner costs (NRC 2004). Evaporation ponds are best suited for treatment of small concentrate flows in warm, dry climates with high evaporation rates, level terrain, and low land costs.

Process Schematic of Brine Concentrator.



Source: GE Water and Process Technologies.
(Inclusion of trade names does not imply endorsement of products).

FIGURE 3.6

The design and construction of evaporation ponds must consider the regulatory requirements, ecological impacts, and possible concentration of trace elements to toxic levels (ASCE 1990). While evaporation rates in South Florida are high, significant rainfall reduces the net evaporation rates, making evaporation ponds a less-viable concentrate management option. The average evapotranspiration potential within the SFWMD has been estimated to vary between 3.0 inches/month to 5.9 inches/month within a year (Abtew et al. 2003).

Actual evaporation potential will be less for an evaporation pond than that measured by evaporation pans due to differences in scale and sidewall effects, as well as the decrease in water vapor pressure with increasing salinity (Bond and Veerapaneni, 2007). When corrected for the effect of evaporation pans and salinity, the lowest estimated evapotranspiration potential 1.8 inches/month corresponds to a land requirement of 0.9 acres/gpm or 624 acres/mgd. The concentrate volumes for the plants considered in this report, 0.6 mgd to 1.5 mgd, would range from 4 gpm to 10 gpm, after brine concentration, with a volume reduction of 99 percent (concentration factor is 100). The land requirement would be from 3.5 acres to 9 acres. Due to these excessive land requirements, evaporation ponds are not a practical solution for managing the large concentrate volumes associated with desalination in South Florida.

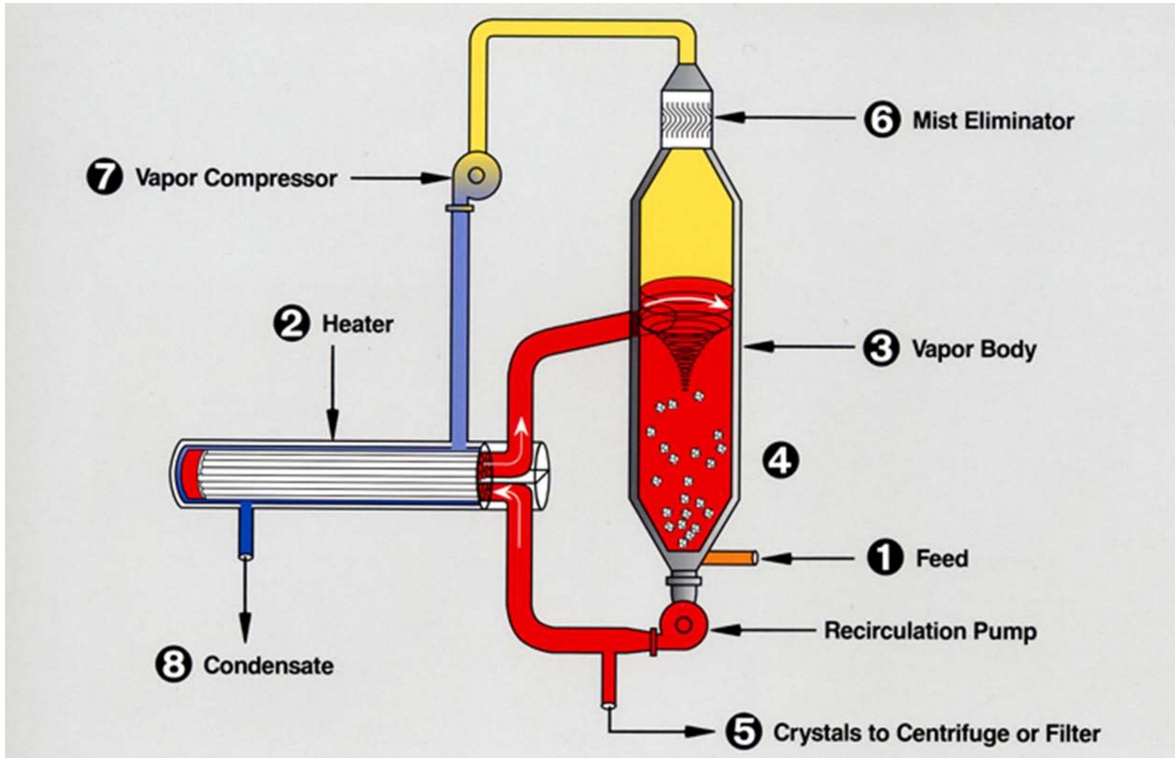
3.4.3 Thermal Evaporation (Brine Concentration) and Brine Crystallization

This concentrate treatment train consists of a brine concentration step and a brine crystallizer. Brine concentration was described in Section 3.4.2. Brine crystallization is similar to brine concentration since it includes a distillation step; however, while brine concentration converts the concentrate into a slurry, the brine crystallization step further converts the slurry to a solid product.

In a brine crystallizer (Figure 3.7), the concentrate feed enters a boiler and is continuously recirculated and reheated. Within the boiler, some concentrate evaporates and is recovered as distillate through vapor compression. The latent heat of condensation from the vapor is passed to the recirculating concentrate through a heat exchanger. A crystalline seed material, such as sand, is fed to the boiler continuously by the feed stream. The seeds provide favorable precipitation sites for precipitation of saturated salts within the boiler. As the seeds grow in size they settle to the bottom of the boiler and are drawn off for dewatering via centrifugation or filtration. The centrate or filtrate is then blended with the RO permeate. Near zero liquid discharge is possible with brine crystallization. An assessment summary for this technology is provided in Table 3.5.

FIGURE 3.7

Process Schematic of Brine Crystallizer.



Source: GE Water and Process Technologies.
(Inclusion of trade names does not imply endorsement of products).

Table 3.5 Assessment Summary for Thermal Evaporation and Brine Crystallization	
Criterion	**Evaluation**
Production efficiency	Recovery is 100 percent (or very close to 100 percent).
Product water quality	Mixed brine concentrator and brine crystallizer distillate is typically very pure with a TDS as low as 10 mg/L.
Infrastructure considerations	Brine concentrator and crystallizer are located outdoors for heat dissipation.
Energy consumption	Energy usage is very high due the thermal concentrate treatment processes, estimated to be about 85 to 135 kWh/1000 gal of concentrate treated. Energy recovery is possible using typical energy recovery devices.
Chemical consumption	Scale inhibitor may be added before the brine concentrator and heat exchanger. A defoaming agent may be added before the brine crystallizer to prevent formation of foam in the crystallizer.
Life cycle	The brine concentrator and crystallizer are constructed of corrosion resistant metal alloys and have a design life of about 20 years.
O&M considerations	Scale control in the brine concentrator and heat exchanger must be maintained. Both the brine concentrator is energy intensive and will have high energy operating costs. The crystal slurry in the crystallizer will help minimize formation of scales on the crystallizer walls.
Overall costs	Costs vary with feed water salinity, plant capacity and site-specific factors. However, in general costs are due to the high capital and energy costs associated with the thermal processes. Typical total product costs range from $3-$5/kgal.
Pre-and post treatment	Scale inhibitor may be added before the brine concentrator and heat exchanger to prevent scaling of the interior walls. For the crystallizer, crystalline solids may require dewatering before ultimate disposal.
Concentrate management	Concentrate treatment includes brine concentration and crystallization. Solids from the crystallization process need to be ultimately disposed offsite.
Permitting	The brine concentrator will increase the concentration of constituents in the RO concentrate by a factor of 10 to 100. If there is a liquid discharge handling of highly concentrated brine would require a reevaluation of concentrate disposal at the plant for potentially hazardous levels of brine constituents. However, most of the dissolved solids will be transformed into crystalline solids, and handling and disposal of these solids may require regulatory approval.
Adapted from Sethi. et al. 2009	

3.4.4 Salt Extraction and Recovery

Salt extraction and recovery is an approach to concentrate minimization that views RO concentrate as a potential resource containing multiple minerals with economic value (Figure 3.8). Unlike brine concentration, salt extraction and recovery focuses on the selective recovery of beneficial salts of high purity from the saline water.

An assessment of this technology was included in a recently completed study (Sethi et al 2009) by the Water Research Foundation (formerly AwwaRF) and is summarized in Table 3.6, as well as discussed in the following paragraphs. Multiple physical and chemical processes may be employed to isolate the desired salt from the concentrate, and many different applications have been tested. Jibril and Ibrahim (2001) treated ammoniated brine with CO_2. In a series of reactions, sodium chloride (NaCl) was converted into valuable products such as sodium bicarbonate ($NaHCO_3$), soda ash (Na_2CO_3), ammonium chloride (NH_4Cl), and magnesium chloride ($MgCl_2$).

Sandia National Laboratories developed salt adsorption and sequestration techniques to recover salts from brine. Certain layered materials are able to sequester inert inorganic materials around anionic and cationic brine water components at room temperature. The crystallized precipitates can be used as a sellable building material (incorporated into cement, etc.). Turek et al. (2005) examined the viability of using electrodialysis-electrodialysis reversal, ED-EDR, to pre-treat and pre-concentrate coal-mine brine. When compared to a brine crystallizer operating at a nearby desalination plant, they found that the ED-EDR brine treatment reduced the energy consumption for salt recovery from 970 kWh/ton of salt with brine crystallization to 500 kWh/ton of salt for the ED-EDR treated brine.

The patented SAL-PROC™ process also uses sequential or selective extraction to recover beneficial salts from inorganic saline waters (such as irrigation drainage, produced water and RO concentrate, etc.) (Geo-Processors USA, Inc.). Depending on the chemical composition of the saline feedwater the process route may involve one or more steps of reaction and evapocooling supplemented by conventional mineral and chemical processing steps. Field trials, piloting and public demonstrations have indicated the capacity of SAL-PROC™ to convert a number of saline waste streams into saleable products and achieve zero or regulated discharges. Geo-Processors USA Inc. demonstrated the application of SALPROC™ technology by extracting 64,000 tons salts from the Lake Tutchewop, Victoria, per year. Portable units having a salt load removable capacity (SLRC) of up to 22,000 tons per year were used at a derelict coal mining field in Cessnock, NSW. Fixed units with SLDC of 21,600 tons per year was used to recover salts from the brine of multistage-RO system during treatment of Coal Bed Methane (CBM) produced water (Queensland, Australia).

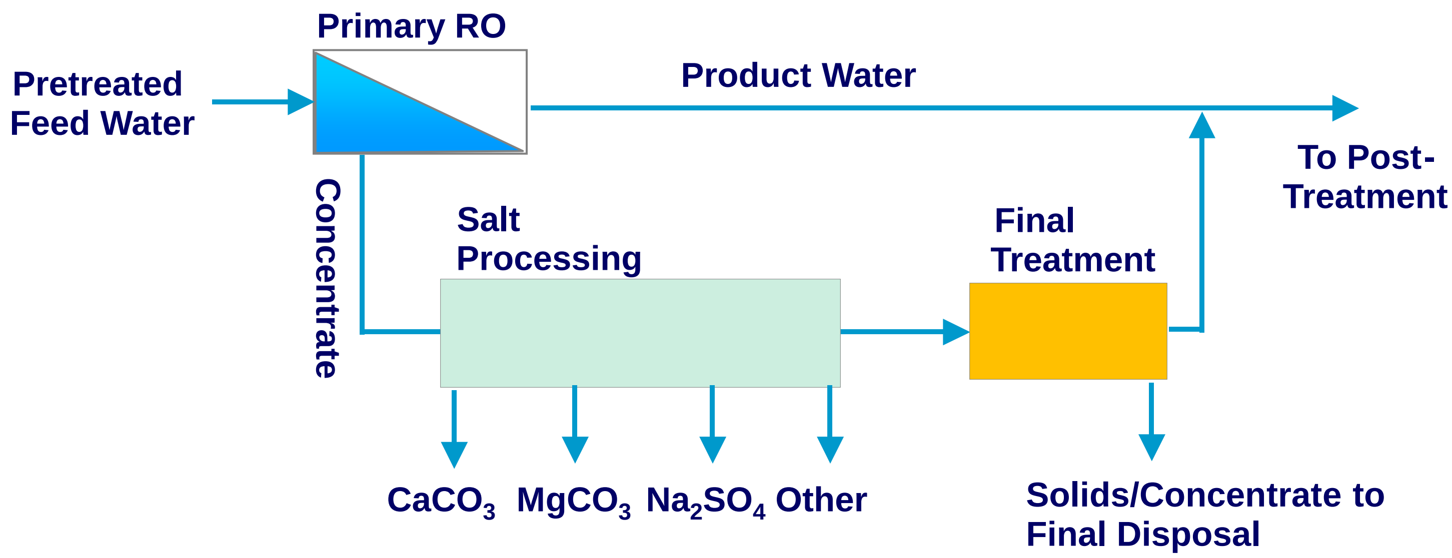


FIGURE 3.8

Process Schematic of Salt Extraction and Recovery Approach (Source: Sethi et al., 2009).

Table 3.6 Assessment Summary for Salt Extraction and Recovery Approach	
Criterion	**Evaluation**
Production efficiency	The system can recover 80 percent of the water, and ZLD can be achieved as well. During pretreatment, some water is lost in the generated sludge. No information is available on down time.
Product water quality	Product water quality is independent of improved recovery and/or concentrate management.
Infrastructure considerations	Modules can be custom built in size, configurations and cost packages to suit site-specific conditions and client requirements. No specific basic infrastructure constraints.
Energy consumption	No information reported.
Chemical consumption	Lime, acid and other chemicals are used to react with brine to extract salts.
Life cycle	No information available.
O&M considerations	The required level of operation and maintenance consideration is intermediate. The system is simple to operate and carries low operating risks. Temperature, conductivity, flow rate, and pH need to be routinely monitored and controlled.
Overall costs	The capital investment and operation costs depend on water sources and the chemical composition, ranging \$2.3-22.1/gpd as capital costs, \$3.9 - 13.9/kgal of water treated as operating costs, and \$5.5-21.7/kgal as total cost.
Pre-and post treatment	No special pretreatment is typically required.
Concentrate management	The generated concentrate and sludge need to be pH adjusted and disposed.
Permitting	Handling and marketing of purified solids may require regulatory approval.
Adapted from Sethi. et al. 2009	

Kumar et al. (2006) employed a series of innovative tests utilizing ion exchange (IX), bipolar electrodialysis (BED) and electrochlorination (EC) technologies to recover useful products from RO concentrate that can be utilized at the treatment facility. Experiments were conducted on RO concentrate obtained from a pilot-scale integrated membrane system (IMS) treating wastewater. The IX experiments focused on recovering phosphate from RO concentrate using a chelating ion exchange resin and converting the phosphate rich regenerant into struvite, a commercially viable fertilizer. RO concentrate with minimal pretreatment provided reasonably long run lengths of up to 1500 BVs. Bipolar electrodialysis was used for generating mixed acids and bases from the RO concentrate solution after suitable softening pretreatment. Electrochlorination using RO concentrate was utilized to convert this waste stream into hypochlorite disinfectant. Salt addition was still needed to supplement the low salt concentration of the RO concentrate, but this process presents the potentially viable alternative of blending a waste stream for the production of a useful product instead of having to dispose of the waste brine into the environment.

The positive attribute of salt solidification is salt recovery and resale, and near zero liquid discharge. The sale of products from the facilities would provide significant payback to the projects and could potentially cover the costs involved in installing and running the full-scale facilities. Potential saleable products recoverable from RO concentrates in South Florida include, $CaCO_3$ (calcite), $CaSO_4$ (gypsum). Calcite is used by manufacturers who produce lime, and plastics. Gypsum is used by manufacturers who produce drywall and other construction materials.

3.5 Comparison of the Concentrate Minimization Technologies and Pilot Study Recommendation

Table 3.7 includes a broad-based comparative summary of the relative attributes of the four concentrate minimization technologies considered in this study. When compared to other three concentrate management technologies, dual RO with intermediate chemical precipitation is favorable because of the relatively lower capital cost and lower energy consumption (especially when compared to the approaches using thermal technologies like brine concentrator or brine crystallizer), as well as the general status of development and testing of the approach. Furthermore, it has been tested effectively by at bench-scale (Sethi et al, 2009), and piloted at high recovery by Carollo Engineers for two brackish waters in California and Arizona; the TDS of those brackish waters is on the mild side, i.e. less than about 2,000 mg/L.

A pilot study on a brackish RO concentrate in the District would help provide the information needed to establish the potential for intermediate chemical precipitation to manage concentrate and enhance utilization of high-value Floridan Aquifer water. The technology can require significant amounts of chemicals and does create a sludge that must be disposed; however, the opportunity to increase recoveries to nearly 95 percent using well established chemical treatment processes at a reasonable cost will offset added expenses.

Among the four representative RO desalination plants, two were considered relatively less attractive for pilot testing consideration. The Deerfield Beach West RO Plant represents a unique RO feed that blends brackish groundwater with NF concentrate, and was thus not representative of the typical brackish water RO facility. It was also under construction during the study, and would not have been available for the piloting. The Florida Keys Aqueduct Authority Marathon desalination facility treats seawater, and concentrate minimization for seawater facilities is difficult as the recovery is dictated by pressure considerations rather than solubility of salts. The water is rich in NaCl and would not benefit from intermediate chemical precipitation like a brackish RO plant.

Table 3.7 Broad-Based Comparison of Concentrate Minimization Technologies

Item	Dual Reverse Osmosis with Intermediate Chemical Precipitation	Brine Concentrator and Evaporation Pond	Brine Concentrator and Brine Crystallizer	Salt Extraction and Recovery
Production efficiency (recovery)	High	Moderate[1]	Very High	High
Product water quality	High	Very High	Very High	High
Footprint	Moderate	Large (for pond)	Small	Moderate
Energy consumption	Moderate	High	Very High	Moderate
Chemical consumption	Moderate-High[2]	Low	Low	Moderate-High[2]
O&M considerations	Sludge Disposal	High Energy Use	High Energy Use	Marketability of Salts
Overall costs	Moderate	Very High	Very High	Moderate-High
Concentrate management	Final concentrate disposal; sludge disposal	Regular sludge disposal from pond or capping at end of life	Disposal of crystalline solids	Marketing of saleable products and final disposal of concentrate
Permitting Complexity[3]	Low-Moderate for final concentrate and sludge disposal	Moderate for evaporation pond	Low-Moderate for disposal of concentrate solids[3]	Low-Moderate for final concentrate disposal; use of recovered salts

Notes:

1. Due to the water lost in the evaporation pond.
2. Will depend on the water quality characteristics of the concentrate stream being treated.
3. Permitting complexity will be higher in a scenario where constituents are concentrated to a level that classify the final concentrate or solids to be disposed of as 'hazardous'.

Thus, the two most favorable brackish RO plants remaining in consideration for a pilot study were the Hollywood WTP and the North Miami Beach WTP. The RO system at Hollywood WTP operates at 80 percent recovery, and the RO system at North Miami Beach WTP operates at 75 percent recovery. Based on several other considerations, such as representative source water TDS, distance factors, etc., the North Miami Beach WTP was selected as the site for the pilot test of the concentrate minimization technology.

3.6 Summary

- The process trains for four RO desalination facilities, representing different water quality types in the SFWMD, were introduced with information provided on flow rates, chemical addition, concentrate disposal method, and other process characteristics.
- Updated membrane simulations were conducted for the three brackish RO desalination facilities, using each plant's membrane type and membrane manufacturer software.
- The RO feed comprising a blend of brackish groundwater with NF concentrate at the Deerfield Beach WTP was projected to increase the calcium, alkalinity, and silica of the feedwater to the brackish RO process, while decreasing the magnesium, sodium, potassium, sulfate, and chlorides.
- Four concentrate treatment trains were considered including dual reverse osmosis with intermediate chemical precipitation, brine concentrator with evaporation pond, brine concentrator with brine crystallizer, and selective salt recovery.
- While evaporation rates in South Florida are high, significant rainfall reduces the net evaporation rates, making evaporation ponds a less-viable concentrate management option for any of the RO facilities, which are all sited in suburban settings with limited open space.
- The combination of brine concentrator followed by a brine crystallizer is a proven technology that has been used to provide zero liquid discharge for power plants through thermal desalination. High energy and capital costs make these technologies less attractive for the water treatment industry.
- Selective salt recovery views desalination concentrate streams as potential mineral resources. The sale of recovered salt products is essential to supporting the added capital expense of salt recovery. A market for coproduced salts from water treatment has yet to emerge in North America.
- Dual RO with intermediate chemical precipitation is a less-energy intensive technology of moderate cost that has been previously proven at bench and pilot scale. The approach has demonstrated the ability to achieve an overall recovery of up to about 95 percent. There is a need to test this approach systematically on representative Florida waters (i.e. RO concentrate generated from Florida brackish waters).

4.0 EXAMINATION OF TECHNICAL, PERMITTING, AND IMPLEMENTATION FACTORS

4.1 Purpose

Concentrate management by volume reduction has the potential of concentrating the final waste stream to high enough salt concentrations as to be likely classified as hazardous. Salt concentration, therefore, can become an environmental as well as a permitting issue. This section identifies the potential risks, if any, associated with increased recovery at desalination treatment plants in the District. It examines the technical, permitting, and implementation factors related to actual concentrate water quality and disposal practices within the District. The findings presented herein will assist regulatory agencies in evaluating and making better decisions on permitting concentrate management technologies.

4.2 Scope

The scope for this task included characterization of the constituents of the concentrate stream, based on the water quality data collected or estimated (via simulations) in this study, followed by comparison with well-known hazardous substances. Preliminary conclusions are made regarding concentration levels at which significant adverse environmental effects may occur for the treatment schemes proposed.

4.3 Background

RO water treatment takes a feed water and separates it into two streams. One stream contains purified water and the other stream contains concentrated dissolved solids, which can include salts, pathogens, organic matter, radionuclides, and any other substances present in the original feed water. It is desirable to increase the recovery of purified water by reducing the amount of water wasted in the concentrate stream; however, depending on the source water and enhanced recovery, a side effect of removing more water from the concentrate stream is the increase in concentrations of regulated compounds to concentrations that might threaten human health or the environment receiving the final concentrate discharge. Further treatment of the concentrate stream may also generate solid wastes that must be evaluated for safe disposal. If the liquid or solid residuals were classified as “hazardous wastes,” then safe disposal options would be restricted.

4.4 Approach

If concentrate recovery generates a solid or liquid hazardous waste, current concentrate disposal methods may be restricted or unavailable. Consequently, an investigation of concentrate recovery should identify what level of treatment has the potential to generate hazardous wastes. An optimal approach to concentrate minimization would balance water efficiency with environmental health and safety. This section uses the following approach to identify potential challenges to increased recovery of desalination concentrate, including the risks associated with disposal of membrane process residuals. First, Section 4.5 defines “hazardous waste” and introduces regulations relating to liquid and solid waste disposal. Section 4.6 describes the existing concentrate disposal systems of four desalination plants in the District. Section 4.7 evaluates the effect of increased RO system recovery on projected final concentrate water quality. Key parameters are compared to regulatory levels relevant to existing concentrate disposal methods. Section 4.7 also examines the advantages and disadvantages of a reduction in concentrate volume on the receiving environment, without regard to which concentrate minimization technology is used. Treatment to zero liquid discharge is used as a worst-case scenario for identifying potentially hazardous solid wastes using water quality data. Section 4.8 assesses four concentrate treatment alternatives for their technical feasibility, permitting complexity, and potential for implementation at each of the three brackish water RO plants identified in this report, excluding the seawater RO plant.

Overall, this approach compares selected concentrate water quality data from RO plants within the District to current applicable regulations. The result is a preliminary assessment of the potential challenges to increased concentrate recovery for RO plants.

4.5 Regulations for Disposal of Reverse Osmosis Concentrate

This section reviews state and federal regulations applicable to disposal of membrane concentrate. The first subsection examines the definition of hazardous waste. The following subsections look at regulations pertaining to disposal of liquid waste and solid waste respectively. Under federal regulations, reverse osmosis concentrate would be classified as a liquid process residual. The following paragraph provides a broad overview of federal regulations.

Three factors control which federal regulations apply to a residual management practice. These include the solid or liquid state of the residual, its management, and its chemical makeup (EPA 2000). Figure 4.1 summarizes the numerous federal regulatory programs governing waste disposal. Liquid concentrate disposal by direct discharge and underground injection are governed by the Clean Water Act (NPDES Program) and the Safe Drinking Water Act (Underground Injection Control Program) respectively. Landfill disposal of treatment sludges and other solid waste is governed by the Resource Conservation and Recovery Act (RCRA Subtitle C&D Programs). State regulations, in general, go further than federal regulations by enacting water quality standards for ground water and surface water or by restricting the handling of hazardous waste. Table 4.1 lists selected Florida regulations affecting the disposal of liquid and solid membrane residuals.

Table 4.1	Selected Florida Regulations Affecting Membrane Residual Disposal	
Chapter FAC	**Regulation**	**Agency**
62-4	Permits	FDEP
62-302	Surface Water Quality Standards	FDEP
62-520	Groundwater Classes, Standards, and Exemptions	FDEP
62-522	Groundwater Permitting and Monitoring Requirements	FDEP
62-528	Underground Injection Control	FDEP
62-550	Drinking Water Standards, Monitoring, and Reporting	FDEP
62-620	Wastewater Facility and Activities Permitting	FDEP
62-660	Industrial Wastewater Facilities	FDEP
62-730	Hazardous Waste	FDEP
64E-5	Control of Radiation Hazard Regulations	FDOH

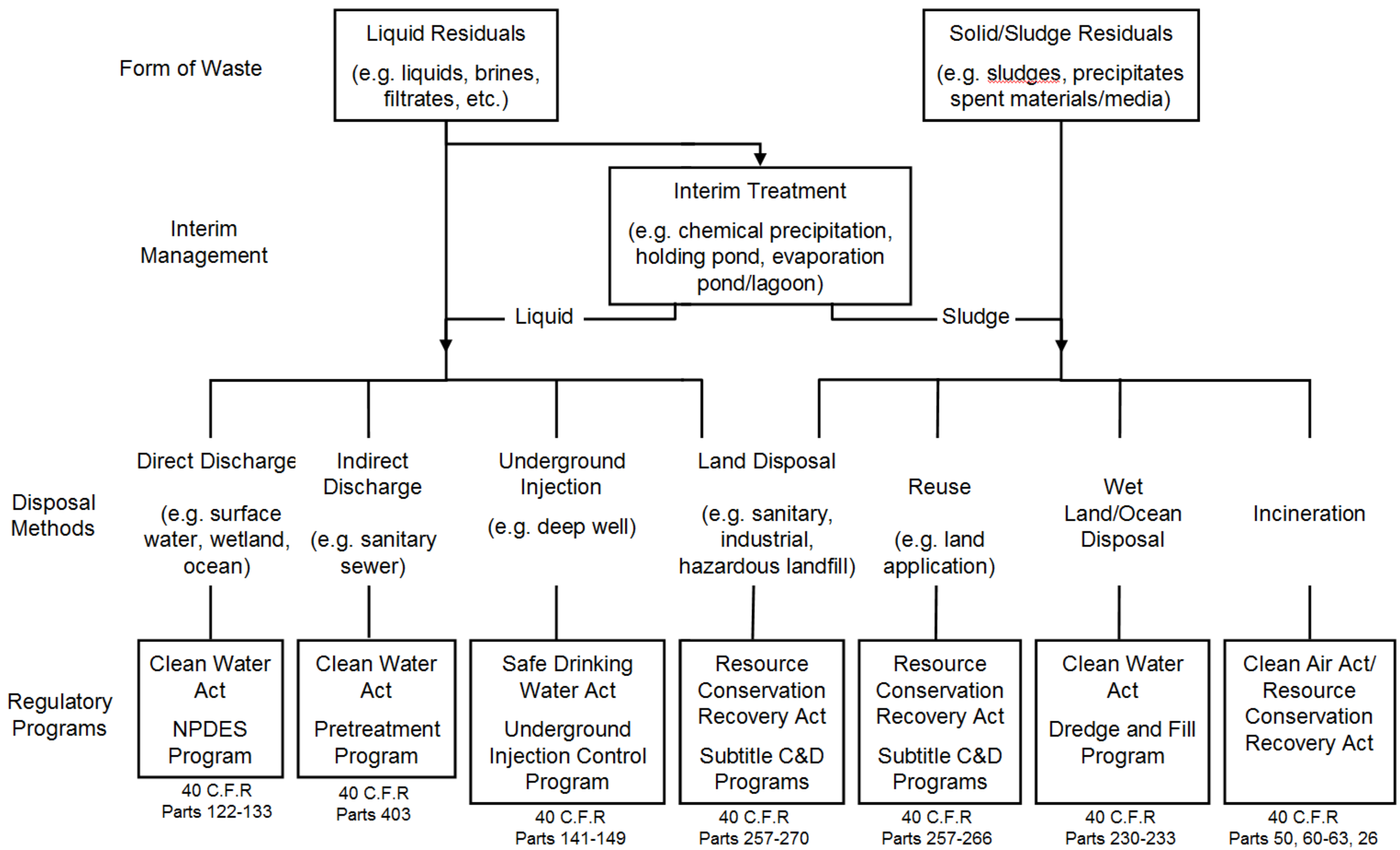
4.5.1 Hazardous Waste

In Florida, RO concentrate is classified as a non-hazardous “potable water byproduct” (403.0882.(2) FS). Drinking water utilities are responsible to determine that they are not generating hazardous waste. The federal definition of “hazardous waste” is given in the Resource Conservation and Recovery Act (RCRA) (40 CFR 260.10). Under this regulation, hazardous wastes are specified on a list or display one or more hazardous characteristics. Over 400 specific chemical compositions are listed as hazardous. These listed wastes are not usually present in RO concentrate because raw water containing listed hazardous wastes is typically not used as a source for drinking water treatment by RO.

A waste exhibiting the characteristics of corrosivity, reactivity, toxicity, or ignitability is also considered hazardous. Typically, pH adjustment is the only post-treatment required to make reverse osmosis concentrate non-corrosive, because the concentrate often contains several salts above saturation levels (Mickley and Associates 1993). Most RO concentrates do not ignite or react with their receiving environment to form a hazardous byproduct. Therefore, the hazardous characteristic of concern for RO concentrate is toxicity.

FIGURE 4.1

Federal Regulations Governing the Disposal of Residuals (Source: EPA, 2000).



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Water quality data can be used as an indirect indicator of potential toxicity. Ground water and surface water regulations protect human and environmental health by setting specific water quality limits. However, the sheer number of dissolved compounds in a water source makes analytical screening for all toxic contaminants impractical. Effluent toxicity tests are a more effective approach as they provide a direct indicator of concentrate toxicity to species native to the receiving environment. The Florida Department of Environmental Protection (FDEP) assesses toxicity using a “whole effluent toxicity” test that measures the aggregate toxicity of all substances in the waste stream (62-4.241 FAC). Waste streams discharging to surface waters must also meet surface water quality standards for specific contaminants (62-302 FAC).

In addition to liquid wastes, concentrate treatment technologies may generate solid waste byproducts with potentially hazardous contaminant levels. For example, trace naturally occurring compounds in the Floridan Aquifer, such as radionuclides, arsenic, or others may accumulate to hazardous levels in solids from thermal brine crystallization, or lime-soda softening sludge. Florida has regulations prescribing special handling and landfill disposal requirements for hazardous wastes (62-730 FAC).

4.5.2 Regulations Affecting Concentrate Disposal in the District

The following sections review regulations with the potential to affect concentrate disposal in the District. Regulations considered include the Underground Injection Control program (UIC), the National Pollutant Discharge Elimination System (NPDES), the Resource Conservation and Recovery Act (RCRA), and the Nuclear Regulatory Commission (NRC) Title 10. Some discussion of solid waste disposal is given under the sections on RCRA and NRC.

Underground Injection Control (UIC)

Disposal of desalination concentrate by injection wells is governed by the EPA’s Underground Injection Control (UIC) program, with some authority delegated to the Florida Department of Environmental Protection (FDEP) (62-528 FAC). Florida has prohibited the injection of hazardous waste into any UIC well. With relation to RO concentrate disposal, Class I injection wells are “…industrial and municipal (publicly or privately owned) disposal wells which inject fluids beneath the lowermost formation containing, within one quarter mile of the well bore, and underground source of drinking water.” An underground source of drinking water (USDW) is an aquifer with less than 10,000 mg/L of total dissolved solids (TDS) (Rule 62-528.200 (66).

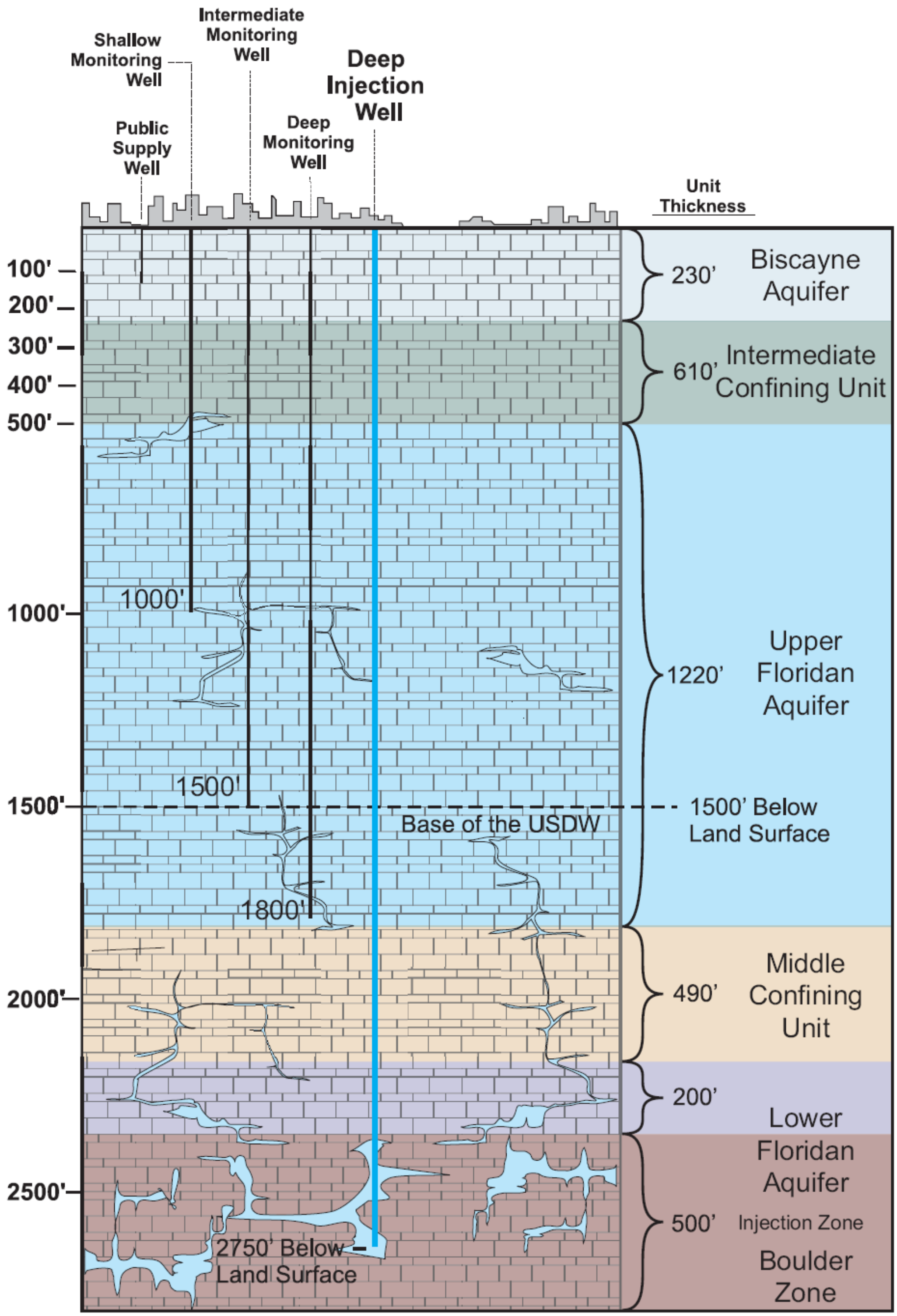
There are five classes of UIC wells. The most common injection well for disposal in water and wastewater treatment is the Class I well, which is classified as municipal or industrial. FAC Class I municipal wells are used for disposal of treated domestic wastewater only. Therefore, by exclusion Class I wells disposing non-hazardous RO concentrate are called industrial wells. Although hazardous waste injection is prohibited in Florida, at a federal level, Class I injection wells also include wells that inject hazardous or radioactive waste below the lowermost formation containing an underground source of drinking water within the well bore. Class V includes “other” injection wells not covered by Class I, II, III, or IV. A RO concentrate disposal well not injecting water beneath an underground source of drinking water (Class I) is a Class V Group 4 - Nondomestic Wastewater Well. It should be noted that utilities utilizing underground injection for concentrate disposal must also have a backup disposal method such as an emergency sewer discharge or surface water discharge. Additional permitting would be required for surface water disposal.

Class I Wells

The UIC program regulates groundwater injection to protect underground sources of drinking water (USDWs). Figure 4.2 represents a typical hydrogeologic cross section for South Florida. Most Class I injection wells in the District dispose RO concentrate into what is referred to as the Boulder Zone. The Middle Confining Unit separates the injection zone from the base of the nearest USDW, which is in the Upper Floridan Aquifer. Injection of waste into the injection zone (Boulder Zone) must not cause a movement of water into the USDW (Upper Floridan Aquifer). Vertical transport of injected water may occur through slow porous media flow and bulk flow through preferential flow paths associated with South Florida’s karst geologic features. Vertical migration of water can occur due to the injection pressure and the positive buoyancy of the injected water compared with the highly brackish water already present in the aquifer.

Monitoring wells are installed near the production well in the USDW to detect any such movement; because the Middle Confining Unit does not always completely confine wastewater within the injection zone, as illustrated by the fissures penetrating the confining unit in Figure 4.2. In some parts of South Florida, injected municipal wastewater has migrated upward into overlying layers. At times, the wastewater has even moved into the base of designated USDWs. It has been reported that a number of Class I municipal injection wells in Florida move water into a USDW.

Consequently, the EPA established new regulations specific to parts of Florida that shift from a confinement approach to a treatment approach (Federal Register 2005). The only contaminants requiring treatment were pathogens. No nutrient removal requirement was enacted because the Relative Risk Assessment found: (1) There is not strong evidence that Class I injection has caused or may cause exceedances of the nitrate MCL in USDWs; and (2) there is not strong evidence that nutrients released by Class I injection wells are migrating into surface waters (EPA 2003). This assessment could change if there were sufficient evidence to compel a nutrient removal standard. Class I industrial wells used for concentrate injection do not have the same vertical migration exemption available for Class I municipal wells.



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Representative Hydrogeologic Cross Section in South Florida (Dade County) (Source: EPA 2003).

FIGURE 4.2

Class V Wells

Class V includes “other” injection wells not covered by Class I, II, III, or IV. A RO concentrate disposal well not injecting water beneath an underground source of drinking water (Class I) is a Class V Group 4 - Nondomestic Wastewater Well. In the case of the Marathon seawater desalination facility, a shallow, 155-ft deep Class V injection well discharges RO concentrate to G-III ground water (G-III - not suitable for potable use). Concentrate disposal at the Marathon facility is discussed further in Section 4.6.

Ground Water Standards

All ground water in Florida is classified according to its designated use (62-520.410 FAC), and ground water standards vary by class. The Upper Floridan Aquifer, an underground source of brackish drinking water is defined as a Class G-I ground water (TDS<3,000 mg/l) or a Class G-II ground water (TDS <10,000 mg/l). All water discharged to the Upper Floridan Aquifer must meet primary and secondary drinking water regulations, except for some situations not applicable to concentrate disposal (62-520.420. FAC). In Section 4.0 projected concentrate water quality with increasing recovery is compared against these standards.

Class G-III refers to an unconfined ground water not suitable for potable use having TDS greater than 10,000 or to a ground water reclassified as non-potable by the Environmental Regulation Commission. Any water injected to a Class G-III ground water is subject to primary and secondary drinking water regulations unless an aquifer exemption has been issued.

Class G-IV refers to a non-potable water use confined ground water with TDS greater than 10,000 mg/l. Class G-IV ground waters, such as the Boulder Zone, are not subject to the minimum criteria established for other ground water classes, although FDEP may specify applicable standards on a case-by-case basis.

When defining “hazardous waste” for purposes of UIC screening, the regulations do not clearly communicate an objective basis for determining if a concentrate is hazardous, instead it seems the EPA and FDEP make these determinations on a case-by-case basis. Conversations with FDEP confirmed that FDEP does not automatically consider radioactive waste a hazardous waste. In order to establish some standard for identifying potentially hazardous wastes in this study, any constituent in the concentrate that violated primary or secondary drinking water regulations was noted as potentially making the concentrate a hazardous waste depending on the source water, enhanced recovery, and local regulatory guidelines. Furthermore, any radionuclides exceeding “radioactive waste” concentration could likewise be considered as potentially toxic and therefore potentially making the concentrate a hazardous waste. It is noted that the overall purpose was to point out substances deserving regulatory attention; and not to make the “hazardous” or “non-hazardous” determination.

National Pollutant Discharge Elimination System (NPDES) and Surface Water Quality Standards

Direct discharge of desalination concentrate to surface waters is governed by the EPA's National Pollutant Discharge Elimination System (NPDES), with some authority delegated to the Florida Department of Environmental Protection (FDEP). In general, discharges to surface water should have water quality adequate to protect all existing beneficial uses of the surface water (602-302.300 F.A.C).

Florida surface water quality standards provide definitions for both acute and chronic toxicity. Acute toxicity means a concentration greater than one third (1/3) of the amount lethal to 50 percent of the test organisms in 96 hours (96 hr LC_{50}) for a species protective of the indigenous aquatic community, with some restrictions as detailed in 62-302.200(1) F.A.C. Chronic toxicity means the concentration of the toxicant that causes a 25 percent reduction in a biological response such as biomass, growth, or fecundity, in a species protective of the indigenous aquatic community. Alternatively, where chronic toxicity studies are not available, the chronic toxicity of a substance is the concentration greater than one-twentieth (1/20) of the amount lethal to 50 percent of the test organisms in 96 hours (96 hr LC_{50}) for a species protective of the indigenous aquatic community, as defined in 62.302.200(4).

The FDEP has enacted surface water quality standards to protect existing uses of surface waters. There are six classes of surface waters with each class varying in the strictness of protection. The six classes include, Outstanding Florida Waters, which receive the most protection, and Class I, II, III, IV, and V surface waters, where the strictness of water quality standards decreases from Class I to V. In general, most surface waters in Florida are classified as Class III waters having the following designated uses: "Recreation, Propagation and Maintenance of a Healthy, Well-Balanced Population of Fish and Wildlife" (62-302.400 F.A.C.).

Low levels of dissolved oxygen along with high levels of hydrogen sulfide have both been identified as leading factors that can make a RO concentrate stream toxic to organisms in a receiving surface water (Mickley and Associates 1993). These two conditions can be addressed by appropriate post treatment including aeration to increased dissolved oxygen and pH depression with air stripping to remove hydrogen sulfide.

Enforcement of water quality standards is not restricted to the point of discharge, instead, a mixing zone is provided to account for natural dilution that occurs upon concentrate discharge to surface water. For ocean discharge, water quality standards must be met within a distance equal to twice the natural water depth at the point of discharge, furthermore, the effluent, when diluted to 20 percent full strength with a laboratory water of equivalent salinity, shall not cause more than 50 percent mortality in 96 hours (96 hr LC_{50}) in a species significant to the indigenous aquatic community.

Resource Conservation and Recovery Act (RCRA)

The Resource Conservation and Recovery Act (RCRA) contains rules for determining if a waste is hazardous. Whereas, effluent toxicity tests may be used to determine the toxicity of a liquid stream, RCRA has established another procedure that is used for identifying toxic liquid and solid wastes.

Under RCRA, the Toxicity Characteristic Leaching Procedure (TCLP) (EPA Test Method 1311) is used to determine if a liquid or solid waste is toxic, and therefore hazardous. For a solid waste, an extract is obtained using an amount of extraction fluid equal to 20 times the weight of the solid. For a liquid waste, the TCLP extract is obtained by running the waste through a 0.6 to 0.8 μm glass fiber filter. A waste is classified as toxic if any contaminant in the TCLP extract exceeds its corresponding maximum concentration listed in 40 CFR 262.1 Table 1. Listed contaminants relevant to brackish water RO include arsenic (5 mg/L), barium (100 mg/L), and selenium (1 mg/L). The list also contains heavy metals, organic solvents, and other contaminants.

Nuclear Regulatory Commission (NRC)

Primary drinking water regulations provide maximum contaminant levels (MCLs) based on the Radionuclides Rule (66 FR 76708) for radionuclides of concern for drinking water. When considering what level of radionuclides would be toxic enough to constitute a toxic hazardous waste, one approach is to consider the levels that define a radioactive waste.

According to UIC regulations, liquid effluent “radioactive” wastes are any waste that contains radioactive concentrations exceeding National Regulatory Commission (NRC) listed values in 10 CFR 20, Appendix B, Table 2, Column 2. Gross measurements of radioactivity, including alpha particles and beta/photon emitters are not included in this definition of radioactive waste. Considering the species listed in the Radionuclides Rule, these concentrations are 60 pCi/L for radium-226, 60 pCi/L for radium-228, and 300 pCi/L for uranium (EPA 2005). A “unity rule” applies, wherein the sum of the concentration fractions for all radionuclides present exceeds 1.0, the liquid is a “radioactive” waste. For example, a liquid has 30 pCi/L of radium-226 (30/60=0.5), 30 pCi/L of radium-228 (30/60=0.5), and 150 pCi/L of uranium (150/300=0.5). The total fraction is 1.5 (0.5+0.5+0.5=1.5) which is greater than 1.0, therefore, the liquid is a radioactive waste. Federal regulations for radionuclide disposal to sanitary sewers are more permissive, taking dilution into account. Limits are presented in 10 CFR 20, Appendix B, Table 3, and are, for the radionuclides considered in this section, 10 times higher than for liquid effluents not going into a sanitary sewer. That is, 600 pCi/L for radium-226, 600 pCi/L for radium-228, and 3000 pCi/L for uranium.

Most RO desalination plants in the District take brackish water from the Upper Floridan Aquifer. The Upper Floridan Aquifer contains trace quantities of naturally occurring radioactive material (NORM) including gross alpha particles, gross beta and photon emitters, radium, uranium, and others. The elevated levels of radionuclides in some residuals are also referred to as technologically enhanced naturally occurring radioactive material (TENORM). RO is a best available technology (BAT) for removal of most radionuclides, except radon gas; however, removing radionuclides from the permeate implies concentrating radionuclides in the concentrate. As will be demonstrated in Section 4.7, the radioactivity of radium in RO concentrate could exceed NRC regulations depending on the recovery.

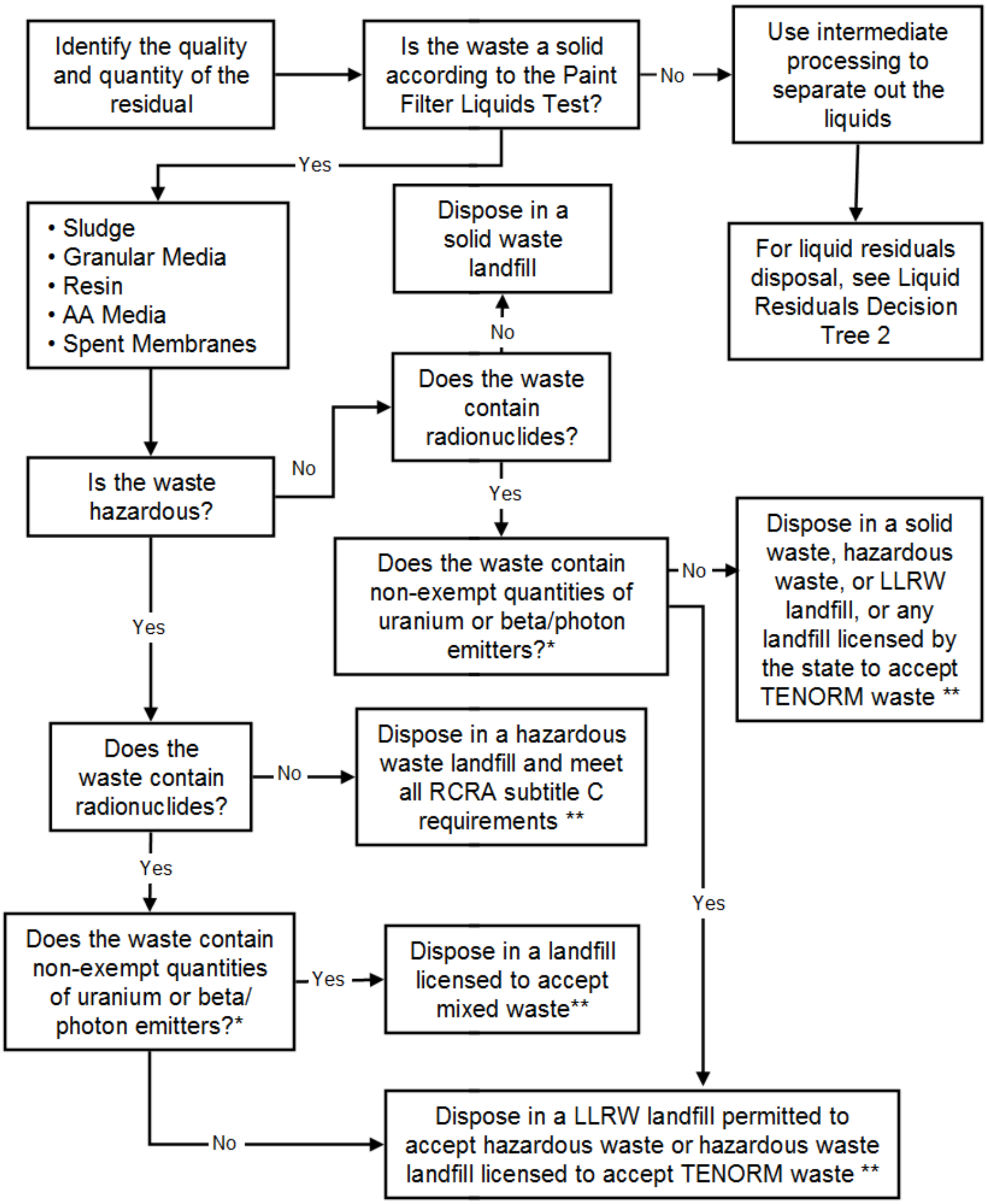
Identifying the Appropriate Disposal Option

Given the multiple issues associated with radioactive wastes and hazardous wastes, a systematic approach to identify the appropriate treatment option is needed. The EPA recently published a guide to management of radioactive residuals from drinking water treatment that contains a set of helpful decision charts for managing solid wastes and liquid wastes (EPA 2005).

Figure 4.3 includes a decision tree for identifying an appropriate solids residual disposal option when radionuclides may be present. Given a solid sludge, two key factors to identifying the appropriate disposal method are whether the sludge is hazardous and whether the sludge contains radionuclides. Any sludge containing hazardous waste cannot be disposed in a municipal solid waste landfill. Furthermore, any sludge containing radionuclides can only be disposed in a landfill that has been licensed to accept TENORM waste. If the waste contains more than 1000 pCi/L of uranium or beta photon emitters, it must be disposed into a landfill permitted to accept mixed waste, permitted to accept low level radioactive waste (LLRW), or a hazardous waste landfill licensed to accept TENORM waste.

Figure 4.4 includes a decision tree for identifying an appropriate liquid residual disposal option when radionuclides may be present. The caveat with this decision tree is that Florida currently prohibits the disposal of hazardous waste, which may include radioactive waste, to injection wells, which are the only option shown on the decision chart. Without an amendment of Florida law, the hazardous waste restriction for underground injection wells may effectively prohibit higher-levels of concentrate recovery.

Figure 4.5 includes a decision tree pertaining to intermediate treatment of liquid residuals. It typifies how most concentrate management technologies generate a solid waste as part of the liquid treatment, requiring the management decisions to be made for disposal of both types of waste.



*Check with the state Radiation Program to see if beta/photon emitters are considered byproduct material and advise system to contact the NRC Regional office or relevant Agreement State agency to discuss potential licensing requirements.

** LDR Treatment Standards also apply. Check with the state Radiation Program to determine the proper disposal methods for waste containing radionuclides and hazardous waste.

Decision Tree 1: Solids Residual Disposal (Source: EPA, 2005)

FIGURE 4.3

Decision Tree 2: Liquid Residual Disposal
(Source: EPA, 2005).

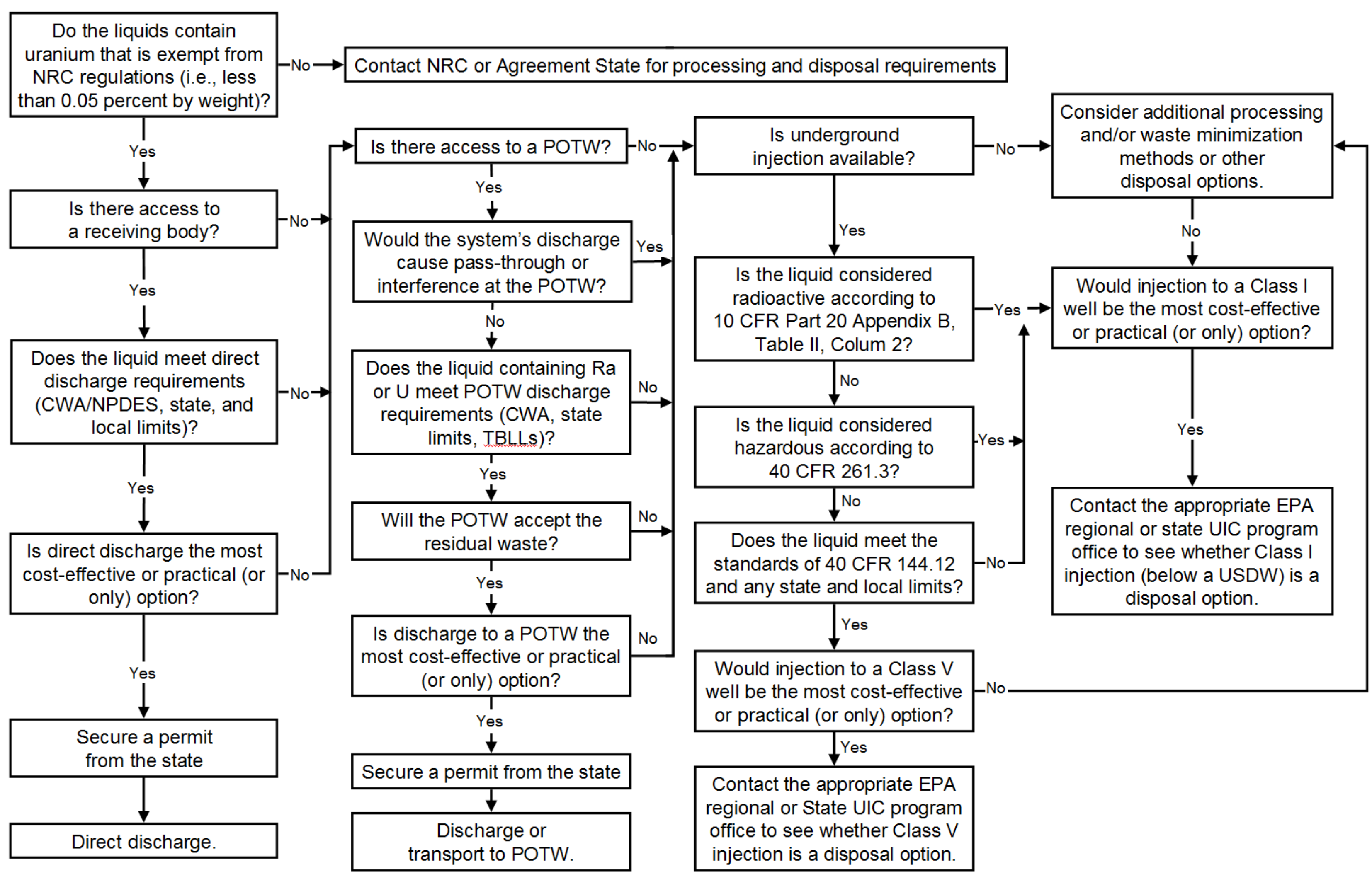


FIGURE 4.4

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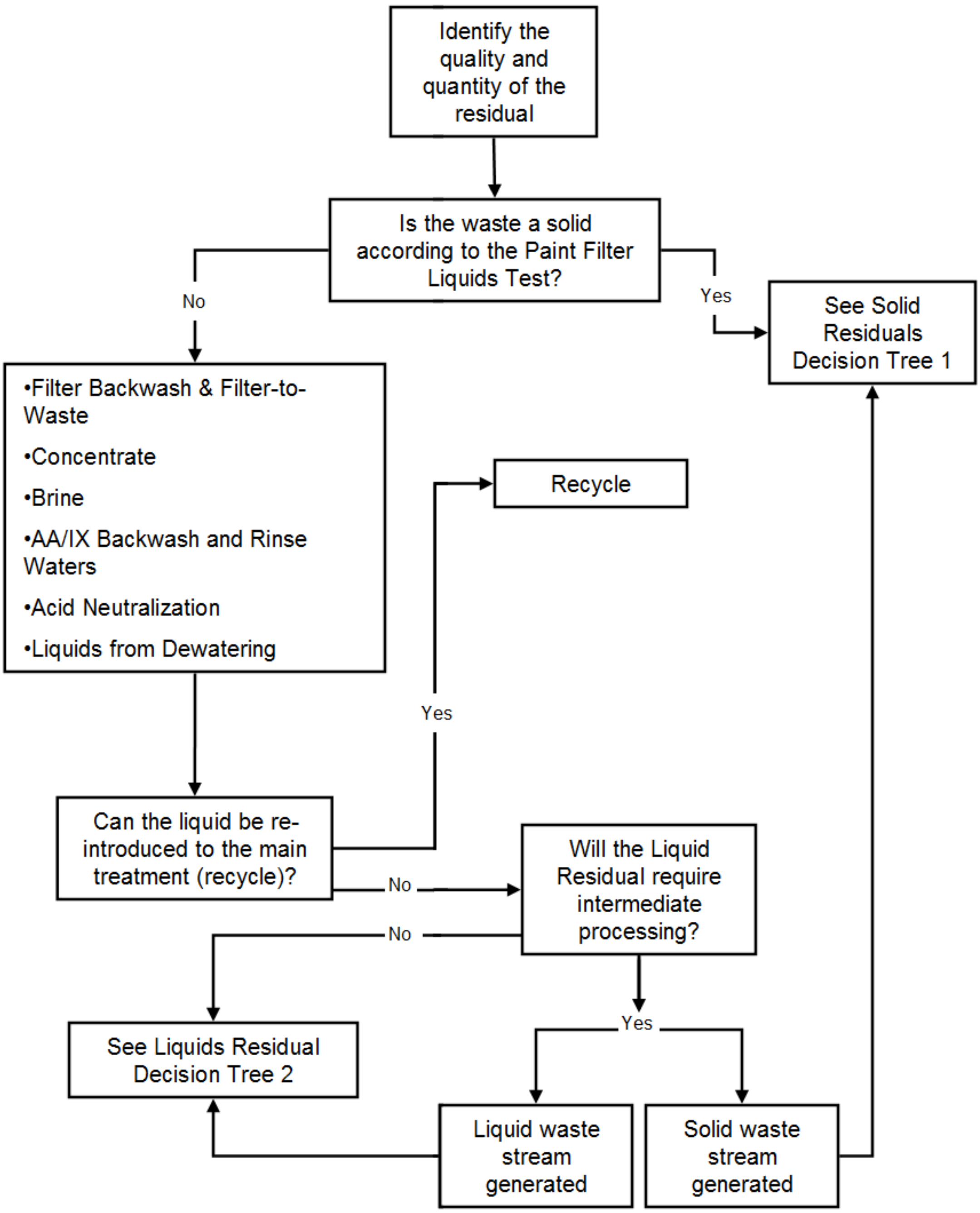

Decision Tree 3: Liquid Residual Disposal - Intermediate Processing (Source: EPA, 2005).

FIGURE 4.5

4.6 Concentrate Disposal Systems

The following subsections describe the concentrate disposal systems for four water treatment facilities within the SFWMD that were selected as representative facilities for further evaluation in this study (see Section 2). These facilities include the Deerfield Beach WTP, the City of North Miami Beach WTP, the Florida Keys Aqueduct Authority Marathon Seawater Desalination Facility, and the City of Hollywood WTP.

4.6.1 City of Deerfield Beach WTP

Upon completion, the City of Deerfield Beach's WTP will dispose of its concentrate to the Lower Floridan Aquifer through a Class I injection well. The well has a diameter of 11.5 inches with a 4.05 mgd capacity.

The Upper Floridan Aquifer is the source of brackish water for the treatment facility and ranges from 1,000 ft below pad level (bpl) to 1,600 ft bpl. The base of the USDW was determined to be at 1,790 bpl. Near the raw water well, there is a dual-zone monitor well with separate zones to monitor water quality at 1,700 ft bpl and 2,000 ft bpl. The Upper and Lower Floridan Aquifers are separated by the Middle Confining Unit which is 1,300 ft thick (1,600 ft bpl - 2,900 ft bpl). The injection zone is located 3,200 ft bpl in the highly transmissive Boulder Zone of the Lower Floridan Aquifer (>2,900 ft bpl).

In addition to treating brackish water from the Upper Floridan Aquifer by RO, Deerfield Beach WTP also treats fresh water from the surficial Biscayne aquifer by NF, producing an NF concentrate. The NF and RO concentrate will be blended before injection. As noted before, disposal of NF concentrate to the Boulder Zone introduces some non-native contaminants such as organic nitrogen, ammonia, nitrate, and pathogens.

4.6.2 City of North Miami Beach WTP

The City of North Miami Beach WTP has a Class I injection well to dispose its concentrate to the Lower Floridan Aquifer through a Class I injection well. The well has a diameter of 14.5 inches with a 7.5 mgd capacity. When the City is unable to use the injection well, the City is permitted to discharge the concentrate to the Miami-Dade Water and Sewer Department (MDWASD) sewer system.

The Upper Floridan Aquifer is the source of brackish water for the RO treatment facility and ranges from 940-2,200 ft below land surface (bls). The base of the USDW was determined to be at 1,509 ft bls. Near the raw water well, there is a dual zone monitor well with separate zones to monitor water quality at 1,580 ft bls and 1,825 ft bls. The Upper and Lower Floridan Aquifers are separated by the Intermediate Confining Unit, which is 600 ft thick (2,200 ft bls to 2,800 ft bls). The injection zone is located 2,850 ft (bls) in the Boulder Zone of the Lower Floridan Aquifer.

In addition to treating brackish water from the Upper Floridan Aquifer by RO, the North Miami Beach WTP also treats fresh water from the surficial Biscayne aquifer by NF, producing an NF concentrate. The NF and RO concentrate are blended before being injected. The City monitors the blended concentrate water quality since the well is permitted for disposal of the blended stream. Disposal of NF concentrate to the Boulder Zone introduces some non-native contaminants such as organic nitrogen, ammonia, nitrate, and pathogens.

4.6.3 Florida Keys Aqueduct Authority Marathon Seawater Desalination Facility

The Marathon Seawater Desalination Facility disposes its concentrate to the surficial unconfined aquifer through a Class V Group 4 injection well. The well has a diameter of 14 inches with a 3.0 mgd capacity. The plant and the concentrate well are maintained on a standby basis for use in an emergency. Operations are limited to those necessary to maintain plant readiness.

The concentrate injection well injects into the same unconfined aquifer that is the source of seawater for the RO treatment facility, with the RO supply well tapping a zone 60 ft bls to 80 ft bls. The disposal well injection zone is located 155 ft bls. The surficial aquifer is a G-III aquifer directly interconnected to the ocean and tide and not considered to be a potable water source. No other supply wells are located within a 1-mile radius of the concentrate disposal well.

The Marathon desalination facility is the only plant of the four considered here, where water is drawn from the source, treated with RO, and the concentrate returned without mixing to the same source. The Florida Keys Aqueduct Authority does not pretreat the concentrate before disposal. Because the discharge is subterranean, impacts to marine flora and fauna are likely limited.

4.6.4 City of Hollywood Water Treatment Plant

The City of Hollywood Water Treatment Plant disposes its RO and NF concentrates to the Atlantic Ocean after blending with treated wastewater. Near the discharge point, the Atlantic Ocean is a Class III surface water. One-mgd of RO concentrate is blended with 2.5 mgd NF concentrate, which are then blended with as much as 48 mgd of treated wastewater effluent before ocean outfall discharge. The ocean outfall is through a 60-inch reinforced concrete pipe extending 2.0 miles offshore. The discharge is on the ocean floor at a depth of 90 ft.

During pilot testing of the RO and NF processes chronic toxicity testing and an ocean discharge evaluation were conducted for the City of Hollywood RO and NF concentrates with sea urchin fertilization as the parameter for chronic toxicity (Metcalf and Eddy 1994). The results indicated that the RO or NF concentrate, whether individually, or in combination had minimal effect on sea urchin fertilization. Most of the time, the full strength sample had no observable affect. Chronic effects were only observed three times with the highest strength treatment. A total of 23 toxicity tests were conducted. The toxicity tests indicated that a dilution factor of less than three would entirely eliminate any observable toxic effects. The minimal toxicity impacts indicate that the RO and NF concentrates, in themselves, pose no toxicity threat to marine life in the Atlantic Ocean. The RO concentrate is diluted by a factor of about 50:1 with the NF concentrate and treated wastewater effluent. Furthermore, given the 20:1 or greater initial dilution occurring at the ocean outfall (Metcalf and Eddy 1994), the RO concentrate is diluted by about 1000:1 before the Class III standards are evaluated.

4.7 Effects of Increased Recovery

This section screens the water quality data of RO concentrate for substances that exceed regulatory limits after treatment. The RO plant concentrates disposing to injection wells are compared against primary and secondary drinking water regulations. The RO plant concentrate disposing to open ocean outfall is compared against Class III surface water quality criteria. This quantitative analysis is followed by a discussion of the qualitative effects of increased recovery on potential risks associated with well injection and ocean disposal.

4.7.1 Effect of Increased Recovery on RO Concentrate Water Quality

Increased recovery of RO concentrate will produce a reduced volume of RO concentrate containing higher concentrations of dissolved solids that are rejected by the membranes. The effect of increased recovery was simulated using existing concentrate data, or raw water data, and predicted elevated concentrations are provided in Tables 4.2 and 4.3 for each of the four water treatment plants. An overall, enhanced recovery of 95 percent was chosen to represent the upper bound of recoveries achievable without thermal technologies.

Primary and secondary drinking water regulations, as well as the Class III surface water criteria are provided as reference points. For each water treatment plant, substances that exceed these regulatory limits are presented in Tables 4.2 and 4.3. For deep well injection to the Boulder Zone, the primary water quality restriction is that the waste be non-hazardous. The water quality characterization of concentrate from the Marathon facility is presented at its current 30 percent recovery, without any projection for higher recovery.

As mentioned in Section 4.5.2, injections to USDWs must not exceed primary or secondary drinking water regulations, unless a mixing zone is provided. Although primary and secondary drinking water standards do not govern deep well injection, they provide a relevant, conservative baseline for assessing the potential water quality impacts of a vertical migration of injected concentrate.

Table 4.2 Concentrate/Parameters Projected to Exceed Drinking Water Regulations at Existing and 95% Recovery

Parameter	Units	Deerfield Beach WTP		Marathon Desalination Facility[1]		North Miami Beach WTP		*Primary Drinking Water Regulations*	*Secondary Drinking Water Regulations*
Recovery	-	75%	95%	30%	-	75%	95%	-	-
Total Dissolved Solids (TDS)	mg/L	11,900	59,300	52,600	-	15,500	60,500	-	*500*
Arsenic	mg/L	N/A[2]	N/A	N/A	-	0.002	0.01	*0.01*	-
Chloride	mg/L	3,200	16,200	29,600	-	7,600	34,900	-	*250*
Fluoride	mg/L	N/A	N/A	1.2[3]	-	0.46	2.3[4]	*4*	*2*
Sodium	mg/L	1,600	8,000	15,700	-	3,400	16,800	-	*160*[5]
Sulfate	mg/L	1,500	7,400	4,200	-	2,100	10,400	-	*250*
Gross Alpha Particles	pCi/L	N/A	N/A	170	-	15.9	700	*15*	-
Beta/Photon Emitters	pCi/L	N/A	N/A	640	-	116	580	*50*[6]	-
Radium 226+228	pCi/L	N/A	N/A	5.7	-	12.4	81	*5*	--

Notes:
1. Marathon facility concentrate data presented as reported at 30% recovery.
2. N/A- Not available
3. Does not exceed regulations
4. Reported below method detection limit of 0.458 mg/L at 75% recovery
5. Florida has a 160 mg/L secondary standard for sodium.
6. The MCL for beta/photon emitters is written as 4 mrem/year. The U.S. EPA considers 50 pCi/L as the level of concern for beta emitters.

Table 4.3 Concentrate Parameters Projected to Exceed Drinking Water Regulations or Surface Water Criteria at Existing and 95% Recovery without Dilution

Parameter	Units	Hollywood WTP		*Class III Surface Water Criteria*	*Primary Drinking Water Regulations*	*Secondary Drinking Water Regulations*
Recovery	-	80%	95%	-	-	-
Total Dissolved Solids (TDS)	mg/L	23,200	93,000	-	-	*500*
Arsenic	mg/L	0.006	0.03	*0.05*	*0.01*	-
Chloride	mg/L	10,200	51,200	*<10% increase*	-	*250*
Fluoride	mg/L	5.7	28	*5*	*4*	*2*
Sodium	mg/L	6,800	34,100		-	*160*[2]
Sulfate	mg/L	4,300	21,300	-	-	*250*
Gross Alpha Particles	pCi/L	110	440	*15*	*15*	-
Beta/Photon Emitters	pCi/L	N/A[1]	N/A	-	*50*[3]	-
Radium 226+228	pCi/L	11	50	*5*	*5*	--
Total Phosphorus	mg/L	0.4	1.8	*0.1*	-	-
Total Ammonia	mg/L	2.7	13	*Discharge may not cause adverse impacts to flora or fauna*	-	-
Nitrate + Nitrite	mg/L	0.03	0.17		*11*	-

Notes:
1. N/A- Not available
2. Florida has a 160 mg/L secondary standard for sodium.
3. The MCL for beta/photon emitters is written as 4 mrem/year. The U.S. EPA considers 50 pCi/L as the level of concern for beta emitters.

Similarly, a conservative approach was taken with RO concentrate discharged to surface waters. The full-strength undiluted RO concentrate is compared against the Class III surface water criteria. However, regulations would apply to the diluted end of pipe concentrations.

For well injection of concentrate from a 95 percent recovery RO process, the following parameters had concentrations greater than primary or secondary drinking water regulations: TDS, arsenic, chlorides, fluoride, sulfate, gross alpha particles, beta/photon emitters, and radium 226+228. The only species with concentrations below these regulations at 75 percent recovery were arsenic and fluoride in the North Miami Beach concentrate. Similarly, for ocean disposal of concentrate from a 95 percent recovery RO process, all of the above-mentioned parameters as well as phosphorus, ammonia, nitrate, and nitrite had concentrations greater than primary or secondary drinking water regulations or Class III surface water criteria. Likewise, for the Hollywood RO plant at 80% recovery the arsenic concentration was below the regulations. In summation, most of the parameters predicted to exceed regulations at 95 percent recovery are already close to or above regulations at the current 75 to 80 percent recovery.

4.7.2 <u>Predicted Solid Waste Composition</u>

Of the four RO plants considered in this report, North Miami Beach, had the most complete set of radionuclide data. Therefore, it is used as an example to calculate the potential radioactivity of solid residuals generated during concentrate treatment.

Using the measured total dissolved solids, the predicted radium 226+228 radioactivity of dry solids from a ZLD process at the North Miami Beach facility is 1.0 pCi/g. A similar calculation with uranium and beta/photon emitters yields 0.08 pCi/g and 7.38 pCi/g respectively. For radium, this solid waste would fall below the DOT's radioactive material transport regulations, which only apply at 2,700 pCi/g of radium (EPA 2005). Using a specific gravity of 2.7 for the solids, based on the weight of calcium carbonate, the previously calculated radioactivities convert to 370 pCi/l radium 226+228, 30 pCi/l uranium, and 2730 pCi/l of beta/photon emitters.

This level of radioactivity, especially the beta/photon emitters, may restrict landfill disposal options. Section 4.5.2 discussed the regulations limiting disposal of solid wastes containing radionuclides. A level of 1,000 pCi/l or greater of uranium or beta/photon emitters would require the solid waste to be disposed in landfills licensed to receive radioactive waste.

4.7.3 <u>Potential Effect of Concentrate Treatment on Waste Stream Disposal</u>

Among the water treatment plants considered as a part of this study, desalination concentrate is disposed by shallow well injection, deep well injection, or open ocean outfall. The following sections discuss the risks associated with the degraded water quality associated with an increase in concentrate recovery.

Deep Well Injection

Concentrate minimization could reduce RO concentrate volumes by an additional 40 to 80 percent, which for a baseline recovery of 75 percent, corresponds to an overall 85 to 95 percent recovery of the source water. The effective solute concentrations in the RO concentrate would increase by a factor of 1.7 to 5.0 compared to concentrations at 75 percent recovery.

Zero liquid discharge technologies, such as brine concentrators, are excluded from this discussion, as they would replace the liquid concentrate disposal issue with a solids disposal issue. Deep well injection is mostly used by moderate to larger capacity plants, because the high capital cost makes it uneconomical for smaller flows. Smaller desalination plants have used surface water discharge, which is subject to the EPA National Pollution Discharge Elimination System (NPDES). The Florida Department of Environmental Protection (FDEP) imposes water quality based limits according to the designated use class of the surface water.

Class I well operating permits prohibit any underground injection “that causes or allows movement of fluid into an underground source of drinking water.” A movement of fluid into the Upper Floridan Aquifer may occur if concentrate in the injection zone passes through preferential flow paths in the Middle Confining Unit. A movement of fluid into the Upper Floridan Aquifer as well as the Biscayne Aquifer may occur if the mechanical integrity of the injection well is compromised.

The movement of RO concentrate alone into the Upper Floridan Aquifer would not introduce any new contaminants; however, it could increase the ambient concentration of contaminants already present. The movement of NF concentrate alone into the Upper Floridan Aquifer would introduce new contaminants, with the most significant being organic nitrogen, ammonia, nitrate, and pathogens. The addition of water treatment chemicals such as acids, caustic, dechlorinators, and antiscalants is not expected to introduce any hazardous components to the concentrate.

Increased concentrate recovery will reduce the volume of concentrate being injected into the Lower Floridan Aquifer. Overall, this should not increase the risk of movement of water into the Upper Floridan Aquifer or the Biscayne Aquifer; however, the mechanical integrity of the well must be protected against increased corrosivity.

Reducing the volume of concentrate injected into the Lower Floridan Aquifer is unlikely to increase the movement of water into USDWs. A few factors suggest that a decrease in concentrate volume could actually reduce this risk.

Because the flow rate of concentrate will be reduced, the dynamic pressure required to maintain positive flow into the confining zone should decrease. A reduced pressure would reduce the driving force for vertical movement of water into the overlying USDW.

Because the salinity of the concentrate will increase, its buoyancy will decrease, reducing the driving force for vertical movement of water into the overlying USDW. Concentrate with salinity greater than the ambient salinity would actually have negative buoyancy and tend to move downward.

Because the volume of concentrate injected will be reduced, the “area of review” could decrease. Regulations require that the permit applicant “identify the location of all known wells within the area of review … that penetrate the injection zone or confining zone”(Rule 62-528 FAC). The area of review must cover at least one mile around the radius of the injection well. The permit applicant must verify that all such wells are properly sealed, completed, or abandoned. Reducing the concentrate volume will reduce the lateral area and number of wells within the zone of endangering influence.

For example, in the recent Operation Permit Application for the North Miami Beach Injection Well (MWH 2009), the consultant used a simplified geometrical approach to calculate a 2.1 mile radius of influence assuming that 6.5 mgd of concentrate expands like a cylinder in the confined zone over a 50 year period. The contribution of NF concentrate and RO concentrate to this projected concentrate flow was not given. Currently, the maximum concentrate flow rate is 3.6 mgd (2 mgd RO concentrate, 1.6 mgd NF concentrate), which would correspond to a 1.6-mile radius of influence. Halving the RO concentrate by increasing the recovery from 75% to 88% would reduce the concentrate to 2.6 mgd and decrease the radius of influence to 1.4 miles.

Bulk flow of concentrate into an USDW can occur along improperly constructed or poorly maintained injection-well systems having an incomplete seal between the well and its casing (EPA 2003). Such flow can also occur due to corrosion failure of the well tubing. Increased concentrate recovery will reduce the volume of concentrate and increase the concentration of corrosive species such as chloride and sulfate. A recent publication by the St. Johns River Water Management District (SJRWMD 2008) reviewed the literature on corrosion of Florida Class I injection wells for concentrate disposal. Failure of wells with mild steel tubing was high, with 11 of 19 (58 percent) wells using mild steel tubing failing due to corrosion. The report noted that fiberglass is the most common corrosion resistant material used for well construction. The total dissolved solids content of the injected water was not found to be an overriding factor impacting corrosion rates and well failure. The corrosivity of the membrane concentrate can be significantly reduced by post treatment to increase pH (Mickley and Associates 1993).

Ocean Discharge

Whereas the other plants presented in this report use deep injection wells or shallow wells for concentrate disposal, the Hollywood RO plant contributes to a surface water discharge. As such, there is a potential for impacts to marine flora and fauna. Because RO concentrate is produced from a source that is not ocean water, there is potential to introduce solutes not initially present in the ocean water, or to add species/ions in ratios out of balance with natural conditions.

Before construction of the membrane treatment processes, an evaluation of the impact of concentrate on the City of Hollywood's marine environment was conducted (Metcalf & Eddy 1994). The RO/NF concentrates from the Hollywood WTP were evaluated both together and separately for their impact on a pre-existing treated wastewater ocean outfall. Sampling of ambient water conditions near the effluent plume indicated that radium 226 was in excess of the 3 pCi/L criteria from the Primary Drinking Water Regulations; however, the concentration of radium 226 was lower in the plume than in the ambient seawater. Mercury was below the 0.1 μg/L detection limit outside the effluent plume and detectable at low concentrations in the plume. No significant concentrations of either mercury or radionuclides were detected in the effluent samples. Therefore, the authors of the report concluded that the radium and mercury results were not attributable to the plume itself. Blending also had the beneficial effect of diluting most metals in the effluent (e.g. copper, cadmium, lead, and zinc). Water quality data indicated that blending of concentrate with the wastewater did not increase any of the end-of-pipe concentrations in excess of criteria except for the gross alpha activity (18 pCi/L), which was slightly above the marine standard of 15 pCi/L. Blending of concentrate was also found to reduce the dilution requirements for phosphorus.

The effects of concentration addition on dilution and mixing were also evaluated using theoretical models accounting for fluid momentum, buoyancy, and turbulence. Introducing the concentrate water would increase the salinity of the water and increase its density. Reduced effluent buoyancy was found to cause a slight decrease in rapid dilution.

As mentioned in Section 4.6.4, the RO concentrate is diluted nearly 50:1 by blending with NF concentrate and treated wastewater effluent. Increased recovery of RO concentrate (e.g. from 80 to 90 percent) would reduce this dilution to 25:1. The RO concentrate will still be highly diluted even after increased concentrate recovery, making impacts on marine life unlikely. Nevertheless, the following paragraphs review the potential impacts on salinity, nutrient loading, turbidity, and entrainment of marine organisms that would be expected if the impact of RO concentrate volume reduction were not minimized by dilution.

The salinity of the outfall effluent will increase as the salt loading from the RO concentrate remains unchanged and the flow rate of the ocean outfall effluent decreases. This will increase the density of the outfall effluent, reducing mixing from buoyancy. In addition, the effect of any major ion imbalance present in the outfall effluent would be somewhat increased, with potential toxic effects (FDEP 1995).

The nutrient loading of the outfall effluent will increase as the reduction in RO concentrate volume decreases the overall outfall effluent volume. There is relatively little nutrient load within the RO concentrate, and most of the nutrient loading is in the nanofiltration concentrate or treated wastewater effluent. Adverse effects of increased nutrient concentrations in the outfall effluent could include algal blooms (red tide), causing eutrophication, and killing marine fauna (Alcock 2007).

The turbidity of the outfall effluent could increase as the relatively low-turbidity RO concentrate is reduced in volume. Most of the turbidity would come from the wastewater effluent. Increases in turbidity would reduce sunlight penetration through the water column, potentially disturbing the natural balance of marine plants and animals that depend on sunlight to survive.

Reducing the overall RO concentrate flow will reduce the flow rates at the ocean outfall and water velocities near the submerged discharge points. This will be beneficial as it reduces the potential for marine fauna to be entrained in outfall discharges. A more significant concern for marine fauna is impingement intakes of seawater desalination facilities, because the Hollywood RO facility draws from groundwater, no impingement of marine fauna occurs.

4.8 Concentrate Minimization Technologies

Concentrate minimization technologies were introduced in Section 3. The following sections discuss some considerations associated with the implementation of each approach. In general, all options generate some form of solid waste or product, and all options except the thermal evaporator and brine crystallizer generate a liquid waste.

4.8.1 Dual Reverse Osmosis with Intermediate Chemical Precipitation

Dual RO with intermediate chemical precipitation desalts primary RO concentrate using a secondary seawater RO train. An intermediate chemical precipitation process consisting of lime-soda ash softening and filtration before the secondary RO unit removes the high concentrations of scaling compounds present in the RO concentrate. This reduces the potential for scaling in the secondary RO train, while also creating a calcium/magnesium sludge that must be disposed. The secondary RO train recovers about 50 to 60 percent of the concentrate and produces a high TDS concentrate. The concentrate from the secondary RO process has a reduced volume compared to the original concentrate, but an increased salinity. The sludge from lime-soda softening is a mixture of calcium and magnesium solids with a mixture of co-precipitated barium, strontium, and silica. Not only scalants are removed in the sludge, but also non-targeted contaminants including nutrients, organics, and radionuclides.

Like the other concentrate management options, this approach generates a solid waste. Additionally, it requires the addition of large quantities of chemicals. Unlike other concentrate management options, the solid waste that is generated consists of only a portion of the dissolved solids in the concentrate, including calcium, and if desired magnesium. The softening approach is water quality specific. However, if only calcium removal is required, then all soluble salts including magnesium, sodium, chloride, potassium, and others can be retained in the concentrate where they will not scale the membrane and may be most easily disposed of through liquid discharge methods.

An optimized chemical precipitation step will require minimal chemical addition, remove only those salts that would scale the membrane, and leave most of the more soluble salts in solution where they can be disposed of by the existing liquid disposal method. Because the chemical precipitation process has the potential to provide selective solids removal, it may be the least onerous of all four concentrate management options presented herein in terms of day-to-day solids handling.

4.8.2 Thermal Evaporation and Brine Crystallizer

Concentrate management with a thermal evaporator and brine crystallizer represents a zero liquid discharge option. The concentrate water quality may be used to estimate the final solids composition. In general, for a 1 mgd stream, each 1000 mg/L will evaporate to 4.2 tons of dry solids per day. Considering the salinity and flow rates for the three brackish RO concentrates considered in this report, the solids generation rate of this and other ZLD options could range from 50 to 120 tons per day of salts. Complete recovery of solids at the Marathon desalination facility would generate 400 tons per day of salts. Of all the solutes, radionuclides in particular, pose the potential to make the sludge a radioactive waste.

4.8.3 Thermal Evaporation and Evaporation Pond

Concentrate management with a thermal evaporator and a solar evaporation pond can provide zero liquid discharge of RO concentrate. The thermal evaporator significantly reduces the concentrate volume by distillation before being disposed to the evaporation pond.

A preliminary sizing of evaporation ponds was performed for the four representative water treatment plants discussed in this report. Even after a 99 percent reduction in concentrate volume by thermal evaporation, an estimated 3.5 to 9 acres of land were required in order to manage the remaining concentrate volume through evaporation ponds.

Evaporation ponds release water to the atmosphere, leaving behind any solids that were in the concentrate. Over time the evaporation pond will fill with solids and these must be removed, or the evaporation pond be abandoned. An impervious clay or synthetic liner is often required to prevent contamination of the underlying aquifer. In addition, leak-monitoring wells may also be required.

The design and construction of evaporation ponds must consider the regulatory requirements, ecological impacts, and possible concentration of trace elements to toxic levels (ASCE 1990). A simplified approach to estimating the composition of the remaining precipitated solids is to look at the dissolved solids composition of the concentrate. This will provide guidance for the suitability of the sludge for disposal in municipal landfills or other options.

4.8.4 Salt Extraction and Recovery

Concentrate management through salt extraction and recovery is a near zero liquid discharge approach that utilizes the economic value of recovered salt products as a resource to offset the costs of increased concentrate recovery. As a near ZLD technology, it is similar to the thermal evaporation approaches in that the concentrate water quality can provide a good initial estimate of the composition of the dry solids. One caveat with the salt extraction approach is that the multiple salt extraction steps will alter the composition of the end of the line waste solids. In addition, with this approach, multiple contaminants in the RO concentrate may restrict the marketability of solids products that cannot achieve industrial standards of purity.

4.9 Summary

- RO water treatment takes a feed water and separates it into two streams. One stream contains purified water and the other stream contains concentrated dissolved solids, which can include salts, pathogens, organic matter, radionuclides, and any other substances present in the original feed water.
- The major hazard associated with deep well injection is the potential for vertical migration of fluid into an underground source of drinking water (USDW). Concentrate disposal wells are prohibited from causing a movement of water into an USDW. Primary and secondary drinking water regulations regulate direct injections to USDWs.
- The major hazard associated with ocean discharge is the potential for toxic effects to marine flora and fauna. Class III Surface Water Standards regulate discharges to most surface waters in Florida.
- Treatment of RO concentrate for enhanced recovery of additional water will reduce the volume of liquid waste while increasing the concentration of many contaminants in the liquid waste. Depending on the specific source water characteristics and the allowable ‘non-hazardous’ concentrations implied by the local/federal regulatory guidelines, the practical increase in recovery via concentrate treatment can be limited to a certain level. In each site-specific case, this limitation would simply be to avoid increases in recovery and hence concentrations that result in potentially classifying the concentrate as ‘hazardous’. Some treatment technologies may generate a solid waste also. Zero liquid discharge technologies such as brine crystallizers would eliminate the liquid waste and produce a solid waste only.
- Considering concentrate water quality at the Deerfield Beach and North Miami Beach RO plants, at 95 percent recovery, the following parameters have projected concentrations greater than primary or secondary drinking water regulations: TDS, arsenic, chlorides, fluoride, sulfate, gross alpha particles, beta/photon emitters, and radium 226+228. However, even at the current 75 percent recovery, the only species with concentrations below these regulatory standards are arsenic and fluoride in the North Miami Beach concentrate.

- Considering concentrate water quality at the Hollywood RO plant at 95 percent recovery, all of the parameters mentioned for well injection as well as phosphorus, ammonia, nitrate, and nitrite had concentrations greater than primary or secondary drinking water regulations or Class III surface water criteria. However, even at the current 80 percent recovery, the only contaminant with concentration below these regulatory standards is arsenic. Additionally, it is noted that although the arsenic concentration at 95 percent recovery is above the primary MCL, it is still below the Class III Surface Water Criteria.
- Most of the parameters predicted to exceed regulations at 95 percent recovery are already close to or above regulations at the current 75 to 80 percent recovery.
- Depending on the source water characteristics, solid wastes generated through enhanced recovery can contain increased levels of radionuclides, restricting where the solid waste may be disposed.
- FDEP prohibits deep well injection of hazardous waste; however, water injected by deep well injection is not required to meet primary or secondary drinking water regulations.
- The major hazardous characteristic displayed by RO concentrate is toxicity due to low dissolved oxygen and high hydrogen sulfide. These can be treated by pH adjustment and aeration.
- Enhanced concentrate recovery will produce a concentrate of increased density and reduced volumes. The associated decrease in injectate buoyancy and reduced injection pressures needed for deep well injection suggest that concentrate recovery might actually reduce the risk for a vertical migration of water into an USDW.
- Most of the chronic toxicity studies on RO and NF concentrate at the City of Hollywood showed no toxic effect on mysid shrimp. The toxicity tests indicated that a dilution factor of 3:1 would entirely eliminate any observable toxic effects.
- Increased concentrate recovery of the Hollywood RO concentrate is not likely to have any toxic impact on marine flora or fauna due to the significant dilution that occurs through blending with treated wastewater effluent (25:1) and natural mixing (20:1).
- Enhanced concentrate recovery may increase the radionuclide concentrations in the concentrate to the level that it becomes a radioactive waste. According to the FDEP, a radioactive waste is not necessarily hazardous. Current regulations are not explicit on this matter and the EPA and FDEP would review modifications on a case-by-case basis. The lack of a clear regulation may make the permitting of liquid waste disposal moderately difficult for any concentrate minimization technology producing a liquid waste.
- Depending on the source water characteristics, all concentrate treatment technologies presented in this report would produce a solid byproduct containing radionuclides. Permitting for the disposal of this waste would be moderately difficult because disposal to a municipal landfill would not be allowed.

- Because the chemical precipitation process has the potential to provide selective solids removal, it may be the least onerous of all four concentrate management options presented herein in terms of day-to-day solids handling.

5.0 ESTIMATION OF THE COSTS AND BENEFITS OF IMPLEMENTING THE RECOMMENDED IMPROVEMENTS

5.1 Purpose

The previous sections discussed the water quality characteristics, existing treatment plant characteristics, and examined the technical permitting, and implementation factors for the four concentrate minimization technologies. This section focuses on a planning level economic analysis of the two most promising concentrate minimization technologies for the representative desalination plants.

5.2 Scope

The key purpose of the economic analysis is to demonstrate the benefit of additional investment in a concentrate management effort beyond what utilities in the District currently plan for and implement. The cost estimates developed in this study follow the guidelines published in “Cost Estimating and Economic Criteria for 2005 District Water Supply Plan” and are reported in October 2009 dollars. This document was published for the District as a means of providing a standard method of cost estimation among water supply alternatives. The economic criteria and cost estimates also utilized the guidelines and data found in the District’s Technical Memorandum (SFWMD, 2005).

Capital costs were developed for two promising concentrate minimization methodologies for each of the three representative brackish water WTPs, by sizing individual components for each candidate site. Because the recovery of a seawater facility is typically limited by pressure and not the solubility of limiting salts, the fourth representative WTP, a seawater facility (Florida Keys Aqueduct Authority’s Marathon Seawater Desalination Facility) was not included in this economic analysis for concentrate minimization.

5.3 Approach

Section 3 included discussion on the broad based economic and non-economic criteria for the four concentrate minimization alternatives. Based on the evaluations discussed in the previous sections, the two concentrate minimization methodologies selected for further economic analysis were identified as (1) dual RO with intermediate chemical precipitation and (2) thermal evaporation (brine concentrator). Although a brine crystallizer was also discussed along with the brine concentrator in the general discussions in the previous sections, a crystallizer is only required to be included in the case of a zero-liquid-discharge (ZLD) facility. For the purposes of the economic analysis presented in this section, the brine concentrator alone is considered as the second concentrate minimization alternative.

Phase 2 of the study included a pilot test that was undertaken at the City of North Miami Beach Norwood-Oeffler WTP; details regarding the test are discussed in Section 6. The primary goal of the pilot test was to demonstrate the feasibility of the dual RO with intermediate chemical precipitation methodology, and evaluate its conceptual performance. Where possible, performance data from the pilot test were used to aid the order-of-magnitude cost opinions presented in this section.

5.4 Treatment Alternatives

Four concentrate minimization treatment alternatives were discussed in detail in Section 3. As discussed above, based on the results from previous tasks, the two concentrate minimization alternatives selected for further economic analysis were (1) dual RO with intermediate chemical precipitation (with softening/filtration/secondary RO comprising the concentrate treatment steps) and (2) brine concentrator. The process schematics for these two treatment alternatives are presented in Figures 5.1 and 5.2, respectively.

In the case of the softening/filtration/secondary RO treatment alternative (i.e. dual RO with intermediate chemical precipitation approach), lime (and soda ash if needed) is added to the primary RO concentrate to reduce the concentration of calcium from the primary RO concentrate. The chemically treated concentrate is subsequently filtered and processed through another RO step ('secondary' RO). A dual media filter was assumed in the economic analysis performed in this study. The chemical precipitation process reduces the scaling potential of the primary RO concentrate, allowing the recovery of more product water through a second RO step. The additional product water was assumed to be blended with the primary RO permeate. The final concentrate from the secondary RO was assumed to be disposed using the existing disposal method at the representative WTP.

The brine concentrator concentrates a saline feed stream through distillation and vapor compression. Before entering the concentrator, the feed stream passes through a heat exchanger with the distillate and a deaerator that removes non-condensable gases such as carbon dioxide and oxygen. Scale inhibitor is added to prevent scaling in the heat exchanger and evaporation chamber. A high purity distillate is produced and was assumed to be blended with the primary RO permeate. The brine concentrator typically recovers over 90 percent of the concentrated feed stream as distillate. The final concentrate from the brine concentrator was assumed to be disposed using the existing disposal method at the representative WTP.

5.5 Flows for Cost Opinions

Table 5.1 summarizes the characteristics of the primary RO process employed at the representative brackish water plants, in terms of the RO system design flows and system recovery, as well as TDS. These characteristics were discussed in previous sections. The RO process feed TDS for North Miami Beach WTP was noted as 4,000 mg/L in Section 3, based on the reported data; however, it was revised to 3,000 TDS (Table 5.1) based on observations during the pilot testing that was performed at the WTP as part of this study.

FIGURE 5.1

Process Flow Schematic for Concentrate Treatment via Softening/Filtration/Secondary RO.

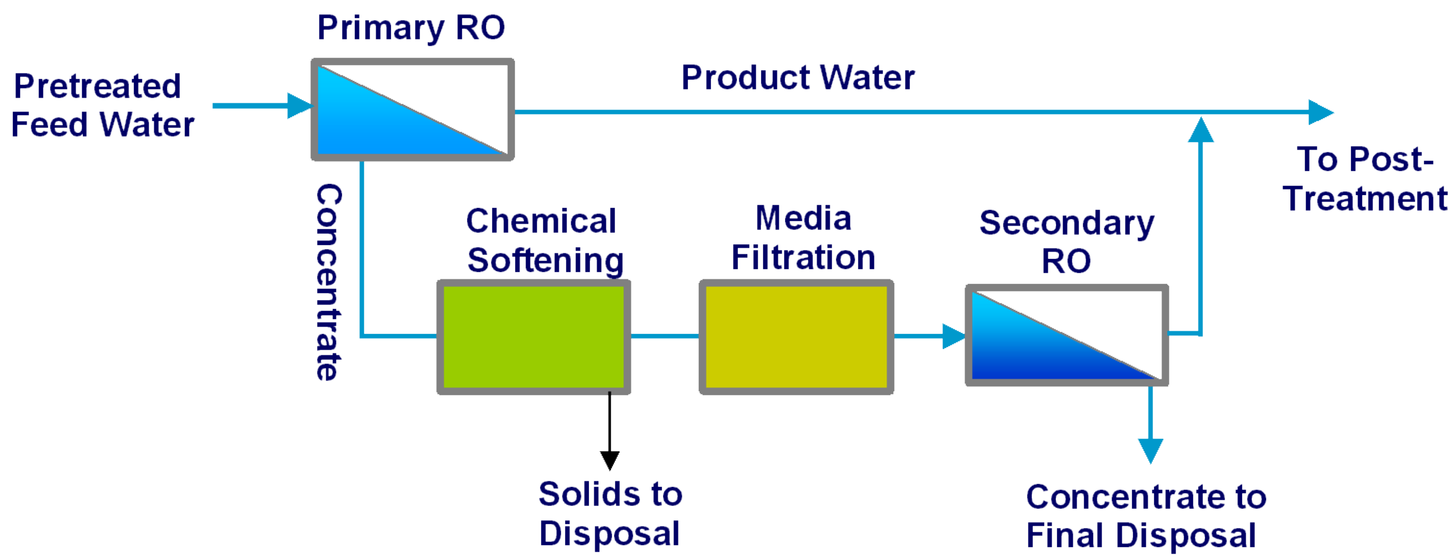

FIGURE 5.2

Process Flow Schematic for Concentrate Treatment via Brine Concentrator.

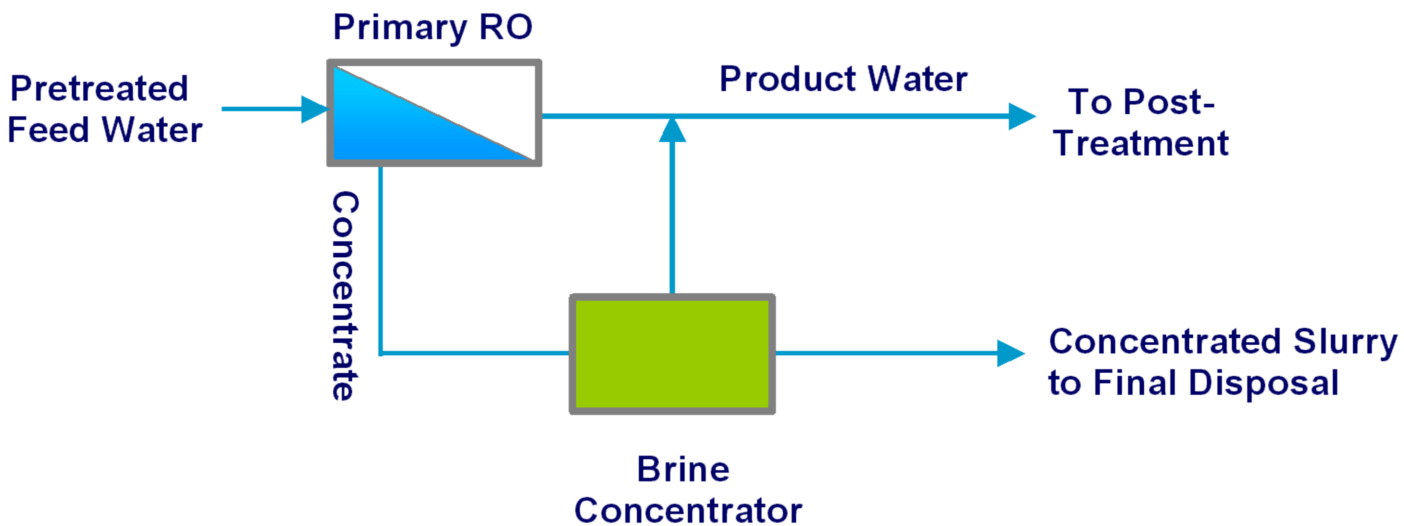

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Table 5.1 Characteristics of the Primary RO Process Used at the Representative Plants				
Parameter	**Unit**	**North Miami Beach WTP**	**Hollywood WTP**	**Deerfield Beach WTP**
Recovery	%	75%	80%	75%
TDS:				
Feed	mg/L	3,000	4,900	3,300
Concentrate[(1)]	mg/L	12,000	24,500	13,200
Design Flows:				
Feed	mgd	8.0	5.0	4.0
Permeate	mgd	6.0	4.0	3.0
Concentrate	mgd	2.0	1.0	1.0

Notes:
1. Estimated based on process recovery.

The design concentrate flow was used as the basis for the capital cost opinion. A peak flow factor of 1.5 was assumed to estimate the corresponding operating flow for the RO concentrate, which was then used as the basis for developing the O&M cost opinion (Table 5.2).

Table 5.2 Flows for Capital and O&M Cost Opinions of Concentrate Treatment				
Parameter	**Unit**	**North Miami Beach WTP**	**Hollywood WTP**	**Deerfield Beach WTP**
Primary RO:				
Design Product Flow	mgd	6.0	4.0	3.0
Concentrate Treatment:				
Design Concentrate Flow[(1)]	mgd	2.0	1.0	1.0
Peak Flow Ratio[(2)]	-	1.5	1.5	1.5
Operating Concentrate Flow[(3)]	mgd	1.3	0.7	0.7

Notes:
"Concentrate" from primary RO serves as "feed" to the concentrate minimization process
1. Used as basis for developing capital cost opinion for concentrate treatment.
2. Assumed value.
3. Used as basis for developing O&M cost opinion for concentrate treatment.

It is noted that the design and operating “concentrate” flows in Table 5.2 represent the “feed” flows to the concentrate treatment process. The additional product recovered from the concentrate treatment process (i.e. its product capacity) is a function of its recovery and is discussed subsequently.

5.6 Assumptions for Cost Opinions

The order-of-magnitude cost opinions that were developed are based on information from prior experience in estimating processes of this nature, other similar projects completed recently, and information provided by vendors. It should be noted that these are planning level cost opinions with an estimated accuracy of +30 percent to - 20 percent. The cost opinions expressed in this section were based upon October 2009 levels. Where the source provided actual cost data for a previous time period, the costs were updated to October 2009 values utilizing the relevant cost indices obtained from Engineering News Record. The unit prices generated include provisions for contractor and subcontractor overhead and profit. Furthermore, a 10 percent construction contingency and a 10 percent project contingency are included to reflect the level of detail associated with the cost opinions, and because of the currently favorable construction market.

The generation of the capital cost opinions is based primarily upon Carollo’s experience and judgment as a professional consultant. The “order of magnitude” opinion for each alternative was developed for comparing the capital costs associated with each alternative. Since Carollo has no control over such factors as weather, cost and availability of labor, material and equipment, labor productivity, contractor’s procedures and methods, competitive bidding, market conditions or other factors affecting such opinions or projections, Carollo does not guarantee that the actual rates, costs, etc. will not vary for the opinions and projections developed herein.

“Order of Magnitude” level of operations and maintenance (O&M) or life cycle costs do not include any costs associated with operator training or certification that may be required by current or future regulations.

5.6.1 Common Assumptions

The key assumptions common to all the cost opinions included in this section are summarized in Table 5.3. These essentially include all the fiscal parameters such as unit cost of energy and unit chemical costs, as well as the selected design and operating parameters for the two concentrate treatment alternatives.

In case of both treatment alternatives, i.e. softening/filtration/secondary RO process or brine concentrator, a final disposal step will still be required for the remaining (reduced) concentrate volume. For the purposes of this section, it is assumed that the existing concentrate disposal method will continue to be used for the disposal of the final concentrate. These disposal costs are not included in the cost estimates presented in this section. Note that these disposal costs can be assumed to be lower than the present concentrate disposal costs due to be the reduced concentrate volume. In reality, this cost reduction in concentrate disposal will represent a 'saving' that will offset some of the costs associated with the new concentrate treatment step. This possible saving is not included in the cost estimates presented in this section.

Table 5.3 Key Common Assumptions for Cost Opinions

Parameter	Unit	Value
Fiscal		
ENR Construction Cost Index (CCI)	-	8,596
Month/Year Corresponding to ENR CCI	-	Oct-09
Economic Service Life(1) - Equipment	Yrs	20
Economic Service Life(1) - Building, Tankage, Etc.	Yrs	35
Interest Rate	%	6.0%
Energy Cost	$/kwh	0.10
Labor Rate (including benefits)	$/hr	50
Sludge Disposal Cost	$/ton	30
Membrane Element Cost	$/element	550
Cartridge Filter Cost	$/filter	10
Chemical Costs:		
Lime	$/lb	0.07
Soda-ash	$/lb	0.18
Scale Inhibitor	$/lb	2.00
Sulfuric acid	$/lb	0.10
Miscellaneous Design and Operation Parameters		
Dewatered Sludge Percent Solids	%	40%
Membrane Element Area	ft^2	400
Membrane Life	Yr	5
Membrane Chemical Cleaning (CIP) Frequency	Days	90
Cartridge Filter Length	Inch	40
Cartridge Filter Loading Rate	gpm/10inch	4.0
Cartridge Filter Replacement Frequency	Days	30
Brine Concentrator Cleaning Frequency	Days	180

Notes:

1. For softening and media filtration, 50 percent of the associated capital cost was attributed to equipment and the other 50 percent was attributed to tankage, etc.

5.6.2 Other Assumptions for Concentrate Treatment Operations

Several other operating parameters were assumed or estimated for developing the cost opinions for the two treatment alternatives for each of the three representative WTPs. These additional parameters are summarized in Table 5.4.

Table 5.4 Additional Assumptions for Concentrate Treatment Operations Employed in the Cost Opinions

Parameter	Unit	North Miami Beach WTP	Hollywood WTP	Deerfield Beach WTP
Alternative 1: Softening/Filtration/Secondary RO				
Softening/Filtration				
Calcium Hardness	mg/L $CaCO_3$	1,300	2,230	3,900
Magnesium Hardness	mg/L $CaCO_3$	1,820	3,070	1,450
Bicarbonate	mg/L $CaCO_3$	410	310	2,760
Lime Dose	mg/L $CaCO_3$	500	500	3,000
Soda Ash Dose	mg/L $CaCO_3$	150	150	200
Labor Hours/Week	#	100	100	100
Belt/filter Press Operation	hr/d	8.0	8.0	8.0
Secondary RO				
Feed Pressure	psi	300	500	220
Recovery	%	55%	55%	55%
Scale Inhibitor Dose	mg/L	4.0	4.0	4.0
Permeate Flux	gfd	8.5	8.5	8.5
Labor Hours/Week	#	80	80	80
Alternative 2: Brine Concentrator				
Scale Inhibitor Dose	mg/L	4.0	4.0	4.0
Recovery	%	94%	88%	93%
Unit Energy Usage Main Compressor	kw/kgal	100	100	100
Labor Hours/Week	#	150	150	150

The calcium and magnesium hardness in the primary RO concentrate was estimated from the model simulations, except for North Miami Beach WTP where values observed during the pilot testing were employed. It is noted that for the alternative involving intermediate chemical precipitation, a partial lime softening is assumed in all cases. This is because only a certain degree of calcium carbonate removal is required to achieve the desired operating recovery of the secondary RO. Excess removal of carbonate hardness, or removal of magnesium hardness via addition of soda-ash is neither required nor desired due to the high associated chemical costs. Thus, in the case of the North Miami Beach WTP, a lime dose of 500 mg/L (as $CaCO_3$) is estimated for partial softening. This was confirmed through jar testing performed at the WTP using the primary RO concentrate. Based on the results from the jar testing, a small dose of soda ash (150 mg/L as $CaCO_3$) is also included as it was found to improve the removal of calcium carbonate. This combination of lime and soda ash doses resulted in approximately 25 percent removal of calcium hardness and approximately 5 percent removal of magnesium hardness. This level of calcium carbonate removal was estimated to allow about 55 percent recovery in the secondary RO.

It is noted that due to the size limitations of the pilot equipment, the dose of lime and soda ash that had to be employed during the pilot test at North Miami Beach WTP was much higher, representing excess softening, with both lime and soda ash each dosed at about 2,000 mg/L as $CaCO_3$. Higher doses had to be employed in the pilot test as the lower doses determined during the jar tests did not result in desired levels of turbidity in the softened water, which is further treated with the pilot scale dual media filter and RO process. This is believed to be largely due to the limitations on the settling times and other size based limitations of the pilot equipment. However, the much higher doses used in the pilot test that resulted in the desired turbidities, did also result in much greater removal of the calcium hardness (46 percent) and magnesium hardness (98 percent). In reality, such high removals of magnesium are not required for the purposes of the secondary RO. Since the limitations associated with the pilot equipment are overcome at full-scale, and the jar testing with primary RO concentrate did indicate desired hardness removals with partial softening, the chemical doses estimated for partial softening are employed in the cost opinions.

The estimated chemical doses for partial softening of the concentrate at the Hollywood WTP are similar to that of North Miami Beach WTP, due to the similar carbonate hardness reflected by the similar levels of bicarbonate concentrations. However, the lime dose for partial softening at Deerfield Beach is estimated to be much higher due to the associated high level of calcium carbonate hardness in the primary RO concentrate. This high level of carbonate hardness is due to the blending of NF concentrate with the primary RO feed at Deerfield Beach WTP. As expected, the NF concentrate contains high levels of hardness that was rejected by the NF membranes.

5.7 Cost Opinions

5.7.1 North Miami Beach WTP

The planning level capital cost opinions for the two concentrate treatment alternatives for North Miami Beach WTP are summarized in Tables 5.5 and 5.6, respectively. Similarly, the O&M cost opinions are summarize in Tables 5.7 and 5.8, respectively. Finally, the total treatment costs are summarized in Tables 5.9 and 5.10, respectively.

Table 5.5 Capital Cost Opinion for North Miami Beach WTP - Softening/Filtration/Secondary RO Treatment Alternative

Key Criteria	***Unit***	***Value***
Average Daily Flow(1)	*mgd*	*1.33*
Design Capacity(1)	*mgd*	*2.00*
ENR Construction Cost Index	*Oct-09*	*8,596*
Item Description	**Allowance Factor**	**Cost**
Softening		$3,600,000
Media Filtration		$600,000
Secondary RO Process		$1,040,000
Post Treatment		$880,000
Building		$700,000
Subtotal:		$6,820,000
Yard Piping	7%	$477,000
Electrical	10%	$682,000
Instrumentation & Controls	7%	$477,000
Site Work	5%	$341,000
Subtotal:		$8,797,000
General Requirements	2%	$176,000
Contractor Overhead & Profit	15%	$1,320,000
Construction Contingency	10%	$880,000
Opinion of Probable Construction Cost:		$11,173,000
Engineering Services, Permitting, CMS	25%	$2,793,000
Owner Administration and Legal	5%	$559,000
Project Contingency	10%	$1,117,000
Opinion of Probable Capital Cost:		$15,642,000

Notes:
1. Depicting concentrate flow from primary RO system.

Table 5.6 Capital Cost Opinion for North Miami Beach WTP - Brine Concentrator Treatment Alternative

Key Criteria	**Unit**	**Value**
Average Daily Flow[(1)]	*mgd*	*1.33*
Design Capacity[(1)]	*mgd*	*2.00*
ENR Construction Cost Index	*Oct-09*	*8,596*
Item Description	**Allowance Factor**	**Cost**
Brine Concentrator		$12,000,000
Subtotal:		$12,000,000
Yard Piping	7%	$840,000
Electrical	10%	$1,200,000
Instrumentation & Controls	7%	$840,000
Site Work	5%	$600,000
Subtotal:		$15,480,000
General Requirements	2%	$310,000
Contractor Overhead & Profit	15%	$2,322,000
Construction Contingency	10%	$1,548,000
Opinion of Probable Construction Cost:		$19,660,000
Engineering Services, Permitting, CMS	25%	$4,915,000
Owner Administration and Legal	5%	$983,000
Project Contingency	10%	$1,966,000
Opinion of Probable Capital Cost:		$27,524,000

Notes:
1. Depicting concentrate flow from primary RO system.

Table 5.7 O&M Cost Opinion for North Miami Beach WTP - Softening/Filtration/Secondary RO Treatment Alternative

Key Criteria	***Unit***		***Value***
Average Daily Flow[(1)]	*mgd*		*1.33*
Recovery	*%*		*55%*
Average Daily Product Flow[(2)]	*mgd*		*0.73*
Energy Cost	*$/kwh*		*0.10*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Softening/filtration	$823,000	$3.07	$3,075
Secondary RO Process	$454,000	$1.70	$1,696
Post-Treatment	$54,000	$0.20	$202
Opinion of Probable O&M Cost:	$1,331,000	$4.97	$4,973

Notes:
(1) Depicting concentrate flow from primary RO system.
(2) Depicting additional product water recovered from concentrate treatment scheme.

Table 5.8 O&M Cost Opinion for North Miami Beach WTP - Brine Concentrator Treatment Alternative

Key Criteria	***Unit***		***Value***
Average Daily Flow[(1)]	*mgd*		*1.33*
Recovery	*%*		*94%*
Average Daily Product Flow[(2)]	*mgd*		*1.25*
Energy Cost	*$/kwh*		*0.10*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Brine Concentrator	$6,163,000	$13.47	$13,472
Post-Treatment	$91,000	$0.20	$199
Opinion of Probable O&M cost:	$6,254,000	$13.67	$13,671

Notes:
1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

Table 5.9 Opinion of Probable Total Treatment Cost for North Miami Beach WTP - Softening/Filtration/Secondary RO Treatment Alternative			
Key Criteria	***Unit***		***Value***
Average Daily Flow(1)	*mgd*		*1.33*
Average Daily Product Flow(2)	*mgd*		*0.73*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Capital	$1,247,000	$4.66	$4,659
Operations and Maintenance	$1,331,000	$4.97	$4,973
Opinion of Total Treatment Cost:	$2,578,000	$9.63	$9,631

Notes:
1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

Table 5.10 Opinion of Probable Total Treatment Cost for North Miami Beach WTP - Brine Concentrator Alternative			
Key Criteria	***Unit***		***Value***
Average Daily Flow(1)	*mgd*		*1.33*
Average Daily Product Flow(2)	*mgd*		*1.25*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Capital	$2,400,000	$5.65	$5,246
Operations and Maintenance	$6,254,000	$13.67	$13,671
Opinion of Total Treatment Cost:	$8,654,000	$18.92	$18,917

Notes:
1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

5.7.2 Hollywood WTP

The planning level capital cost opinions for the two concentrate treatment alternatives for Hollywood WTP are summarized in Tables 5.11 and 5.12, respectively. The O&M cost opinions are summarize in Tables 5.13 and 5.14, respectively and the total treatment costs are summarized in Tables 5.15 and 5.16, respectively.

Table 5.11 Capital Cost Opinion for Hollywood WTP - Softening/Filtration/Secondary RO Treatment Alternative

Key Criteria	*Unit*	*Value*
Average Daily Flow[(1)]	*mgd*	*0.67*
Design Capacity[(1)]	*mgd*	*1.00*
ENR Construction Cost Index	*Oct-09*	*8,596*
Item Description	**Allowance Factor**	**Cost**
Softening		$1,800,000
Media Filtration		$300,000
Secondary RO Process		$520,000
Post Treatment		$440,000
Building		$350,000
Subtotal:		$3,410,000
Yard Piping	7%	$239,000
Electrical	10%	$341,000
Instrumentation & Controls	7%	$239,000
Site Work	5%	$171,000
Subtotal:		$4,400,000
General Requirements	2%	$88,000
Contractor Overhead & Profit	15%	$660,000
Construction Contingency	10%	$440,000
Opinion of Probable Construction Cost:		$5,588,000
Engineering Services, Permitting, CMS	25%	$1,397,000
Owner Administration and Legal	5%	$279,000
Project Contingency	10%	$559,000
Opinion of Probable Capital Cost:		$7,823,000

Notes:
1. Depicting concentrate flow from primary RO system.

Table 5.12 Capital Cost Opinion for Hollywood WTP - Brine Concentrator Treatment Alternative

Key Criteria	***Unit***	***Value***
Average Daily Flow(1)	*mgd*	*0.67*
Design Capacity(1)	*mgd*	*1.00*
ENR Construction Cost Index	*Oct-09*	*8,596*
Item Description	**Allowance Factor**	**Cost**
Brine Concentrator		$8,200,000
Subtotal:		$8,200,000
Yard Piping	7%	$574,000
Electrical	10%	$820,000
Instrumentation & Controls	7%	$574,000
Site Work	5%	$410,000
Subtotal:		$10,578,000
General Requirements	2%	$212,000
Contractor Overhead & Profit	15%	$1,587,000
Construction Contingency	10%	$1,058,000
Opinion of Probable Construction Cost:		$13,435,000
Engineering Services, Permitting, CMS	25%	$3,359,000
Owner Administration and Legal	5%	$672,000
Project Contingency	10%	$1,344,000
Opinion of Probable Capital Cost:		$18,810,000

Notes:
1. Depicting concentrate flow from primary RO system.

Table 5.13 O&M Cost Opinion for Hollywood WTP - Softening/Filtration/Secondary RO Treatment Alternative

Key Criteria	***Unit***		***Value***
Average Daily Flow[(1)]	*mgd*		*0.67*
Recovery	*%*		*55%*
Average Daily Product Flow[(2)]	*mgd*		*0.37*
Energy Cost	*$/kwh*		*0.10*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Softening/filtration	$612,000	$4.57	$4,573
Secondary RO Process	$381,000	$2.85	$2,847
Post-Treatment	$27,000	$0.20	$202
Opinion of Probable O&M Cost:	$1,020,000	$7.62	$7,621

Notes:
1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

Table 5.14 O&M Cost Opinion for Hollywood WTP - Brine Concentrator Treatment Alternative

Key Criteria	***Unit***		***Value***
Average Daily Flow[(1)]	*mgd*		*0.67*
Recovery	*%*		*88%*
Average Daily Product Flow[(2)]	*mgd*		*0.59*
Energy Cost	*$/kwh*		*0.10*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Brine Concentrator	$3,379,000	$15.82	$15,825
Post-Treatment	$43,000	$0.20	$201
Opinion of Probable O&M cost:	$3,422,000	$16.03	$16,026

Notes:
1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

Table 5.15 Opinion of Probable Total Treatment Cost for Hollywood WTP - Softening/Filtration/Secondary RO Treatment Alternative			
Key Criteria	***Unit***		***Value***
Average Daily Flow[(1)]	*mgd*		*0.67*
Average Daily Product Flow[(2)]	*mgd*		*0.37*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Capital	$624,000	$4.66	$4,663
Operations and Maintenance	$1,020,000	$7.62	$7,621
Opinion of Total Treatment Cost:	$1,644,000	$12.28	$12,284

Notes:

1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

Table 5.16 Opinion of Probable Total Treatment Cost for Hollywood WTP - Brine Concentrator Alternative			
Key Criteria	***Unit***		***Value***
Average Daily Flow[(1)]	*mgd*		*0.67*
Average Daily Product Flow[(2)]	*mgd*		*0.59*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Capital	$1,640,000	$7.68	$7,681
Operations and Maintenance	$3,422,000	$16.03	$16,026
Opinion of Total Treatment Cost:	$5,062,000	$23.71	$23,707

Notes:

1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

5.7.3 Deerfield Beach WTP

The planning level capital cost opinions for the two concentrate treatment alternatives for Deerfield Beach WTP are summarized in Tables 5.17 and 5.18, respectively. The O&M cost opinions are summarize in Tables 5.19 and 5.20, respectively and the total treatment costs are summarized in Tables 5.21 and 5.22, respectively.

Table 5.17 Capital Cost Opinion for Deerfield Beach WTP - Softening/Filtration/Secondary RO Treatment Alternative

Key Criteria	***Unit***	***Value***
Average Daily Flow[(1)]	*mgd*	*0.67*
Design Capacity[(1)]	*mgd*	*1.00*
ENR Construction Cost Index	*Oct-09*	*8,596*
Item Description	**Allowance Factor**	**Cost**
Softening		$2,300,000
Media Filtration		$300,000
Secondary RO Process		$520,000
Post Treatment		$440,000
Building		$350,000
Subtotal:		$3,910,000
Yard Piping	7%	$274,000
Electrical	10%	$391,000
Instrumentation & Controls	7%	$274,000
Site Work	5%	$196,000
Subtotal:		$5,045,000
General Requirements	2%	$101,000
Contractor Overhead & Profit	15%	$757,000
Construction Contingency	10%	$505,000
Opinion of Probable Construction Cost:		$6,408,000
Engineering Services, Permitting, CMS	25%	$1,602,000
Owner Administration and Legal	5%	$320,000
Project Contingency	10%	$641,000
Opinion of Probable Capital Cost:		$8,971,000

Notes:
1. Depicting concentrate flow from primary RO system.

Table 5.18 Capital Cost Opinion for Deerfield Beach WTP - Brine Concentrator Treatment Alternative		
Key Criteria	***Unit***	***Value***
Average Daily Flow[(1)]	*mgd*	*0.67*
Design Capacity[(1)]	*mgd*	*1.00*
ENR Construction Cost Index	*Oct-09*	*8,596*
Item Description	**Allowance Factor**	**Cost**
Brine Concentrator		$8,200,000
Subtotal:		$8,200,000
Yard Piping	7%	$574,000
Electrical	10%	$820,000
Instrumentation & Controls	7%	$574,000
Site Work	5%	$410,000
Subtotal:		$10,578,000
General Requirements	2%	$212,000
Contractor Overhead & Profit	15%	$1,587,000
Construction Contingency	10%	$1,058,000
Opinion of Probable Construction Cost:		$13,435,000
Engineering Services, Permitting, CMS	25%	$3,359,000
Owner Administration and Legal	5%	$672,000
Project Contingency	10%	$1,344,000
Opinion of Probable Capital Cost:		$18,810,000

Notes:
1. Depicting concentrate flow from primary RO system.

Table 5.19 O&M Cost Opinion for Deerfield Beach WTP - Softening/Filtration/Secondary RO Treatment Alternative			
Key Criteria	***Unit***		***Value***
Average Daily Flow[(1)]	*mgd*		*0.67*
Recovery	*%*		*55%*
Average Daily Product Flow[(2)]	*mgd*		*0.37*
Energy Cost	*$/kwh*		*0.10*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Softening/filtration	$968,000	$7.23	$7,233
Secondary RO Process	$312,000	$2.33	$2,331
Post-Treatment	$27,000	$0.20	$202
Opinion of Probable O&M Cost:	$1,307,000	$9.77	$9,766

Notes:
1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

Table 5.20 O&M Cost Opinion for Deerfield Beach WTP - Brine Concentrator Treatment Alternative			
Key Criteria	***Unit***		***Value***
Average Daily Flow[(1)]	*mgd*		*0.67*
Recovery	*%*		*93%*
Average Daily Product Flow[(2)]	*mgd*		*0.62*
Energy Cost	*$/kwh*		*0.10*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Brine Concentrator	$3,379,000	$14.87	$14,868
Post-Treatment	$45,000	$0.20	$198
Opinion of Probable O&M cost:	$3,424,000	$15.07	$15,066

Notes:
1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

Table 5.21 Opinion of Probable Total Treatment Cost for Deerfield Beach WTP - Softening/Filtration/Secondary RO Treatment Alternative			
Key Criteria	***Unit***		***Value***
Average Daily Flow$^{(1)}$	*mgd*		*0.67*
Average Daily Product Flow$^{(2)}$	*mgd*		*0.37*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Capital	$713,000	$5.33	$5,328
Operations and Maintenance	$1,307,000	$9.77	$9,766
Opinion of Total Treatment Cost:	$2,020,000	$15.09	$15,093

Notes:
1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

Table 5.22 Opinion of Probable Total Treatment Cost for Deerfield Beach WTP - Brine Concentrator Alternative			
Key Criteria	***Unit***		***Value***
Average Daily Flow$^{(1)}$	*mgd*		*0.67*
Average Daily Product Flow$^{(2)}$	*mgd*		*0.62*
Item Description	**Annual Cost ($/yr)**	**Unit Cost ($/kgal product)**	**Unit Cost ($/MG product)**
Capital	$1,640,000	$7.22	$7,216
Operations and Maintenance	$3,424,000	$15.07	$15,066
Opinion of Total Treatment Cost:	$5,064,000	$22.28	$22,282

Notes:
1. Depicting concentrate flow from primary RO system.
2. Depicting additional product water recovered from concentrate treatment scheme.

5.7.4 Cost Comparison and Conclusions

Table 5.23 includes a summary of the total treatment costs for the two treatment alternatives for each of the three representative WTPs.

As summarized in Table 5.23, while the brine concentrator provides a much higher recovery compared to the softening/filtration/secondary RO alternative, the total treatment costs (on the basis of dollars per thousand gallons of additional product water produced from concentrate treatment) for the brine concentrator alternative for North Miami Beach WTP are about 48 percent higher. Thus, for the North Miami Beach WTP the softening/filtration/ secondary RO alternative is expected to be more promising. Similarly, for the Hollywood WTP the total treatment costs for the brine concentrator alternative are again 48 percent higher. Thus, for the Hollywood WTP as well the softening/filtration/secondary RO alternative is expected to be more promising.

For Deerfield Beach WTP as well, the softening/filtration/secondary RO alternative is estimated to be more cost-effective compared to the brine concentrator alternative. The total treatment costs for the brine concentrator alternative are about 32 percent higher. However, it is noted that the silica levels in primary RO concentrate are almost at limiting concentrations and therefore the softening process would be required to provide some silica removal as well. This is expected to increase the net costs of the softening step; thus, in the worst-case scenario the costs for softening/filtration/secondary RO might be expected become comparable to the costs for brine concentrator treatment in the case of Deerfield Beach WTP.

In general, the softening/filtration/secondary RO alternative is expected to be more, or equally, cost-effective compared to the brine concentrator alternative.

Table 5.23 Comparison of Cost Opinions

Treatment Alternative	North Miami Beach WTP	Hollywood WTP	Deerfield Beach WTP
Design Flow (mgd) (1)	2.00	1.00	1.00
Operating Flow (mgd) (2)	1.33	0.67	0.67
Probable Total Unit Treatment Cost:			
Softening/Filtration/Secondary RO ($/kgal)	9.63	12.28	15.09
Brine Concentrator ($/kgal)	18.92	23.71	22.28

Notes:

1. Concentrate flow to be treated; used as basis for developing capital cost opinion.
2. Concentrate flow to be treated; used as basis for developing O&M cost opinion.

6.0 PILOT STUDY

6.1 Purpose

Phase 2 of the project included further evaluation through pilot testing of the one concentrate minimization method at one representative brackish water RO plant site, both of which were selected based on the Phase 1 evaluations. The Phase 1 evaluations determined chemical precipitation and filtration followed by secondary RO as the most promising method for further evaluation at pilot scale. Compared to the other alternatives, the capital cost and energy use, along with implementation factors associated with this option were found to be more attractive.

The purpose of the pilot test was to demonstrate the feasibility of the selected concentrate minimization methodology, evaluate its conceptual performance, and provide data to establish planning-level cost estimates for a specific site. The pilot study was undertaken at the City of North Miami Beach Norwood-Oeffler WTP.

This section describes the pilot testing components and operations, and summarizes the results obtained from the 3-month pilot operation.

6.2 Background

As a participating utility in the project, the City of North Miami Beach agreed to host the pilot test at its Norwood-Oeffler WTP. A separate memorandum of understanding (MOU) was developed to indicate the responsibilities of Carollo Engineers and the City for this pilot test.

The pilot test was undertaken at the City's WTP, which employs full-scale RO treatment of a brackish groundwater water source. The approach pilot tested for the full-scale (or 'primary') RO concentrate minimization comprised intermediate chemical precipitation followed by filtration and secondary RO. Lime and soda ash were added to primary RO concentrate to reduce the concentrations of calcium and magnesium from the primary RO concentrate. Initial jar tests performed at the WTP as part of this study demonstrated promising results for reduction of sparingly soluble ions from the RO concentrate by co-precipitation with calcium carbonate and magnesium hydroxide. The chemically treated concentrate was filtered using a media filter, and subsequently processed through another RO step ('secondary' RO). The chemical precipitation process thus reduced the scaling potential of the primary RO concentrate, allowing the recovery of more product water through a second RO step.

6.3 Objectives

The specific objectives of the pilot testing were:

1. Test chemical precipitation and filtration for treatment of concentrate from the primary RO system:
    a. Evaluate the softening potential to permit subsequent concentrate reprocessing. Evaluate pH and chemical dose requirements.
    b. Evaluate filter performance and backwash requirements
2. Test secondary RO for treatment of the chemically treated and filtered concentrate:
    a. Evaluate sustainable operation of secondary RO at target recovery between 50 to 60 percent, to result in recovery enhancement for overall system.

6.4 Materials and Methods

The study included both bench and pilot testing and pilot testing. The operation of three pilot units constituted two distinct parts. In the first part of the pilot study, the intermediate chemical precipitation pilot and filtration pilot were operated for a two-month period to screen a range of chemical doses and operating conditions, and subsequently optimize and establish and steady state softening performance. During this time, the available brackish water RO pilot was being upgraded with a new high-pressure pump to accommodate the pressure requirement of treating (softened and filtered) primary RO concentrate. In the second part of the pilot test, the secondary RO pilot was installed and tested under steady-state pretreatment conditions that were established in the first part of the pilot test.

6.4.1 Bench Scale Tests

Bench scale jar tests were utilized to pre-screen a range of chemical doses for the intermediate chemical precipitation/softening process. The bench tests were performed at the City of Miami Norwood WTP using the concentrate from the primary RO system. The tests were performed in the one month preceding the installation of the pilot units.

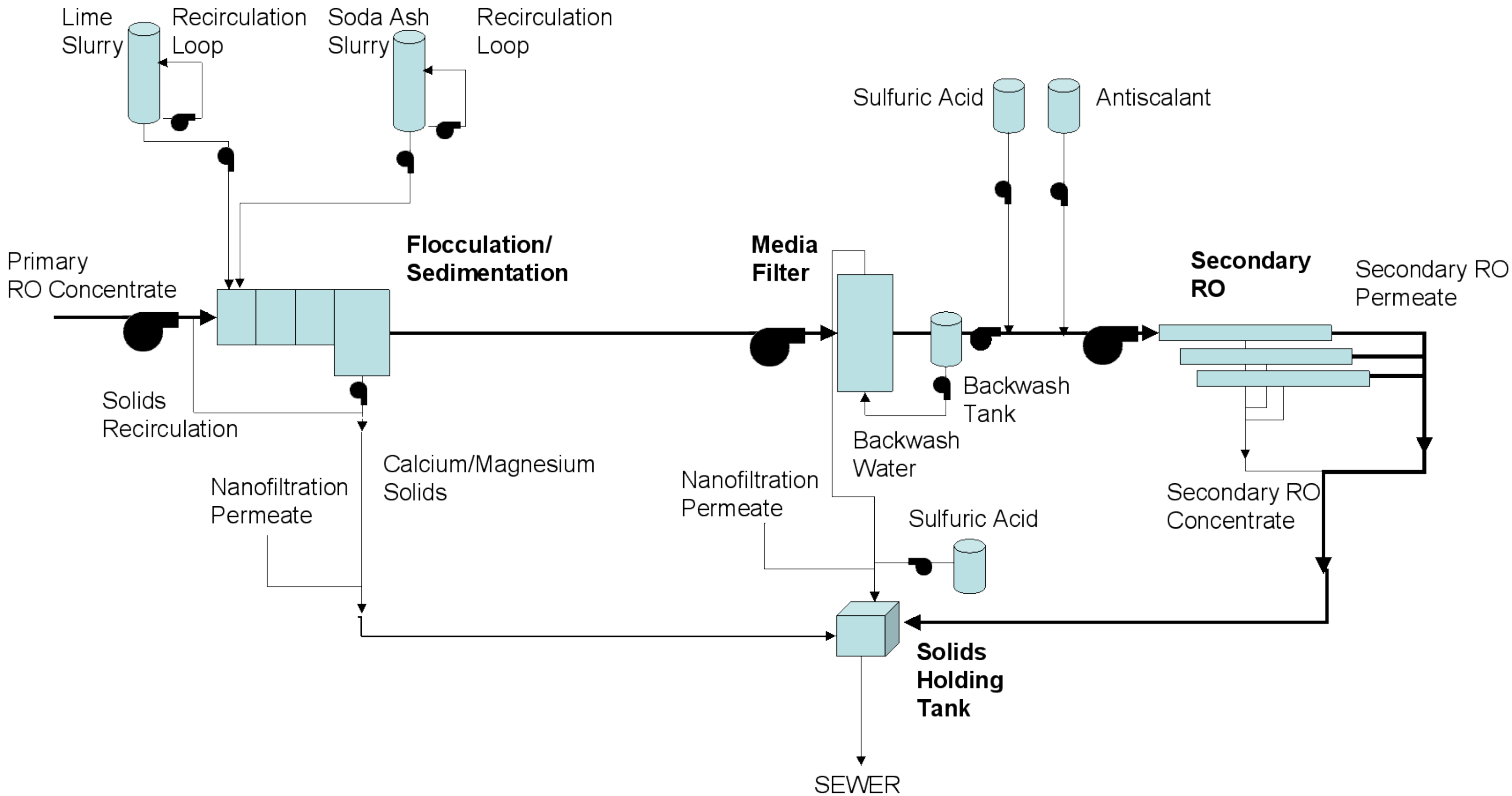
6.4.2 Pilot Unit Process Description

Figure 6.1 includes the process flow schematic of the pilot treatment train. As discussed in Section 6.2, the pilot plant treated concentrate from the ‘primary’ RO, which was the full-scale RO system operating at the WTP.

Three major pilot units were set up on site according to the attached layout (Figure 6.2). These include the sedimentation pilot, the filtration pilot, and the ‘secondary’ RO pilot. This section further details the individual processes in the pilot test program.

Process Flow Schematic for the Pilot Plant.

FIGURE 6.1



South Florida Water Management District
Water Desalination Concentrate Management and Piloting

Equipment Layout for the Pilot Plant.

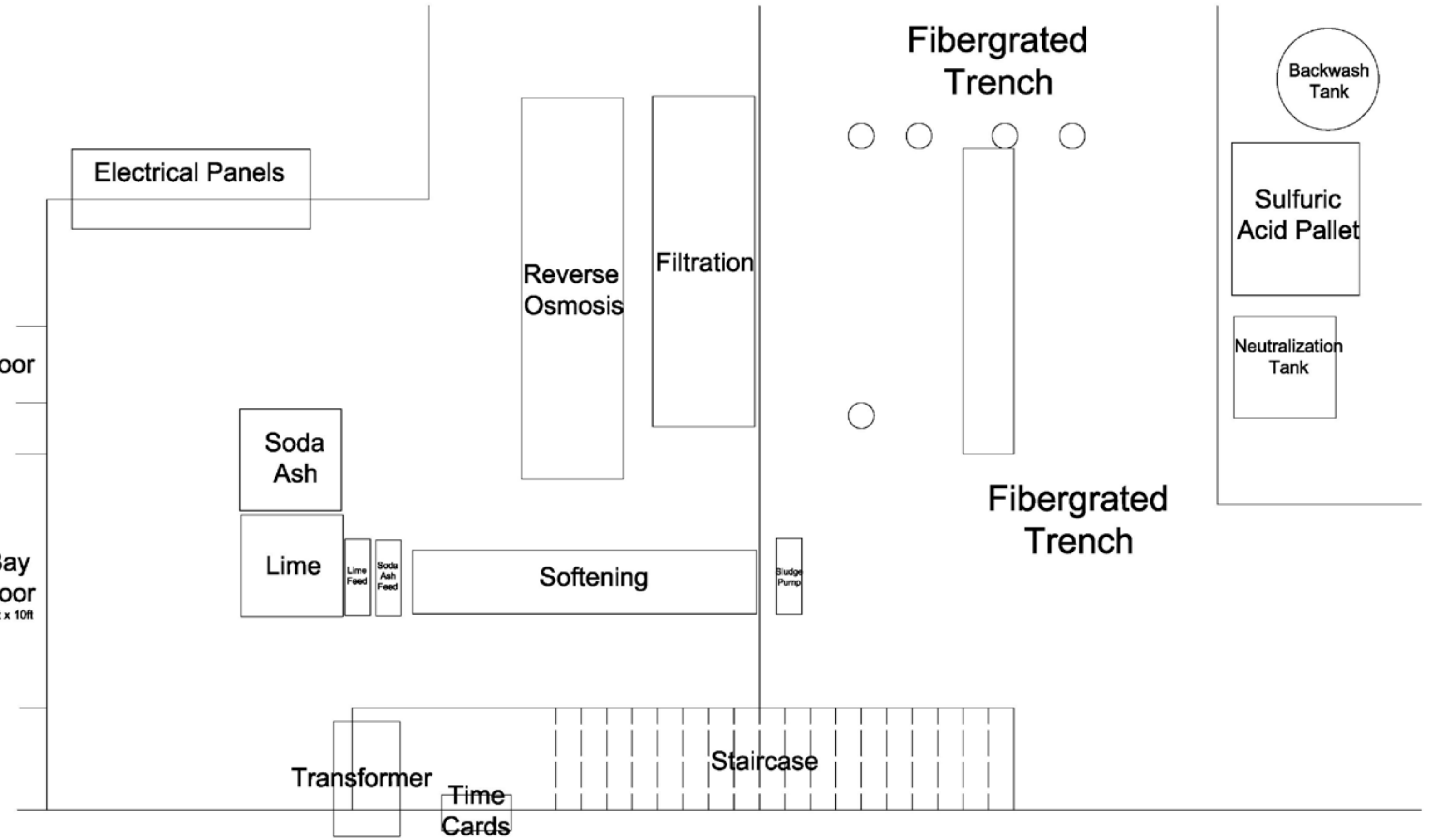


FIGURE 6.2

South Florida Water Management District
Water Desalination Concentrate Management and Piloting

Chemical Precipitation/Softening

Chemical precipitation was achieved using a flocculation/sedimentation pilot unit with a nominal flow of 6 gallons per minute (gpm). The head of the pilot plant included a pre-oxidation unit (constituting two parallel columns that are typically used for pre-ozonation), which was not required for this testing and was bypassed. The rapid mix in the pilot included a chemical mixer that provided flash mixing, with G values in the range of 500 to 1,000 s^{-1}. The flocculation section included three stages so that mixing energy can be tapered and optimized in successive flocculation stages. Sedimentation was provided with plate settlers for overall process performance representative of full-scale facilities. Solids were removed from the sedimentation basin via a manual valve and peristaltic pump arrangement. The skid included five chemical feed systems with storage tanks and peristaltic pumps that maximize the turndown ratio.

The concentrate from the primary RO was fed to the flocculation/sedimentation pilot. Lime and soda ash were dosed to the rapid mix chamber of the pilot with the goal to precipitate ions including calcium, magnesium, strontium and barium. A portion of the solids was re-circulated to the head of the flocculation/sedimentation pilot to assist in the floc formation. The remaining portion of the solids were wasted continuously to the sewer drain in the sump, via a solids holding tank (Figure 6.1). Acid was added to the solids in the holding tank to allow pH adjustment before disposal to the sewer. NF permeate (from the full-scale NF system at the WTP) was blended with the solids stream to flush any solids and provide dilution of the stream.

Freshly-prepared lime slurry was obtained onsite and transferred by plant staff to a 300-gallon lime storage tank. Lime was continuously recirculated to maintain a uniform concentration during dosing. The lime pump feed rate ranged from 0.15 gpm to 1.30 gpm. The lime concentration varied between batches but was typically about 25,000 mg/L as $CaCO_3$. The lime pump feed rate was adjusted to meet a target pH of 9.9 in the softener.

Soda ash was prepared onsite by mixing NF permeate and dry soda ash in a 300-gallon storage tank to provide a 15-percent slurry. Dry soda ash was purchased in 50 lb bags and stored next to the pilot, on a pallet and covered by plastic sheeting. The soda ash solution was continuously recirculated to maintain a uniform concentration during dosing.

Media Filtration

Filtration was achieved following the chemical precipitation/softening using a dual-media filter pilot unit with a nominal flow of 6 gpm and a loading rate of 8 gpm/sf. The top layer contained 18 inches of 0.95-1.05 mm anthracite. The bottom layer contained 24 inches of 0.45-0.55 mm sand. The uniformity coefficient of both media was less than 1.6. The dual media filter was backwashed at the beginning of each test day to minimize biological growth and remove trapped solids. A backwash tank in series after the filter provided the filtered product for backwash water. The spent backwash water was blended in the solids holding tank for subsequent sewer disposed (Figure 6.1).

Secondary Reverse Osmosis

A modified RO pilot was used to accommodate the 6-gpm nominal flow from the media filtration pilot. The original RO pilot has a nominal flow of 20 gpm and is configured in two stages as a 2:2:1:1 array of 4-inch diameter, three and four element vessels. This unit is designed to replicate a full-scale system and can achieve up to 85 percent recovery without the use of concentrate recycle, and higher recoveries with concentrate recycle. The pilot was modified for this study to accommodate the lower flow and higher TDS by retrofitting a new feed pump and valving the vessels to provide a single stage (i.e. one vessel with up to 6 or 7 elements) that can provide between 50 to 60 percent recovery of the high TDS chemically treated concentrate. The secondary RO pilot was installed with low pressure, high-rejection RO membranes obtained from Hydranautics, i.e. ESPA2 membranes rated at 99.6 percent rejection. The pilot includes provision for both antiscalant and acid addition.

The RO pilot was operated with antiscalant and acid addition. Acid addition was required to lower the pH after the chemical precipitation/softening step that increased the operating pH to about 10 to 11. The final concentrate and permeate from the secondary RO pilot unit was blended and discharged to the solids holding tank (Figure 6.1) where all the waste streams from the pilot treatment train was neutralized before disposal to the sewer.

Due to the duration of the pilot (approximately 2.5 months) and the fact that only 6 (or 7) elements were used in the testing, a chemical cleaning of the membrane elements was not planned. Rather, if extensive fouling or scaling of the membranes was to be possibly experienced during the test, then a membrane replacement would be performed.

6.4.3 Pilot Operation

Table 6.1 outlines the test matrix for the pilot study that was based in part on results from includes the preliminary jar testing that was conducted at the WTP as part of this study to screen for the promising pHs (and hence chemical doses) for the chemical precipitation/ softening step. The need for adjustments to the testing matrix was evaluated continuously based on observed performance for the entire duration of the pilot test.

Table 6.1 Testing Matrix

Test No.	Duration	Chemical Precipitation/Softening			Filter Overflow Rate(4) (gpm/ft^2)	Secondary RO		Description
		Target pH(1)	Lime(2)	Soda Ash(3)		Recovery (%)	Flux (gfd)	
1.	1 week	~ 10	Low Dose	Low Dose	8	N/A (see note 5)		Confirm jar testing chemical doses at pilot scale.
2.	1 week	> 10	High Dose	High Dose	8	N/A (see note 5)		Test alkalinity adjustment.
3.	2 weeks	(See note 6)	Yes	(See note 6)	8	N/A (see note 5)		Test extended operation at optimized dose/alkalinity.
4.	4 weeks	(See note 6)	Yes	(See note 6)	(See note 6)	~ 50	8.5	Test RO operation.

Notes:

Test duration indicated was approximately estimated and was adjusted as needed to reconcile with equipment and pilot phase budget.

1. Target pH range was based on bench-scale jar testing that was used for initial screening of pH/chemical doses.
2. Lime dose was adjusted to meet target pH.
3. Soda-ash dose was adjusted to meet alkalinity requirements per observed hardness level.
4. Overflow rate was to be adjusted if initial testing demonstrated inadequate filtration performance.
5. During the optimization tests for the chemical precipitation process (i.e. Test #1 through #3), silt density index (SDI) was monitored to observe potential for secondary RO fouling. Secondary RO operation was performed in Test #4.
6. Test condition/value was selected based on optimal results observed from the preceding tests.

6.4.4 Schedule

The pilot study was scheduled for a total duration of approximately 4 months. The pilot equipment procurement and test protocol was developed in the first month, followed by approximately 2.5 months of pilot operation. Table 6.2 summarizes the pilot test schedule.

Table 6.2 Schedule for Pilot Test

Activity	Month			
	1	2	3	4
Procure/Install/Commission Pilot Equipment and Develop Test Plan	✓			
Operate Pilot Plant		✓	✓	✓
Prepare Draft Project Report				✓

6.4.5 Sampling and Analysis

This section describes the preliminary sampling and analysis procedure proposed for the pilot plant. Various water quality parameters were sampled and analyzed, as detailed in Tables 6.3 and 6.4, during the routine pilot operation over the testing period.

Both onsite and external lab analysis were performed for the sampling events. These analysis and sampling frequencies are discussed in the following subsections.

Onsite and Field Analysis

Several field and onsite tests were performed by Carollo, with assistance as available from the WTP staff, to provide immediate results and to accommodate water quality parameters that require field-testing. The onsite and field sampling plan and frequencies are summarized in Table 6.3.

External Lab Analysis

An external laboratory was also used to analyze the samples collected. Table 6.4 presents a summary of the laboratory analyses planned for the various sample streams.

Table 6.3 Routine Onsite and Field Sampling Plan and Frequency							
Analysis	Primary RO Concentrate(1)	Chemical Precipitation Effluent	Chemical Precipitation Solids	Media Filtration Product	Secondary RO Feed (after acid/ anti-scalant)	Secondary RO Permeate	Secondary RO Concentrate
Flow rate	3W	3W	3W	3W	3W	3W	3W
Conductivity	W(3)	W(3)	-	W(3)	3W(3)	W(3)	W(3)
Temperature	W	W	-	-	3W(2)	W	W
pH	3W	3W	-	-	3W(2)	3W(2)	W(2)
SDI	W(2)	W(2)	-	3W(2)	3W(2)	-	-
Turbidity	W	W	W	W	W	W	-
Alkalinity	3W(2)	3W(2)	-	W	W	W	-
Hardness - Calcium	3W(2)	3W(2)	-	-	W	W	-
Hardness - Total	3W(2)	3W(2)	-	-	W	W	-
Chloride	M	M	-	-	2M	2M	-
UV-254	M	M	-	-	2M	2M	-

Notes:

D = Daily; W = Weekly; M = Monthly (when proceeded by a number, it designates increased frequency during the pertinent time interval (2M = 2 times per month).

Other samples to be included in routine onsite sampling on as-needed basis:

- pH of waste discharge from solids holding tank.
- Turbidity of filter backwash water.

1. Where available, readings for the primary RO concentrate were taken from the full-scale system instruments and/or routine WTP reporting.
2. Frequency pertains to the first 1 to 2 weeks of operation, during which more frequent samples were required to monitor the water quality and confirm achievement of steady state conditions. Frequency was in some cases reduced after the first 1 to 2 weeks of operation.
3. This field sample was in addition to the continuous conductivity data gathered by the online conductivity meter located on the RO pilot skid and the daily manual conductivity reading that was recorded based on this online conductivity meter.

Table 6.4 Routine Laboratory Sampling Plan and Frequency							
Analysis	Primary RO Concentrate[1]	Chemical Precipitation Effluent	Chemical Precipitation Solids	Media Filtration Product	Secondary RO Feed (after acid/ anti-scalant)	Secondary RO Permeate	Secondary RO Concentrate
TDS[3]	W	W	-	W[2]	W	W	W[2]
TSS	M	M	M	M	M	M	-
Silica - Total	2M	2M	-	-	2M		-
Silica - Reactive	2M	2M	-	-	2M	-	-
Sulfate	W	W	-	-	W	W	-
Calcium	W	W	-	-	W	2M	-
Magnesium	W	W	-	-	W	2M	-
Barium	2M	2M	-	-	2M	M	-
Strontium	2M	2M	-	-	2M	M	-
Gross Alpha	2M	2M	-	-	2M	M	-
Nitrate-N	M	M	-	-	M	M	-
TOC	M	M	-	-	M	M	M
Iron - Total	M	M	-	-	2M	-	-
Manganese	M	M	-	-	2M	-	-
Total coliform	-	-	-	-	M	M	M
HPC	-	-	-	-	M	M	M
Hydrogen sulfide	M	-	-	-	M	M	-

Notes:

W = Weekly; M = Monthly; Q= quarterly (when proceeded by a number, it designates increased frequency during the pertinent time interval (2M = 2 times per month).

1. Where available, readings for the primary RO concentrate were taken from the full-scale system instruments and/or routine WTP reporting.
2. Frequency pertains to the first 1 to 2 weeks of operation, during which more frequent samples were required to monitor the water quality and confirm achievement of steady state conditions. Frequency was in some cases reduced after the first 1 to 2 weeks of operation.
3. TDS laboratory sample was in addition to the conductivity measurement performed in the field.

Data Collection

The RO pilot unit was equipped with automatic data collection for several parameters including flow, conductivity, pressure, etc. These data were downloaded from the data logger at least once per week onto a storage device (e.g. CD or flash drive) and a backup made on a computer for data analysis.

In addition to the automatic data collection and storage for the several parameters, the following readings were collected and recorded into logs from three to five times per week:

1. Flows from all the three pilots
2. Pressures form the pumping points at the three pilots
3. Conductivities for the RO pilot
4. Levels of chemicals used in the three pilots
5. Any equipment alarms

6.4.6 <u>Roles and Responsibilities</u>

A memorandum of understanding (MOU) was developed to define the responsibilities of Carollo Engineers and the City for this pilot test. A matrix presenting specific roles, responsibilities, and key assignments of all the parties involved in the pilot testing is summarized in Table 6.5.

Table 6.5 Overall Roles and Responsibilities Matrix

Task	Primary Responsibility	Secondary Responsibility	Review Responsibility
Overall Test Design	Carollo	-	SFWMD, City
Pilot Plant Layout	Carollo	Harn RO	City, SFWMD
Pilot Plant Installation	Harn RO	Carollo	City
Training of Operators	Carollo	Harn RO	-
Pilot Start-up	Carollo	Harn RO	-
Pilot Operation	Carollo	Harn RO	-
Field Sampling	Carollo	-	-
Data Collection and Laboratory Analysis	Carollo	-	-
Data Compilation, Analysis, and Interpretation	Carollo	-	-
Decommissioning	Harn RO	Carollo	-
Pilot Study Report	Carollo	-	SFWMD, City

6.5 Results and Discussion

Results from the pilot testing are presented in the following section in terms of both the water quality and hydraulic performance for the pilot processes.

6.5.1 Water Quality Results

Softening/Precipitation

Jar Testing

As discussed in Section 6.4.1, jar testing was initially performed to evaluate the effect of a range of pH and lime/soda ash doses on the removals of calcium, magnesium, and other ions of concern (Figure 6.3). Moderate lime addition (500 mg/L) with minimal soda ash (150 mg/L) resulted in limited (25 percent) calcium removal, but this reduction was found to be sufficient to allow operation of the secondary RO at 50 percent recovery.

Higher removals of calcium and other ions was observed at higher doses of lime and soda ash, as illustrated in Figure 6.4. However, the higher chemical doses required would translate into a more expensive softening process, greater sludge production, and no significant benefit in the secondary RO operation except a small reduction in feed pressure due to a reduced feed TDS.

Removals of both strontium and barium correlated well with the removal of calcium. Figure 6.5 includes the data for strontium removal versus calcium removal. Silica removal followed the same general trend as magnesium removal (Figure 6.6).

Pilot Testing

Table 6.6 presents the water quality results for the softening process during the pilot testing. Results from both the external laboratory analysis and the field analysis are included; the field results are indicated in bold text.

Removal of calcium and magnesium were about 90 percent and 45 percent, respectively. Over 80 percent removals of silica, strontium, barium, and gross alpha were also observed.

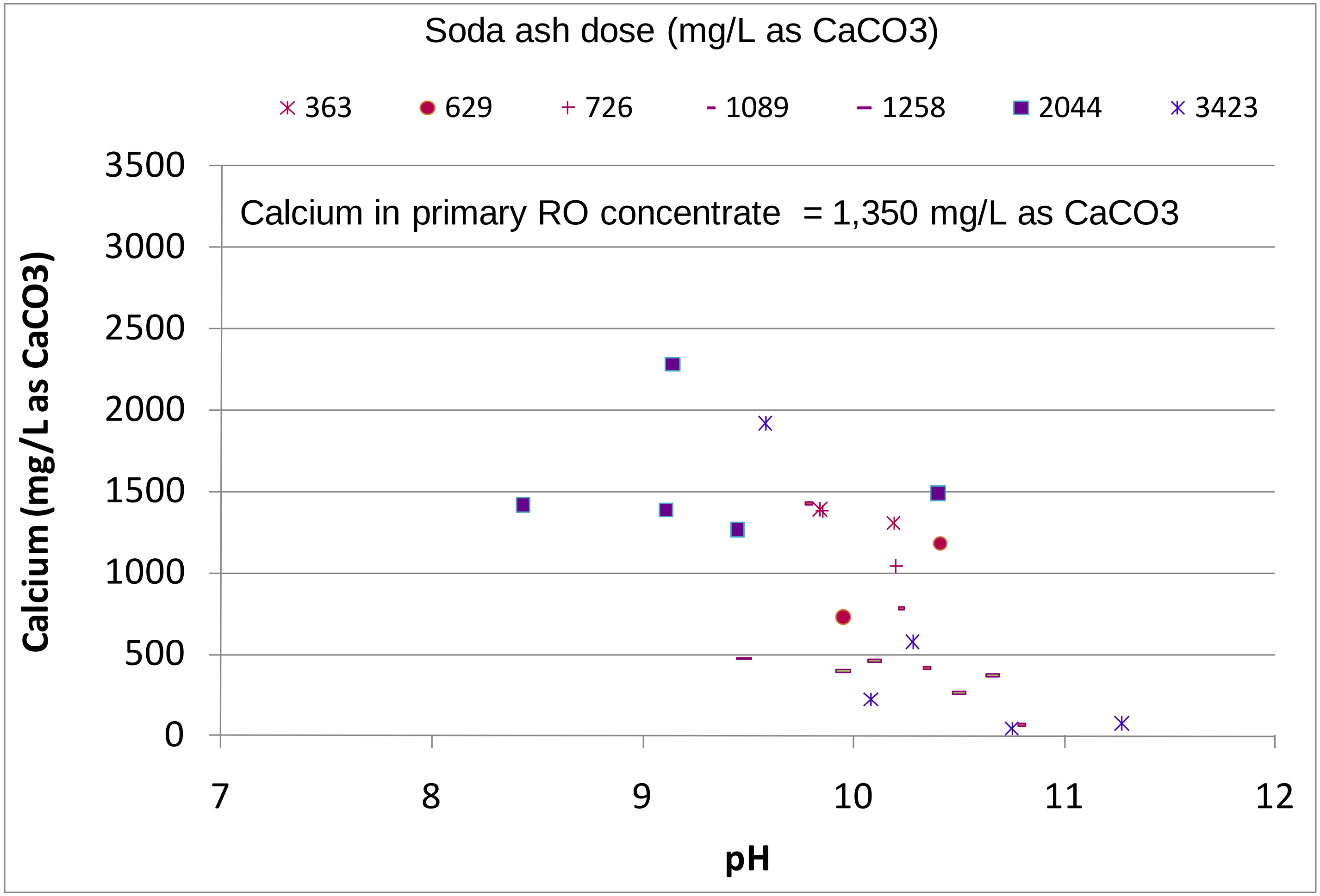
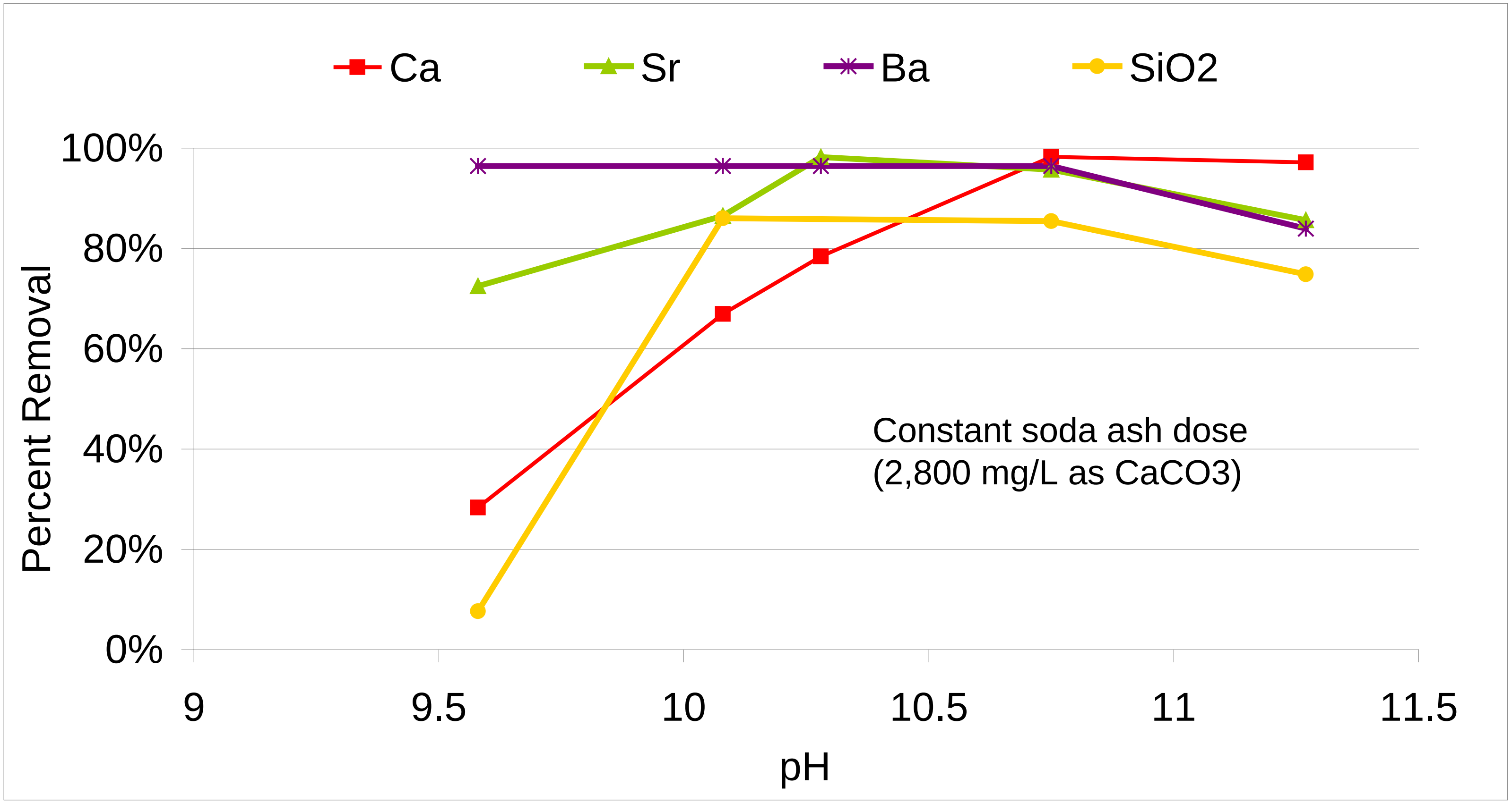


FIGURE 6.3

Calcium Removal via Softening for a Range of pH and Soda-Ash Doses.

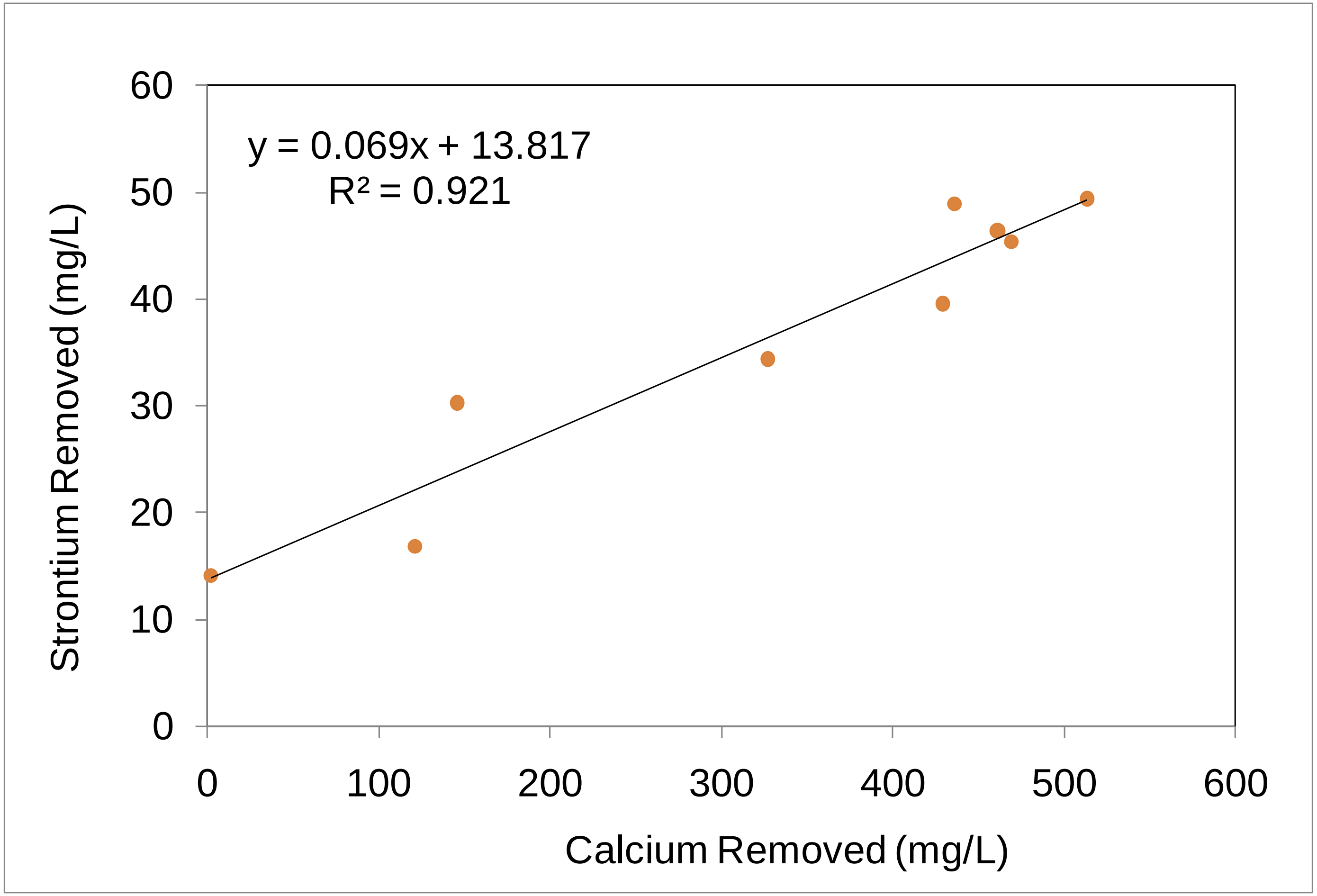


Ion Removal via Softening at High Lime and Soda- Ash Doses.

FIGURE 6.4

FIGURE 6.5

Strontium Removal Correlated with Calcium Removal.



Silica Removal versus Magnesium Removal.

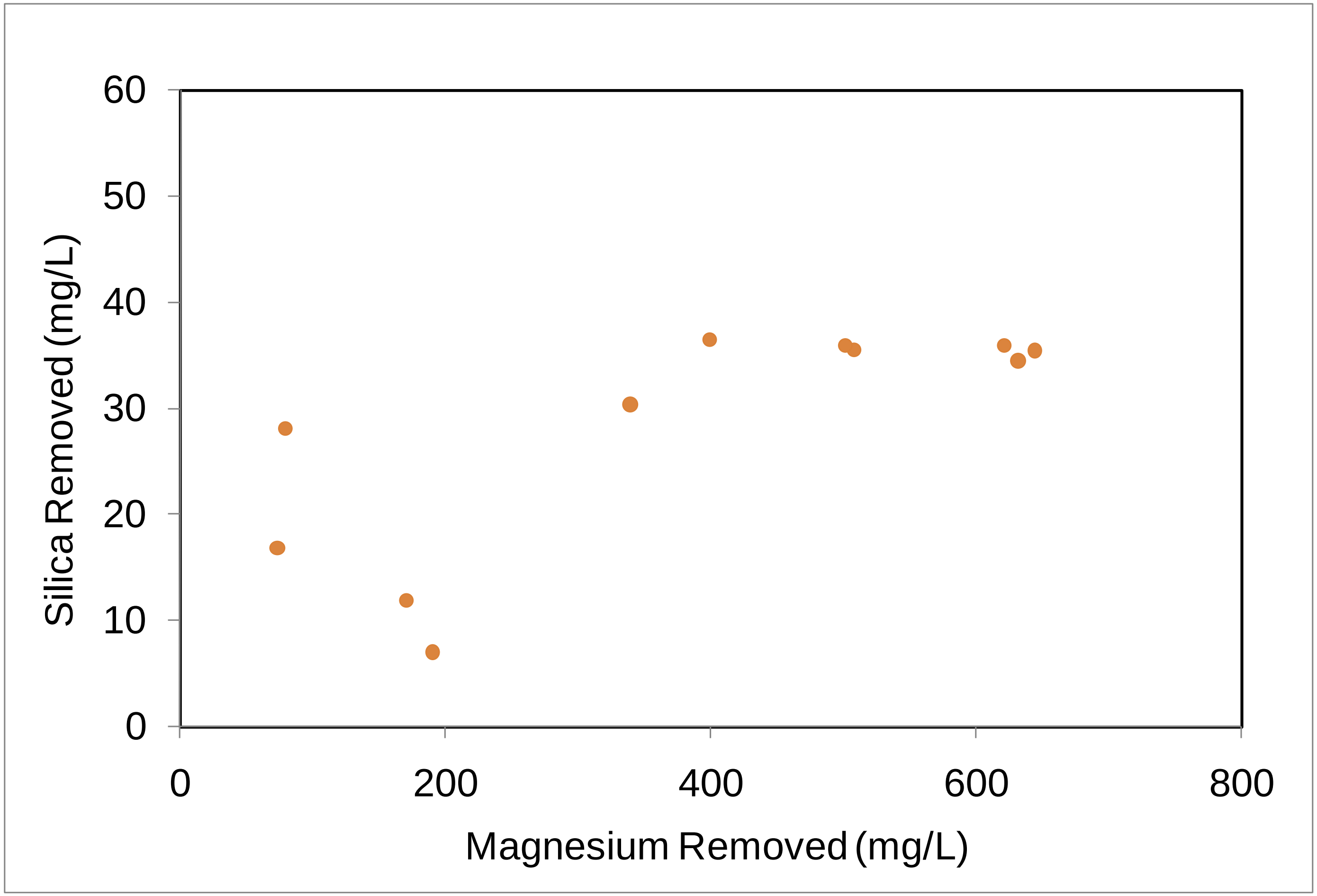


FIGURE 6.6

Table 6.6 Summary of Softening Water Quality

		Influent (Primary RO Concentrate)				Effluent				Percent Removal
Parameter	**Units**	**Min**	**Avg.**	**Max**	**N**	**Min**	**Avg.**	**Max**	**N**	**%**
pH	standard units	7.73	7.74	7.74	2	-	-	-	-	-
Calcium	mg/L as $CaCO_3$	1,183	1,310	1,464	3	89	112	134	2	91.4
Magnesium	mg/L as $CaCO_3$	1,656	1,942	2,108	3	992	1,078	1,165	2	44.5
Barium	µg/L	46	54.6	62	3	<2U	-	3.6	2	-
Strontium	mg/L	45.2	50.8	61.4	3	4.99	5.5	6.01	2	89.2
Silica	mg/L as SiO_2	38.4	47.1	51.9	3	3.73	8.48	13.22	2	82.0
Bicarbonate	mg/L as $CaCO_3$	486	486	486	1	224	253	282	2	47.9
Gross Alpha	pCi/L	11.0 +/- 2.9	11.2	11.3 +/- 2.9	2	1.2 +/- 1.1	1.6	2.0 +/- 1.4	2	85.7
Sulfate	mg/L	1,890	2,015	2,100	4	1,900	1,925	1,950	2	4.5

Note:
Data based on the external laboratory analysis.

Filtration

<u>Silt Density Index</u>

The silt density index (SDI) of the filtered water was measured and found to be consistently less than 0.5 (Figure 6.7). The SDI test kit stopped working properly during the latter portion of the pilot test, when a rubber gasket seal in the filter holder cracked. However, other water quality parameters and RO feed pressures were consistently monitored and indicated stable water quality during the entire duration of the test.

<u>Suspended solids</u>

Over 70 percent removal of total suspended solids was observed across the media filter (Table 6.7). As expected, there was essentially no removal of TDS and UV-254.

Due to scale limitations of the pilot media filter equipment, the solids blanket in the softener occasionally overflowed, causing an increased load of solids on the filter. However, most of these solids were removed by backwashing. Occasional solids blanket overflows caused an associated accumulation of solids inside the turbidimeters, causing subsequent turbidity readings to be artificially high. Manually flushing the turbidimeters with clean water removed the accumulated solids, reducing turbidity readings to levels representative of the actual turbidity of the filtered water. However, occasional upsets in the stability of the solids blanket in the sedimentation basin were enough to cause turbidity values to frequently exceed the 2.0 NTU instrument limit.

FIGURE 6.7

Silt Density Index of the Filtrate.

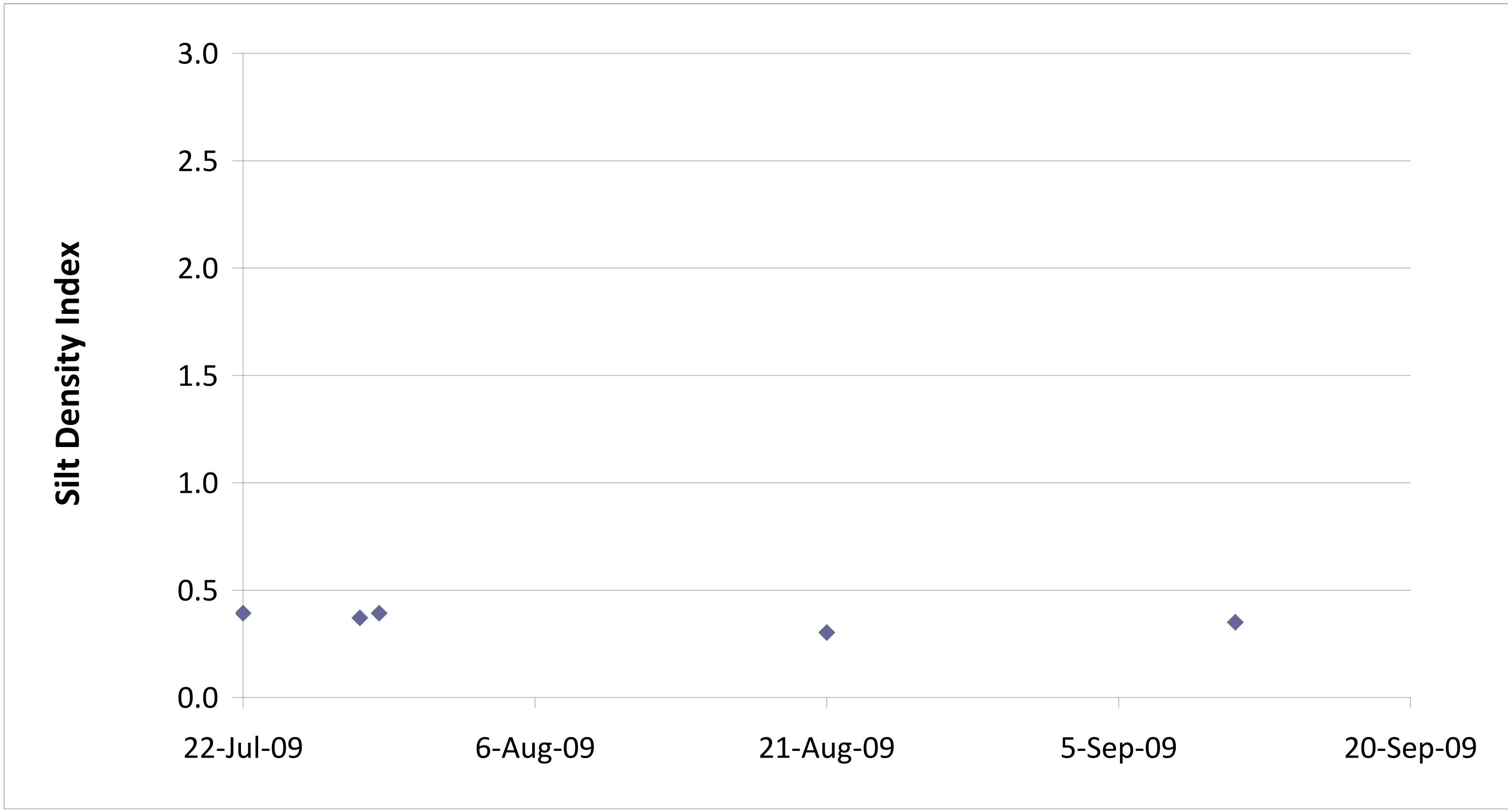


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Table 6.7 Summary of Dual-Media Filter Water Quality

		Feed				Filtrate				Percent Rejection
Parameter	**Units**	**Min**	**Avg**	**Max**	**N**	**Min**	**Avg**	**Max**	**N**	**%**
pH*	standard units	-	-	-	-	9.44	9.89	10.11	21	-
TSS	mg/L	103	106	108	2	24	30	36	2	71.7
Silica	mg/L as SiO_2	3.73	8.48	13.22	2	1.93	2.38	2.83	2	71.9
TDS	mg/L	10,600	10,900	11,200	2	10,600	10,600	10,600	2	2.8
UV-254	cm^{-1}	0.068	0.068	0.068	1	0.065	0.065	0.065	1	4.4

Notes:
* pH data are field measurements. All other data are based on external laboratory analysis.

Secondary Reverse Osmosis

Table 6.8 summarizes the water quality across the secondary RO process. TOC was reduced by about 87 percent. Total coliform and E.*Coli* were both absent in the RO feed and RO permeate.

Excellent removal of ionic species was observed across the secondary RO. Divalent ions (e.g calcium, magnesium, sulfate) were removed by about 99 percent, while monovalent ions (e.g. potassium, sodium) were removed by about 92 percent. Overall TDS removal was also observed to be about 92 percent.

For the RO membranes employed in the pilot system, the TDS of the secondary RO permeate ranged from about 790 to 870 mg/L, which by itself is higher than the secondary TDS limit of 500 mg/L. However, this stream is blended with the primary RO permeate stream in a full-scale application, and the TDS of the blended product water stream is thus of main consideration. In the case of the North Miami Beach WTP, the primary RO system has a design capacity of 6 mgd and the TDS in the primary RO permeate averages about 140 mg/L. Assuming a 55 percent recovery for the secondary RO (as was done in Section 5), the secondary RO system will provide an additional product flow of 1.1 mgd. Even if the maximum observed TDS of about 870 mg/L was assumed for the secondary RO permeate, the blended permeate stream from the primary and secondary RO systems will provide a total flow of 7.1 mgd with a net TDS of only about 250 mg/L. This blended TDS concentration of the final product water is well below the 500 mg/L TDS limit. It is further noted that membranes with even higher rejection can be selected for the secondary RO system to obtain lower TDS in the secondary RO permeate.

Salinity Rejection

Figure 6.8 presents the salinity rejection data inferred from the on-line conductivity measurements from the RO skid. The RO membranes demonstrated about 90 percent salinity rejection. Additionally, the salt rejection did not decrease as the pilot progressed indicating that fouling or scaling was not a concern. Some lower rejection data were initially observed that were attributed to startup conditions. Overall, the pilot testing demonstrated the conceptual feasibility of the treatment scheme in terms of TDS reduction.

6.5.2 Hydraulic Performance of the Secondary RO

The secondary RO process demonstrated stable hydraulic performance over the 1-month operation of the RO at a recovery rate of 50 percent. Figure 6.9 shows the normalized permeate flow (NPF) and Figure 6.10 shows the normalized permeate flux for the system. The NPF was stable during the pilot and no significant decline (due to fouling or scaling) was observed to trigger a chemical cleaning requirement; typically dictated by a 10 to 15 percent decline in NPF. Thus, the RO process did not require any chemical cleaning in the 1-month of operation.

Figure 6.10 presents the specific flux for the RO system. The specific flux was stable and approximated 0.15 gfd/psi during the pilot test.

Figure 6.11 shows the net driving pressure (NDP) during the course of the pilot. The NDP averaged about 6 psi.

6.6 Summary

The pilot test demonstrated stable performance of the softening, filtration and RO processes:

- Relatively low doses of lime and soda-ash were found to provide adequate removal of calcium to allow operation of the secondary RO at the target 50 percent recovery. Higher chemical doses resulted in much higher removal of calcium (and other ions such as magnesium, barium, strontium, and silica); however, such higher removals were not required for the concentrate tested to allow desired secondary RO operational goals.
- The secondary RO process demonstrated excellent removal of dissolved solids, organics, hardness, and pathogens, with removals for all these parameters ranging from about 90 to 99 percent.
- The hydraulic operation of the secondary RO process was stable throughout the pilot test.
- The RO process did not require any chemical cleaning in the 1-month of operation; it did not demonstrate significant decline in flows (due to fouling or scaling) to trigger a chemical cleaning requirement.

Table 6.8 Summary of Secondary Reverse Osmosis Water Quality

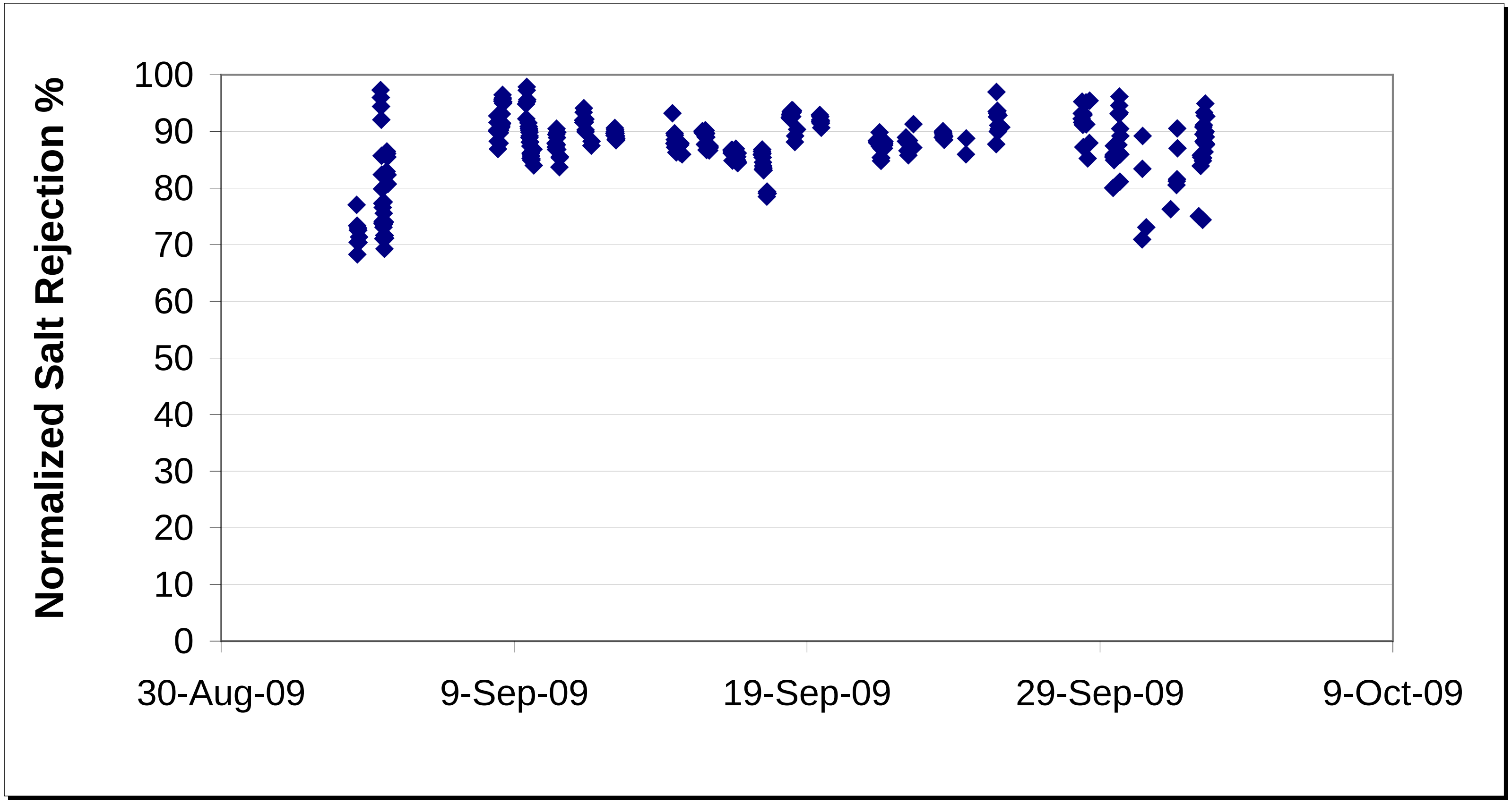
		Feed				Permeate				Rejection
Parameter	**Units**	**Min**	**Avg**	**Max**	**N**	**Min**	**Avg**	**Max**	**N**	**%**
pH*	standard units	-	-	-	0	4.00	5.12	5.74	15	-
TDS	mg/L	10,600	10,850	11,100	2	792	830	869	2	92.4
Calcium	mg/L as $CaCO_3$	89	112	134	2	0.18	0.31	0.44	2	99.7
Magnesium	mg/L as $CaCO_3$	1,062	1,070	1,078	2	1.7	3.6	5.6	2	99.7
Potassium	mg/L	150	150	150	1	13.5	13.5	13.5	1	91.0
Silica	mg/L as SiO_2	1.93	2.37	2.83	2	<0.11	<0.11	0.11	2	>95.4
Sodium	mg/L	3590	3590	3590	1	291	291	291	1	91.9
Strontium	mg/L	1.61	3.08	4.56	2	0.00693	0.0073	0.00760	2	99.8
Sulfate	mg/L	1930	2005	2080	2	2.12	5.14	8.16	2	99.7
Bicarbonate*	mg/L as $CaCO_3$	36	167	460	29	0	2.9	18	15	-
TOC	mg/L as C	4.47	4.52	4.58	2	0.395	0.570	0.746	2	87.4
UV-254	cm^{-1}	0.066	0.066	0.066	1	<0.0017	<0.0017	<0.0017	1	>97.4
UV Trans.	%	86	86	86	1	>99.6	>99.6	>99.6	1	-
Gross Alpha	pCi/L	1.5 +/- 1.4	2.4	3.3 +/- 1.7	2	<2.1 +/- 1.4	<2.6	3.0 +/- 1.7	2	-
HPC (35^{o}C)	MPN/ml	30	222	414	2	51	88	124	2	-
TSS	mg/L	<3.5	<5.08	6.67	2	<3.5	<3.5	<3.5	2	-

Notes:

* pH and bicarbonate data are field measurements. All other data are based on external laboratory analysis.

Salinity Rejection across Secondary RO Process.

FIGURE 6.8



Normalized Permeate Flow for the Secondary RO.

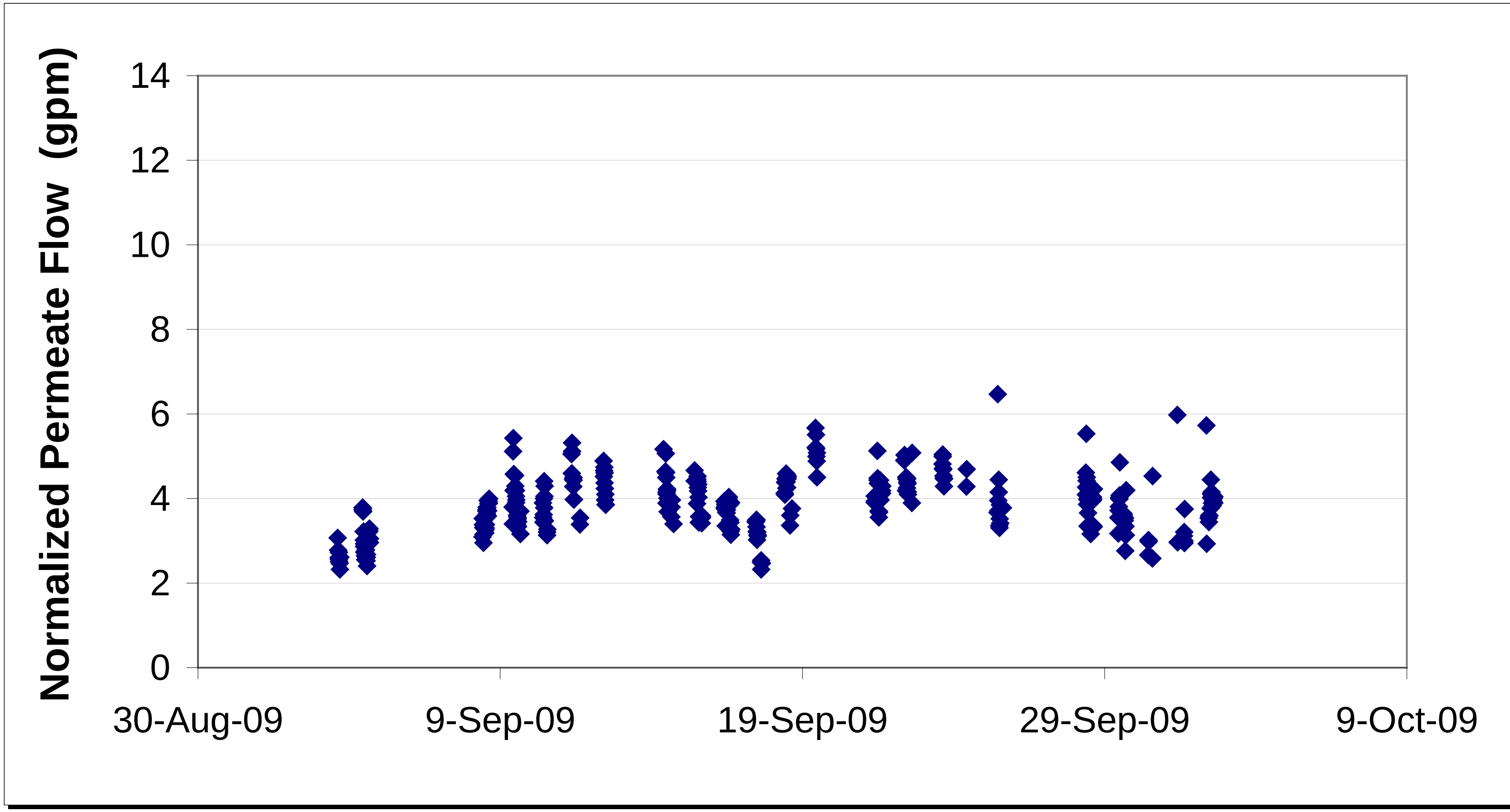


FIGURE 6.9

Normalized Specific Flux for the Secondary RO.

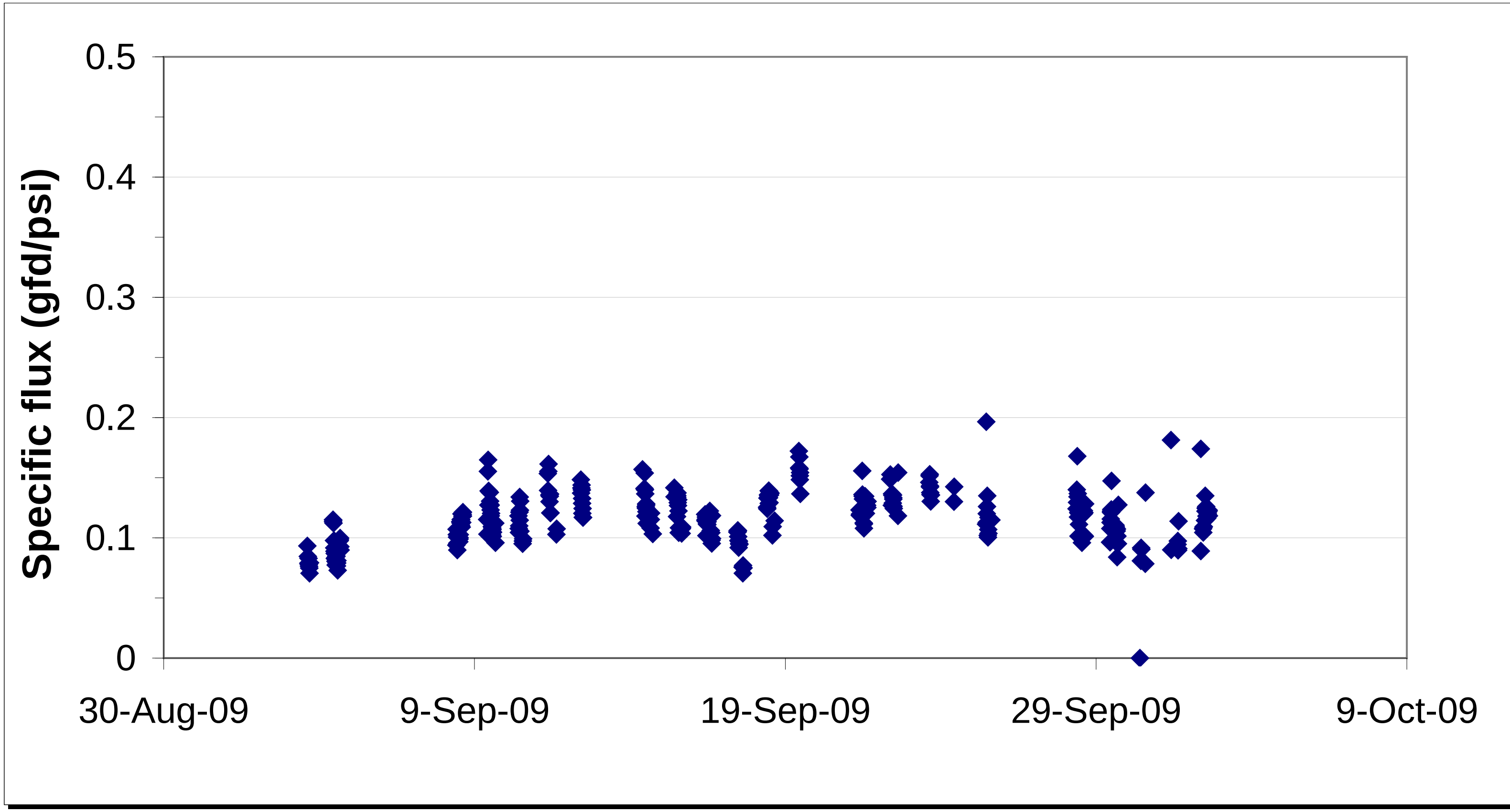
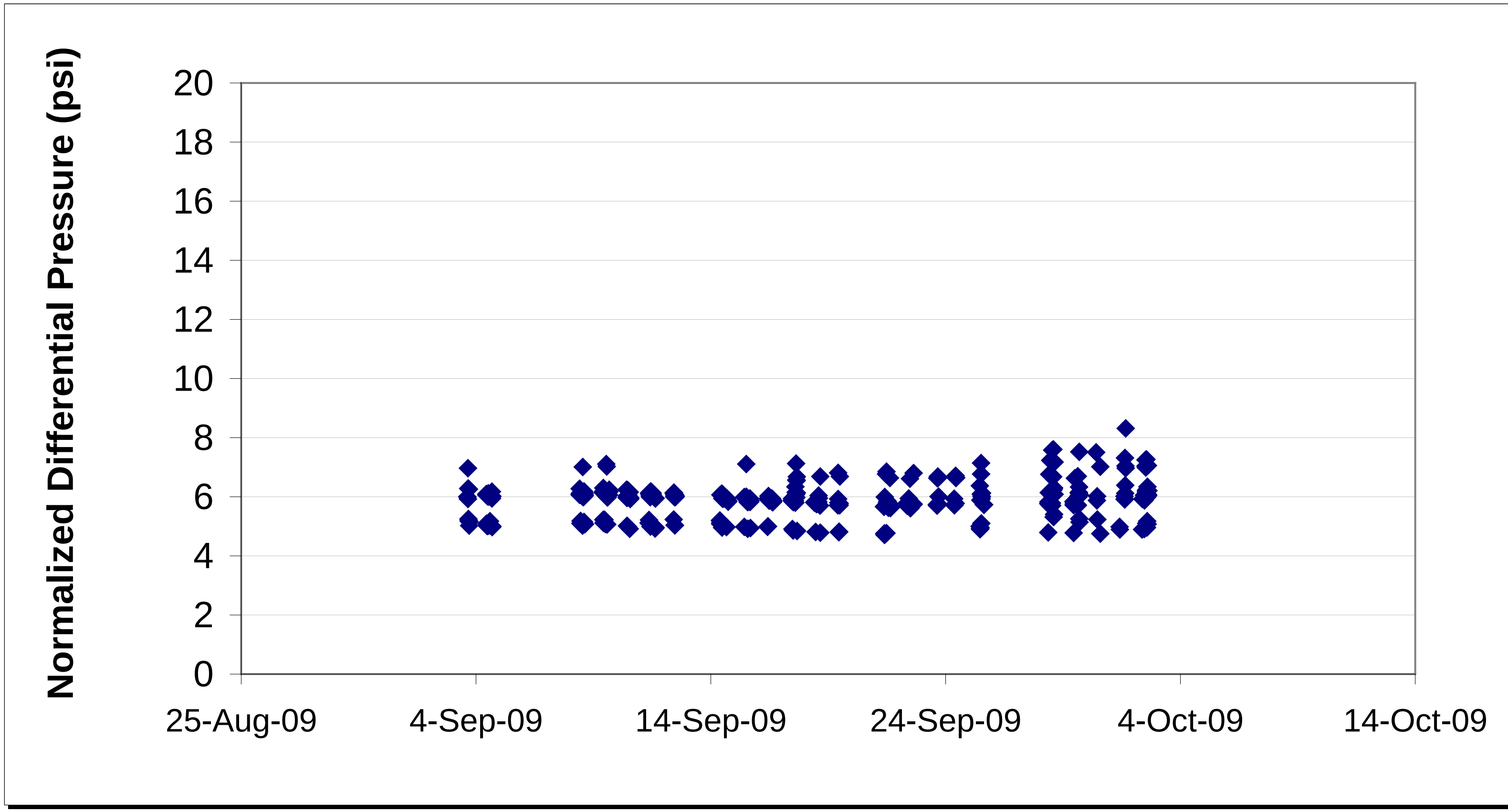


FIGURE 6.10

FIGURE 6.11

Normalized Differential Pressure for the Secondary RO.



7.0 CONCLUSIONS AND RECOMMENDATIONS

The SFWMD selected Carollo Engineers to perform a Water Desalination Concentrate Management and Piloting Study. Phase 1 of the study included various desktop evaluations with Phase 2 being a 3-month pilot test to evaluate the dual RO system with intermediate chemical precipitation as a concentrate minimization technology. The key conclusions and recommendations from the study are summarized in the following paragraphs.

7.1 Desktop Evaluations

1. The “production efficiency” or recovery at the brackish water RO plants within the District’s service area is approximately between 75 to 85 percent. There is a potential to recover more water and increase production efficiency to 90 to near 100 percent via further concentrate treatment. In certain cases, an optimization of the existing RO process via enhancement of the chemical pretreatment (e.g. acid addition/ enhancement of acid dose, and/or enhancement of scale inhibitor type/dose) might aid to increase the recovery. However, this improvement would be limited to a maximum recovery of about 85 percent, since the existing “2-stage” RO systems can hydraulically recover about 85 percent in the best scenario. Another treatment step, or at the minimum a “3rd stage” of RO, would be required to recover additional water.

2. The majority of brackish water RO plants within the District’s service area are limited in process recovery due to the potential to form $CaCO_3$, $BaSO_4$, and $SrSO_4$ scales. The remaining plants are characterized with the potential to additionally form $CaSO_4$ scale. In this study, 75 percent of the brackish water RO plants evaluated (i.e. 9 out of the 12) fell into the former category and the remaining 25 percent brackish water RO plants fell into the latter category. This suggests a good likelihood of the application of a common solution to concentrate minimization/treatment at multiple plants.

3. Three types of potential solutions were evaluated for concentrate minimization. The first approach uses intermediate chemical precipitation to make the stream amenable to another RO treatment step - resulting in a relatively low energy process for concentrate treatment. The second approach avoids the chemical treatment of concentrate and instead uses a thermal process (i.e. brine concentrator) to further concentrate the stream to slurry while recovering additional product water. However, this results in a comparatively high-energy, high cost process. The brine concentrator may be followed by an evaporation pond or a thermal crystallizer to reduce the slurry to solids, resulting in zero liquid discharge; an even more expensive option. Selective salt recovery is a third approach that views desalination concentrate streams as potential mineral resources. The sale of recovered salt products is essential to supporting the added capital expense of salt recovery. A practical market for coproduced salts from water treatment plants has yet to emerge in North America.

4. Due mostly to the very high energy needs and costs associated with the currently available brine concentrator systems, the dual RO process with intermediate chemical precipitation was concluded to be the preferred approach for concentrate minimization for inland desalination plants in Florida. The total treatment cost per gallon of product water generated with this approach was estimated to be about half that for a brine concentrator approach.

5. Concentrate treatment for enhanced recovery will reduce the volume of liquid waste while increasing the concentration of many contaminants in the liquid waste. Depending on the specific source water characteristics and the allowable 'non-hazardous' concentrations implied by the local/federal regulatory guidelines, the practical increase in recovery via concentrate treatment can be limited to a certain level. In each site-specific case, this limitation would simply be to avoid increases in recovery (and hence concentrations of rejected contaminants in the brine) to a level that result in potentially classifying the concentrate as 'hazardous'. Some treatment technologies may generate a solid waste also. Zero liquid discharge technologies such as brine crystallizers would eliminate the liquid waste and produce a solid waste only.

7.2 Pilot Test

The dual RO with intermediate chemical treatment scheme demonstrated to be effective in addressing the goals of the pilot study. Stable water quality and hydraulic performance was observed for all the three unit processes including chemical softening, filtration, and secondary RO. The process was shown to be viable for a representative Florida brackish water. Due to the observed similarity of salts limiting RO recovery in Florida brackish waters evaluated in this study, it may be applicable at many brackish desalting plants in the District.

7.3 Recommendation

This study provided a systematic evaluation of a concentrate minimization approach, and demonstrated its feasibility for a representative brackish water source in South Florida. The desktop evaluations were comprehensive, and the small-scale pilot that was employed demonstrated stable performance over a test duration of about 3 months. The key recommendation from this study is to further optimize the key process and operational parameters for this approach in a subsequent study. This subsequent study should be conducted at a larger pilot/demonstration scale and operated over a longer duration to capture any size-related scale-up effects, and seasonal variability.

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Appendix A

SOURCE WATER QUALITY DATA

Source Water Quality Data

Parameter	Unit	Cape Coral	Clewiston	Deerfield Beach***	Florida Keys (Marathon)	Florida Keys (Stock Island)	Fort Myers	Fort Pierce	Hollywood	Jupiter	Lee County (North)	Lee County (Pinewood)	Manalapan	Marco Island	Martin County (North County)	North Miami Beach	Palm Beach County (Lake Region)	Port St. Lucie (James E. Anderson)	Port St. Lucie (Prineville)
Total dissolved solids (TDS)**	mg/L	1470	2700	3250	32000	38000	3790	800	4650	5710	2220	2400	4400	6170	2420	3332	5200	3100	2600
Specific Conductance	uS/cm		5010		54000	57000	6810	1663	6030	4720	3910	4309	6200	9250	3820	5460	5877		3510
Total Organic Carbon	mg/L		*	1		2.6				2.6	*	1.55	0.63		2.5	1.34	2.3		1.4
Alkalinity	mg/L $CaCO_3$	204	94	180	120	170	152		127	150	114	153	130		158	117	120	150	150
Carbon dioxide	mg/L									6.6		5.83	120		11	107			3.9
Color	color units	5	*		*	5	*		5	*	*	1.95	10		33	7.5	0		*
Dissolved oxygen	mg/L						1.82		1.45				8.7		3.1				
Total Hardness	mg/L $CaCO_3$		790	1204	6145	6145			1020	850	800	770	1166		550	780	872	980	750
Hydrogen sulfide	mg/L		2.9	3						1.2	2.83		25		0.33	3.2	3.6	3.5	
pH	-	7.45	8.68	7.1	7.29	7.07	7.42	7.67	7.7	7.23	7.5	7.5	7.9	7.2	7.35	7.71	7.4		7.61
Silica-Total	mg/L	14	13	24	9.5	9.5			14	16		16	14.4		14.8	11.5	14		18.7
Silica-Dissolved (reactive)	mg/L					2.5					16		14.3					17	11
Silt density index	-			*								0.5		1.8					
Temperature	°C			25			29.6	27.6	23.1	26.86	30.6	26.8	27.6	24	25.2				
Turbidity	NTU	0.11	0.15				1.2		0.1	0.14	*	0.05	2	0.29	20	0.587	8.7		*
Cations																			
Aluminum	mg/L	*				*	*		*	*	*	*	*			*	*		
Ammonium	mg/L		0.42														0.63		
Arsenic	mg/L	*				*	*		*	*	*	*	*		*	*	*		
Barium	mg/L	0.02	0.028	0.02	0.01	0.014	0.036		0.008	0.046	0.044	0.04	0.021		0.03	<0.1	0.032		0.032
Beryllium	mg/L	*			*	*	*		*	*	*		*			*			
Boron	mg/L					3.6													
Calcium	mg/L	63	130	219	400	330	148		180	150	137	117	170		204	120	180	160	120
Cadmium	mg/L	*	*			*	*		*	*	*		*		*	*	*		
Chromium-Total	mg/L	0.046			*	*	*		*	*	*		0.003		*	*	*		
Copper	mg/L	*	*		*	*	*		*	*	*	*	*		*				
Iron-Total	mg/L	0.07	0.25		0.02	0.015	*		0.18	*		0.01	0.12		0.05	0.1	0.83	*	*
Iron-Dissolved	mg/L												0.051						
Lead	mg/L	*	*			*	*		*	*	*	*	*		*	0.005			
Magnesium	mg/L	106	120	160	1250	1300	137		150	204	111	110	180		10	126	110	140	110
Manganese	mg/L	*	*		*	*	0.001		*	*	*		*		*	*	0.014		*
Mercury	mg/L	*	*		*	*	*		*	*	*		*		*	*	*		
Nickel	mg/L	0.032				*	*		*	*	*		*			*			
Potassium	mg/L	20	29	32	385	450			50	49		30	37		26.5	57	21		27
Selenium	mg/L	*				*	*		*	*	*	*	0.01		*	*			
Silver	mg/L	*			0.016	0.012	*		*	*	*		*		*	*			
Sodium	mg/L	434	770	675	11000	11000	976		1400	1675	597	621	1300		467	1134	840	850	670
Strontium	mg/L	19	16	8	13	13			11.9	17	27	17	12		*	10.7	22		14
Thallium	mg/L	*				*	*		*	*			*			*			
Zinc	mg/L	0.02	*		0.22		*		0.006	*	*		0.023		0.03	*	0.21		
Anions																			
Bicarbonate	mg/L	248	115	219	145	207.4	185		159	183	139	187	130		193	143	150	183	183
Bromide	mg/L				65	59				2.8	3.7					4.04			
Carbonate	mg/L									*			0.99			*	0.067		
Chloride	mg/L	820	1300	1498	21000	22000	1920	288	2790	2970	1070	997	2000	2860	1210	1430	1400	1800	1400
Fluoride	mg/L	3.27	*	3.5	0.85	0.84	1.4		1.2	1.4	1.04	1.17	0.86		0.92	1.16	1.1	0.9	1.3
Nitrate	mg/L			*			*		*	*	*	*				*	0.002	*	0.21
Phosphate	mg/L									*						*			*
Sulfate	mg/L	125	570	400	3000	3000	376		795	523	364	621	430		150	458	450	240	230
Radionuclides																			
Gross Alpha Particles	pCi/L	9.8 +/- 2.5			121 +/- 33	77.9 +/- 30	43 +/- 3.9		22 +/- 17		72		22 +/- 12		4 +/- 17	35 +/- 23	12		
Gross Beta Particles	pCi/L				451 +/- 33	339 +/- 30						35				29 +/- 12			
Radium 226	pCi/L				4.0 +/- 0.4	6.9 +/- 0.6	4.0 +/- 0.4		3.3 +/- 0.2		19	8.9	3.9 +/- 0.2		3.7 +/- 2	+/- 0.53	9.7		
Radium 228	pCi/L				*	0.8 +/- 0.5	*		1.0 +/- 0.5		*	0.06	*		0.1 +/- 0.2	+/- 0.45	0.5		
Uranium	pCi/L											0.9				0.321			
Nutrients																			
Ortho-phosphate	mg/L		0.25													*	0.34		*
Total Phosphorus	mg/L				0.95	0.95							*			*			*
Total Ammonia	mg/L					0.45				0.53	0.382				0.6		0.49		
Unionized Ammonia	mg/L				*											0.645			
Nitrate+Nitrite	mg/L	*	*		*	*			*		*	*	0.051		*	*	1.1	*	*
Total Kjeldahl Nitrogen	mg/L									0.66						0.723			

Notes:

Blank cell = No Data available

* Below detection limits

** The reported TDS concentration in this Appendix might slightly differ from the TDS concentration used in Section 2 (Tables 2.2, 2.4, and 2.5). The TDS used in Section 2 is appropriately calculated as part of the process simulations described in Section 2, i.e. from the actual summation of the reported concentrations of the various ions.

*** Deerfield Beach WTP data represents the raw brackish water quality (see Table 3.2 for data on the NF concentrate, and the blended RO feed)

Appendix B

CONCENTRATE WATER QUALITY DATA

Concentrate Water Quality Data

Parameter	Unit	Cape Coral	Clewiston	Deerfield Beach	Florida Keys (Marathon)	Florida Keys (Stock Island)	Fort Myers	Fort Pierce	Hollywood	Jupiter	Lee County (North)	Lee County (Pinewoods)	Manalapan	Marco Island	Martin County (North County)	North Miami Beach	Palm Beach County (Lake Region)	Port St. Lucie (James E. Anderson)	Port St. Lucie (Prineville)
General Parameters																			
Total Dissolved Solids (TDS)	mg/L	6300			52562	52562	8190			11400				33900	4300				12000
Specific Conductance	uS/cm				69000	69000								46800			27160		
Total Organic Carbon	mg/L				*	*				1.91									9.8
Alkalinity	mg/L $CaCO_3$				167	167											443		540
Carbon Dioxide	mg/L																		16
Color	color units														5		15		10
Dissolved Oxygen	mg/L								2.5										
Total Hardness	mg/L $CaCO_3$				8736	8736											4614		3100
Hydrogen sulfide	mg/L								2.08										*
pH	-				7.8	7.8	6.41		6.9	7.06					6.1		7.2		7.48
Silica-Total	mg/L				13.2	13.2				17.1									53.5
Silica-Dissolved (reactive)	mg/L																		33
Silt Density Index	-																		
Temperature	°C								27.5										
Turbidity	NTU																2.19		0.22
Cations																			
Aluminum	mg/L								*										
Ammonium	mg/L																		
Arsenic	mg/L								0.006						*				*
Barium	mg/L				18.6	18.6									0.04				0.13
Beryllium	mg/L								*						*				
Boron	mg/L																		
Calcium	mg/L	250			567	567				370									490
Cadmium	mg/L								*						*				*
Chromium-Total	mg/L				*	*			*						*				*
Cobalt	mg/L								*										
Copper	mg/L				*	*			0.014						*				*
Iron-Total	mg/L				*	*			8.07						0.021				*
Iron-Dissolved	mg/L																		
Lead	mg/L								3E-04						*				*
Magnesium	mg/L	340			1777	1777				430									460
Manganese	mg/L				*	*			0.064	ND					*				*
Mercury	mg/L								*										*
Molybdenum	mg/L																		
Nickel	mg/L								*						*				
Potassium	mg/L	65			548	548				120									110
Selenium	mg/L								*						0.001				
Silver	mg/L								*										
Sodium	mg/L	1200			15665	15665	486			2900					1330				3000
Strontium	mg/L	40			18.6	18.6				34									60
Thallium	mg/L								*						*				
Zinc	mg/L				*	*			0.014						*				*
Anions																			
Bicarbonate	mg/L	366			204	204				426							540		658.8
Bromide	mg/L																		
Carbonate	mg/L																		
Chloride	mg/L	2400			29628	29628	1000			5900				19900	3090				6600
Fluoride	mg/L	8.6			1.2	1.2				3.2					0.982				4.3
Nitrate	mg/L				*	*	0.04								*				*
Phosphate	mg/L														*				
Sulfate	mg/L	1600			4150	4150	1125			1200				2610	912				1200
Radionuclides																			
Gross Alpha Particles	pCi/L				*	*									27.1 +/-8.3				7.4 +/- 1.2
Gross Beta Particles	pCi/L																		7.3 +/- 0.7
Radium 226	pCi/L								5.9						7.2 +/-0.8				1.2 +/- 0.7
Radium 228	pCi/L								*						*				
Uranium	pCi/L																		
Nutrients																			
Ortho-phosphate	mg/L																		*
Total Phosphorus	mg/L				1.4	1.4			0.361										*
Total Ammonia	mg/L				*	*			2.68						0.061		5.65		
Unionized Ammonia	mg/L																		
Nitrate+Nitrite	mg/L								0.034										*
Total Kjeldahl Nitrogen	mg/L													0.48					

Notes:
Blank cell = No Data available
* Below detection limits