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WATER SUPPLY NEEDS AND SOURCES ASSESSMENT
ALTERNATIVE WATER SUPPLY STRATEGIES INVESTIGATION
BRACKISH GROUND WATER TREATMENT TECHNOLOGY ASSESSMENT

by

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EXECUTIVE SUMMARY

St. Johns River Water Management District (SJRWMD) has determined that projected increases in ground water withdrawals between 1990 and 2010 could adversely impact native vegetation, ground water quality, and water resources, including springs. Because of these possible adverse impacts, SJRWMD has begun investigating the technical, environmental, and economic feasibility of alternative water supply strategies, including the development of brackish ground water resources.

This is the second of three technical memorandums (TMs) that address the feasibility of developing brackish ground water resources to help meet future public supply needs. This TM reviews relevant information and technical literature on technologies available to treat brackish ground water and disposal options available to manage the waste concentrate stream associated with brackish water treatment. Based on the results of the review and goals and objectives of the alternative water supply investigations, a methodology is proposed for development of source-based brackish ground water supply cost estimates. These cost estimates and general cost equations developed from the estimates will be documented in TM D.3.b, Brackish Ground Water: Cost Estimates.

Treatment technologies are well established for highly mineralized waters, including brackish ground water. Any brackish or saline water source can be treated to meet drinking water standards. However, the more saline the source, the more extensive the treatment. Membrane treatment, including reverse osmosis, is likely to be the primary technology used to treat brackish ground water within the planning area. Also, the quantity and salinity of the resulting waste concentrate stream increases as a function of the degree of salinity of the source water. Thus, managing the treatment concentrate waste stream is often one of the more difficult issues to be resolved in implementing the brackish ground water supply alternative.

Most of the useful data defining brackish water quality and the geologic structure of the Floridan aquifer system are contained within SJRWMD's geographic information system. Therefore, SJRWMD is identifying and rating potential brackish ground water sources as part of this alternative water supply investigation. The characteristics of the brackish ground water source areas are discussed in TM D.1.a, Brackish Ground Water: Source Identification and Assessment.

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INTRODUCTION

Public water supply within the St. Johns River Water Management District (SJRWMD) is generally provided by high-quality ground water. Several characteristics of SJRWMD's ground water resources make potable ground water the water supply source of choice. First, ground water is inherently reliable—an important attribute for public water supply. Second, treatment requirements and cost are often minimal because of the generally good quality raw ground water. Third, if the resource is developed and managed properly, the quality of the raw ground water remains stable.

To date, high quality, reliable, and inexpensive ground water has been developed as a source of public water supply within SJRWMD. However, it is unlikely that all additional future public water supply needs can be met by increasing the use of ground water resources without incurring unacceptable environmental impacts. Therefore, SJRWMD has initiated an investigation of the feasibility of alternative water supply strategies.

PROJECT BACKGROUND

SJRWMD previously evaluated the potential impact of increased ground water withdrawal through the year 2010 (Vergara 1994). Based on this evaluation, SJRWMD identified areas where water supply problems are now critical or are likely to become critical. An increase in ground water withdrawal could adversely impact area water resources, including impacts on natural systems, ground water quality, and existing legal users.

SJRWMD is investigating the technical, environmental, and economic feasibility of alternative water supply strategies as a means of preventing existing and projected adverse impacts. The SJRWMD-sponsored program includes investigations conducted by several consultants, including CH2M HILL, and by District staff.

Figure 1 illustrates the water supply options being considered for SJRWMD. The primary options include increased supply, demand reduction, and increased system storage to better manage existing supplies. For areas of critical concern, increased supply options could include developing one or more of the following potential water supply sources:

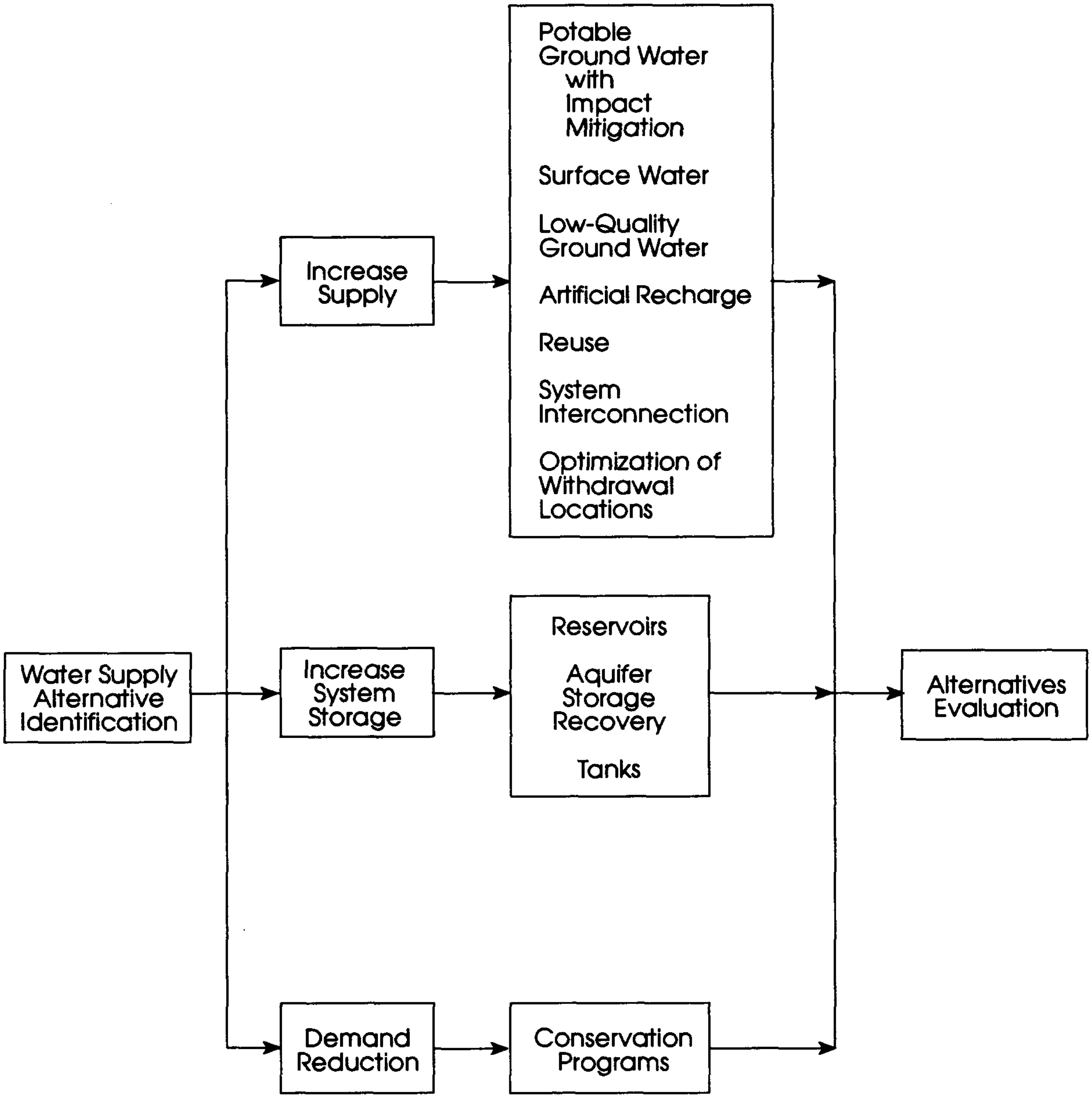

Figure 1. Water Supply Development Options for the SJRWMD

- Potable ground water with mitigation of adverse impacts
- Surface water
- Low quality (brackish) ground water
- Artificial recharge
- Reuse of reclaimed water
- Water supply systems interconnection
- Optimization of withdrawal locations

Increased system storage could include the use of reservoirs, aquifer storage recovery (ASR) facilities, or ground storage tanks. Demand reduction may be achieved by various water conservation initiatives. In many cases, a combination of increased supply, increased system storage, and demand reduction could provide the most environmentally acceptable and cost-effective future water supply systems.

This project is part of CH2M HILL's first phase of the required alternative strategy investigation. Included in the investigation are the following additional water supply sources or water management techniques, collectively referred to as *alternative water supply strategies:*

- Surface water supply development
- ASR
- Development of brackish ground water sources
- Artificial recharge through drainage wells
- Mitigation and avoidance of impacts associated with ground water withdrawal

PURPOSE AND SCOPE

This technical memorandum (TM) is the second in a series addressing the feasibility of developing brackish ground water supplies to augment existing and future public water supplies. Low quality or brackish ground water is defined as ground water that exceeds regulatory standards for potable water with respect to one or more inorganic constituents, such as chloride, sodium, sulfate, and total dissolved solids (TDS).

The purpose of this investigation is to determine the technical and economic feasibility of using brackish ground water to meet part or all of the projected increases in public supply demand. This investigation is a joint effort between SJRWMD and CH2M HILL. During the first phase of the investigation, SJRWMD will identify potential source areas and associated maximum quantities. This TM, which reports on the second part of this investigation, discusses treatment processes applicable to developing brackish ground water supplies and a proposal for developing source-based water supply development cost estimates using selected treatment technologies and source area characteristic data. The third part of this investigation will include application of the cost estimating methodology presented in this TM to the sources identified by SJRWMD. The resulting cost estimates and brackish ground water development cost functions will be presented in TM D.3.b, Brackish Ground Water: Cost Estimates.

The primary goal of this TM is to select appropriate brackish ground water treatment and concentrate disposal technologies for developing planning-level cost estimates.

METHODS

To identify appropriate brackish water treatment and concentrate disposal technologies and a cost estimating methodology, available information was reviewed and important development issues were identified.

A literature review was conducted to locate information that would be helpful in developing criteria for assessing the feasibility of using brackish ground water as an alternative water supply. Information sources considered included reports published by SJRWMD; consultant reports, including in-house CH2M HILL reports; and technical reports prepared by state and federal agencies. The documents acquired and reviewed during this phase of the investigation are listed in the Bibliography and are cited in this TM where appropriate.

Each document was screened for topics of potential interest. Information on treatment technologies was obtained primarily from in-house sources and technical literature, including manuals and journal articles. Information on water utilities was obtained primarily from SJRWMD and the Florida Department of Environmental Protection (FDEP).

TREATMENT PROCESSES

Treatment processes are available for using brackish ground water as a supply source for public drinking water. As defined here, brackish ground water is ground water with inorganic constituent concentrations exceeding safe drinking water standards (DWS). These constituents primarily include chloride, sulfate, sodium, and TDS exceeding 250, 250, 160, and 500 milligrams per liter (mg/L), respectively. The removal processes for these constituents are called desalting.

In some cases, blending brackish ground water may be possible without first desalting the existing water supply that exceeds DWS. However, desalting will be required for most brackish ground water in SJRWMD. Commercially available desalting technologies include the various distillation processes (multi-flash distillation, multiple-effect distillation, and vapor compression) and certain types of membrane processes (reverse osmosis [RO], electrodialysis and, to a lesser extent, nanofiltration). Ion exchange demineralization using anion and cation exchange can desalt water, but costs become prohibitive if the feedwater exceeds about 500 mg/L of TDS. Furthermore, distillation technologies are typically much more costly than membrane desalting processes unless the feedwater salinity approaches sea water concentrations (35,000 mg/L of TDS).

Distillation can sometimes be cost-competitive with membrane technologies for brackish waters if the water treatment facility is co-located with a power generation facility. In this case, the waste heat from the power generation unit can be used as the distillation energy source, resulting in considerable operations cost savings. However, such opportunities are a special case and not a general occurrence.

Figure 2 shows the typical feedwater TDS application range for the various desalting technologies. Membrane technologies have varied application ranges, depending on technical and economic considerations. Typically, application ranges are up to approximately 45,000 mg/L for RO; 3,000 mg/L for electrodialysis; and 800 mg/L for nanofiltration.

Membrane technologies are widely used and generally applicable to a wide range of feedwater quality. Therefore, this investigation

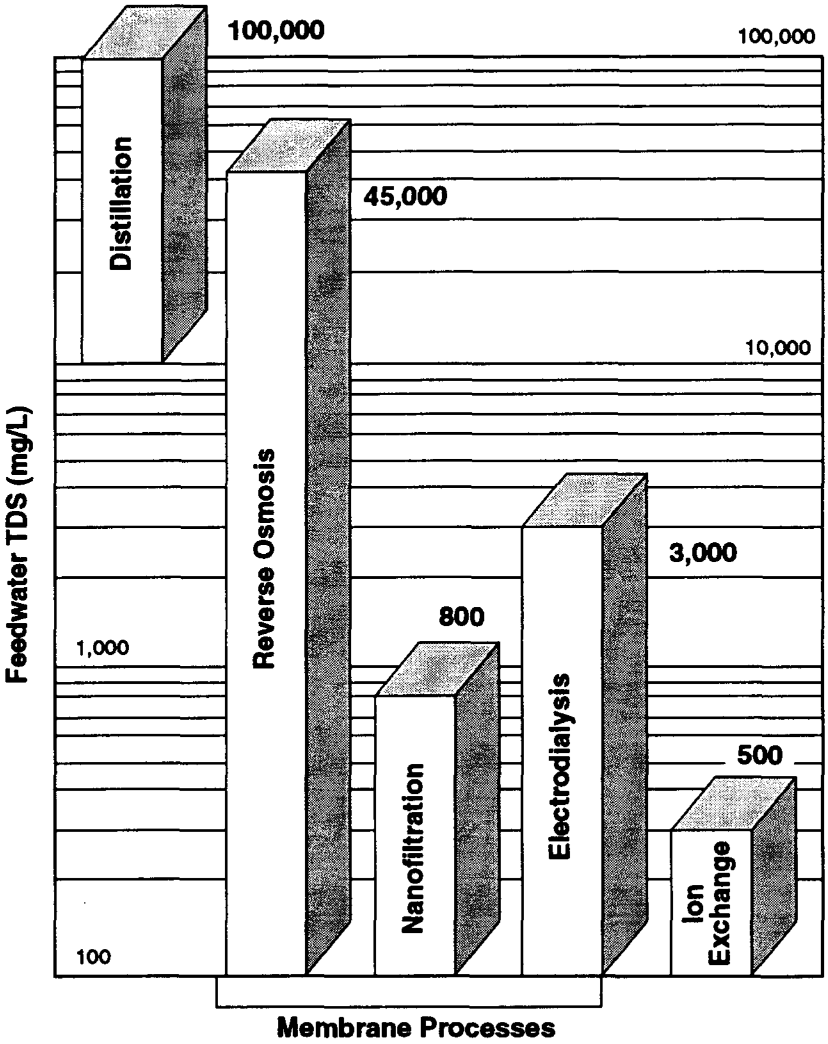

Figure 2. Typical Feedwater Total Dissolved Solids Operating Ranges for Desalting Processes

assumes that membrane technologies, as described in the following subsections, are most generally applicable to brackish ground water treatment technology.

DESCRIPTION OF PROCESSES

Membrane processes can be classified by function according to the type of driving force that causes components of a fluid to separate. Many membrane processes for municipal water treatment use either pressure or electricity as the driving force.

Pressure-Driven Membrane Processes

Pressure-driven membrane processes involving liquid-phase transport include RO, nanofiltration, ultrafiltration, and microfiltration. The processes are distinct as they are based on several factors, including relative membrane pore size, the method by which separation is achieved (perm-selectivity), and the type of components removed. The following removals can be obtained by these processes (Figure 3):

- RO—The smallest components, including dissolved ions (salts) and low molecular weight organics
- Nanofiltration—Some salts (primarily multivalent ions) and medium molecular weight organics
- Ultrafiltration—Large molecular weight organics and colloids
- Microfiltration—Primarily particulates and some colloids

Table 1 presents the typical operating pressures required to achieve separation. Because of its ability to remove solids as small as salts, RO requires the greatest operating pressure. Conversely, microfiltration requires the least. With the wide range of constituents that can be removed, the pressure-driven processes have many applications in municipal and industrial water treatment. For the purposes of this investigation, when desalting to meet DWS, it is assumed that RO can be used in all cases and nanofiltration can be considered for treating waters with less than about 800 mg/L of TDS. Ultrafiltration and microfiltration are not applicable because these processes do not remove dissolved ions, which is required to treat the brackish waters in this study.

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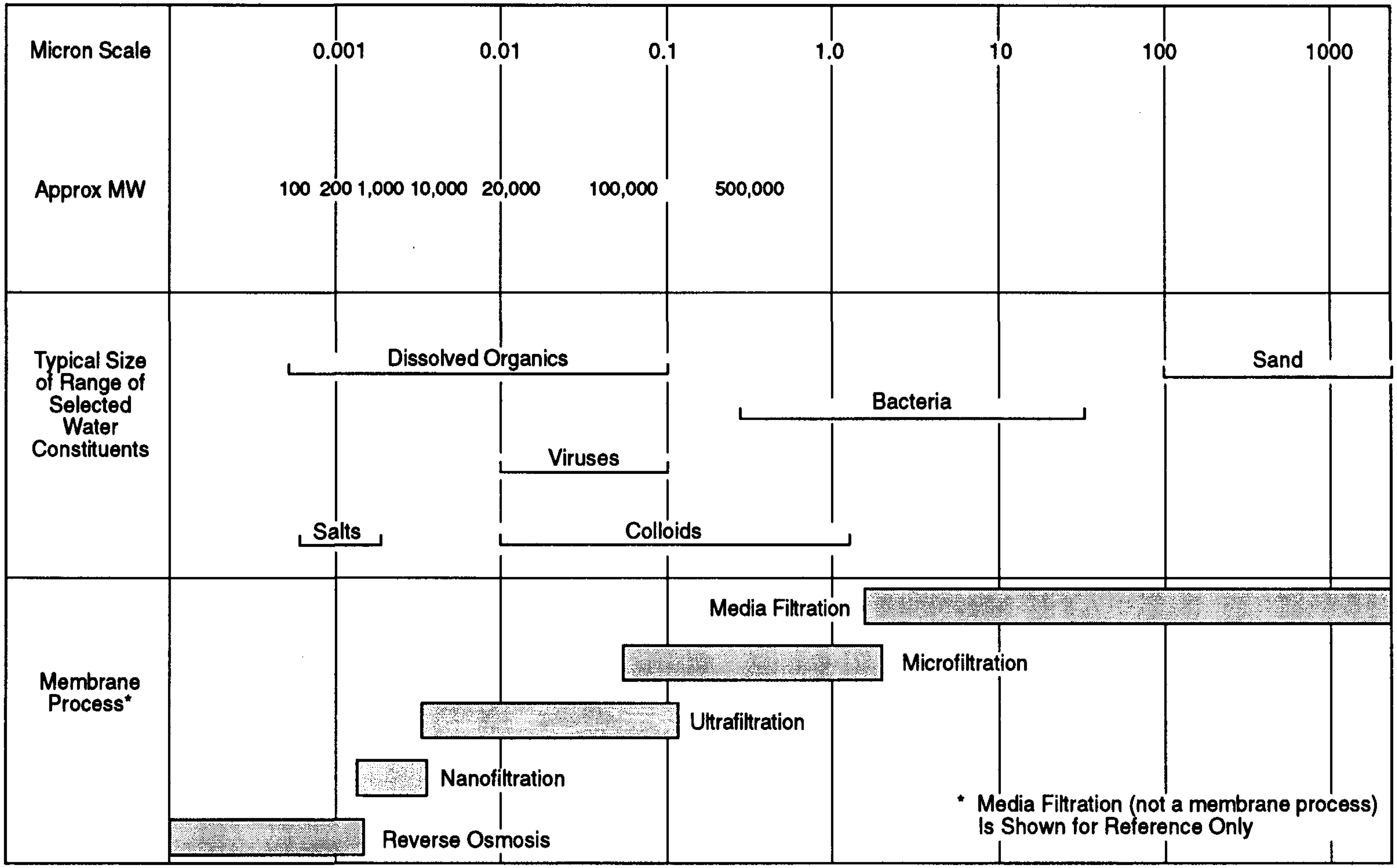

* Media Filtration (not a membrane process) Is Shown for Reference Only

Figure 3. Pressure-Driven Membrane Process Application Guide

Table 1. Typical Operating Pressures for Pressure-Driven Membrane Processes

Membrane Process[a]	Typical Operating Pressure Range (psi)
Reverse osmosis	
Seawater	800 to 1,200
Brackish water	
– Low pressure	150 to 300
– Standard pressure	350 to 600
Nanofiltration[b]	50 to 150
Ultrafiltration	20 to 75
Microfiltration	10 to 30

[a] Includes liquid-phase, pressure-driven membrane processes.

[b] Sometimes referred to as "membrane softening" for hardness removal applications.

A simplified flow schematic for a pressure-driven membrane process is shown in Figure 4. Feed water is pressurized by a pump and passed across the membrane surface by using a cross-flow operational arrangement. A portion of the pressurized feed stream is passed through the membrane and is collected as permeate (product). The remaining fraction exits the system as a concentrate (reject). The perm-selective nature of the membrane means that, compared with the feed stream, the permeate stream will contain lower concentrations of components, such as salts, colloids, and particulates, and the concentrate stream will contain higher concentrations.

Electrically Driven Membrane Processes

Electrically driven membrane processes, which include electrodialysis and its variant, electrodialysis reversal, use a difference in electrical potential to induce dissolved ions to pass through a membrane. This membrane, which is impermeable to water, removes the dissolved ions from the feedwater. The process, shown in Figure 5, places alternating pairs of cation (+) and anion (-) transfer membranes between positively and negatively charged electrodes. When a voltage is applied across the electrodes, a direct current is induced that causes cations to move in the direction of the negatively charged electrode (cathode). The cations are transported through the cation membrane, but are restrained at the surface of the anion membrane. The anions move in the direction of the positively charged electrode (anode) and are transported through the anion membrane, but are restrained at the surface of the cation membrane. The result is a dilute stream with a reduced salt concentration and a concentrate stream with a higher salt content than the feedwater.

With electrodialysis, the direction of current flow is always the same. With electrodialysis reversal, the direction of current flow is reversed several times an hour by reversing the voltage polarity applied to the electrodes. Polarity reversal produces a change in the direction of ion movement through the alternating pairs of membranes and causes an electrical flushing of scale-forming ions from the membrane surfaces. This periodic flushing controls the formation and buildup of scale and often allows the electrodialysis reversal process to operate at higher permeate recoveries than electrodialysis, with no or reduced dosages of scale-inhibiting chemicals.

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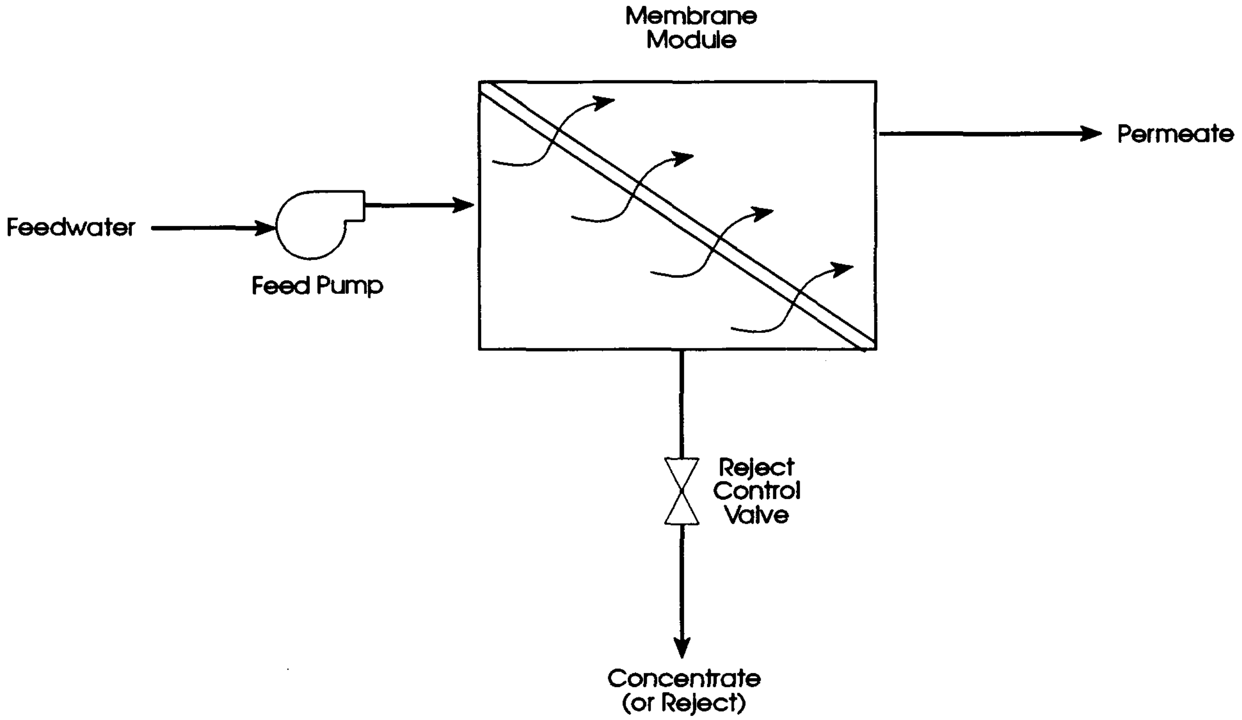
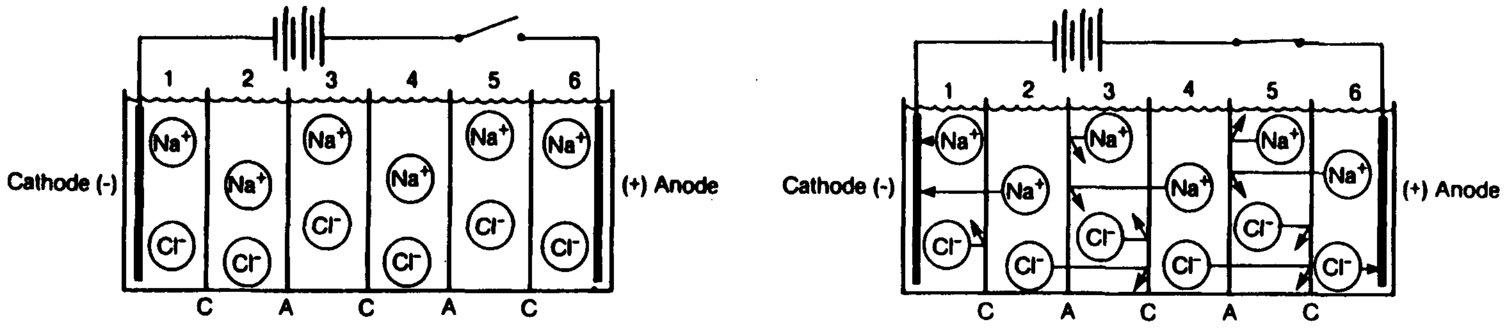
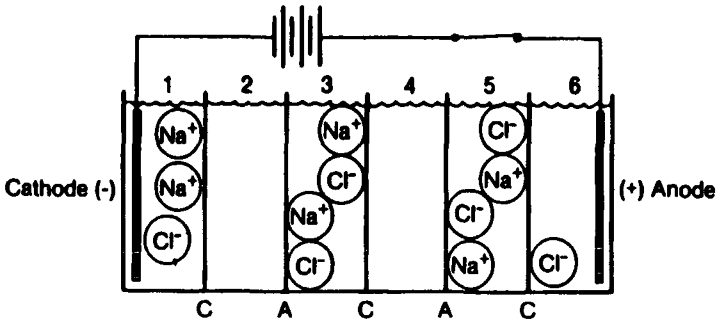


Figure 4. Simplified Flow Schematic for Pressure-Driven Membrane Process



6a. Alternating Cation-Transfer and Anion-Transfer Membranes

6b. Ion Movement During Electrical Current Flow



6c. Resulting Dilute (2, 4), Concentrate (3, 5), and Electrode (1, 6) Components

LEGEND

Na^+	Sodium Ion
Cl^-	Chloride Ion
C	Cation-Transfer Membrane
A	Anion-Transfer Membrane

NOTE: Only the sodium and chloride ions are shown for clarity.

This figure adapted from *Electrodialysis-Electrodialysis Reversal Technology* (Ionics, Inc., 1984).

Figure 5. Simplified Concept of Electrodialysis

Electrodialysis processes are typically used to lower the inorganic ion content of the feedwater. The process is not used for removing particles and dissolved organics, such as color and disinfectant by-product (DBP) precursors, because the product water does not pass through a membrane barrier, as in the case of pressure-driven membrane processes. Furthermore, silica is neither removed or concentrated in the electrodialysis process, which may be advantageous in treating some high-silica waters where the product water recovery (ratio of product water and feedwater flow) is controlled by potential silica scaling in a pressure-driven membrane system.

MEMBRANE SYSTEM COMPONENTS

A typical membrane system for a municipal water supply plant, shown in Figure 6, consists of pretreatment, membrane process trains, membrane product water after treatment and before finished water storage and high-service pumping to the distribution system, and membrane concentrate disposal facilities. Membrane concentrate treatment may be required before disposal, depending on the specific application and location.

Pretreatment

Nearly all membrane systems require some form of pretreatment equipment to condition the treated water source before membrane processing. At a minimum, this may simply be a cartridge filter housing that contains disposable micron-rated filter elements. This pretreatment equipment protects downstream pumps and membranes from damage by particulates present or introduced into the water. In cases where the quality of the feedwater is poor, as in high levels of suspended solids, sparingly soluble salts, and biological matter, conventional clarification or lime softening followed by acidification, gravity filtration, and chemical treatment for scale inhibition may be necessary. The degree and complexity of the pretreatment equipment are determined by the feedwater requirements of the membrane, the quality of the raw water, and other design factors.

Membrane Process Trains

For pressure-driven membrane systems, membranes consisting of varying materials are commonly configured into spiral-wound elements and hollow-fiber bundles and placed inside pressure

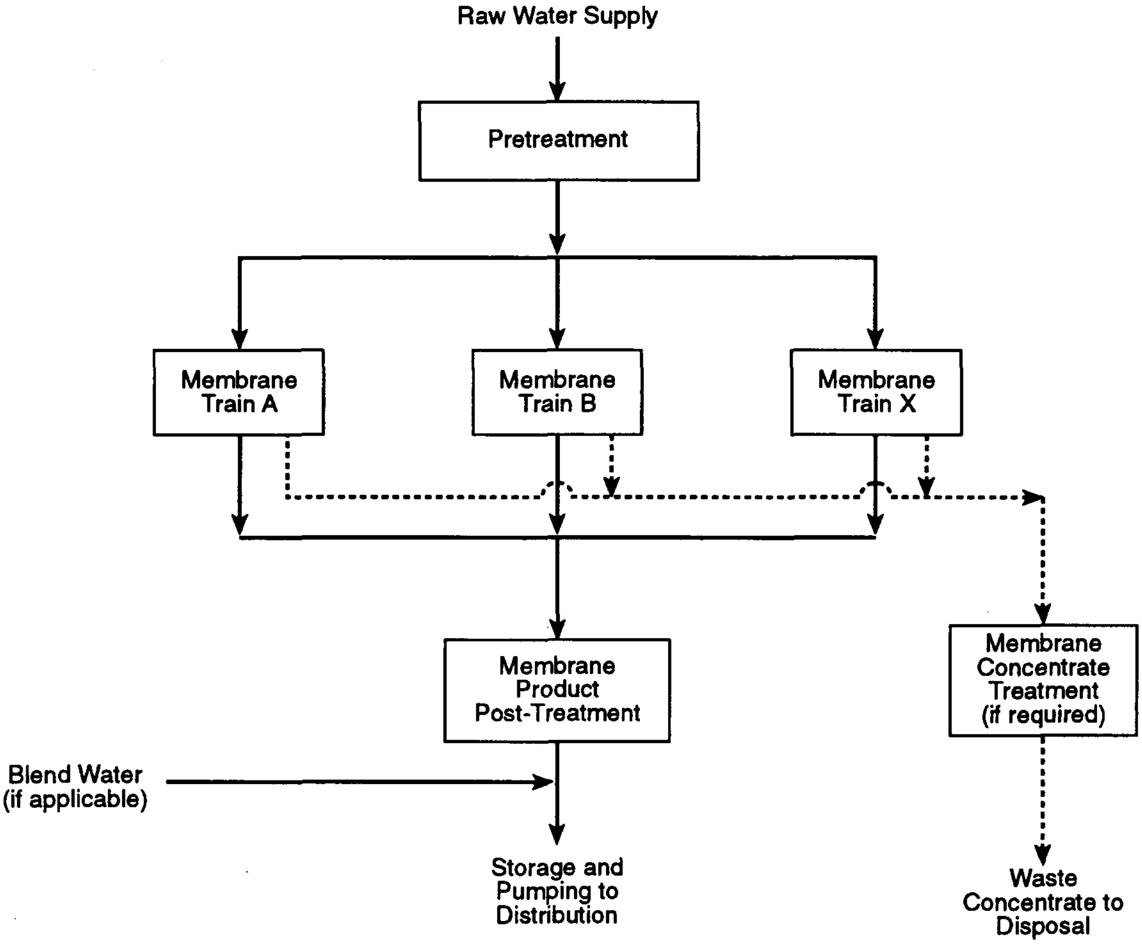


Figure 6. Membrane System Components

vessels that form modules. Depending on the application, membrane modules are typically arranged in parallel and in series, forming independent membrane process trains. For electrodialysis systems, membranes are placed in vertical stacks between electrodes. Electrodialysis membrane stacks also can be placed in series and in parallel to form process trains. For larger facilities, multiple membrane trains are used to subdivide the overall treatment capacity to allow incremental production output and to make construction phasing easier.

Membrane Product Water Post-Treatment

Typically, membrane product water is corrosive and requires post-treatment to achieve corrosion control. Membrane product water commonly has a low pH, which often is caused by the carbon dioxide that is used for calcium carbonate scale control and that forms during pretreatment acid injection. Membrane product water also can have low dissolved ions. The hydrogen sulfide in the raw water is not removed in the membrane system; therefore, it is present in the product and concentrate in concentrations similar to the feed. As a result, the membrane product is generally post-treated using degasification, chemical addition, or both processes to remove undesirable gases, increasing the potential for calcium carbonate precipitation to enhance finished water stability and adjusting pH. In cases where the calcium ion and alkalinity levels of the permeate are low, it may be more cost-effective to achieve stability by adding a corrosion inhibitor such as zinc phosphate, a polyphosphate blend, or sodium silicate. Where finished water quality goals permit, the permeate also can be blended with membrane bypass or split treatment water to increase stability.

As a final step in the membrane treatment process, a disinfectant is added to the permeate or blended water before finished water storage and pumping to the distribution system.

Membrane Concentrate Disposal Facilities

Depending on the application, concentrate quality, and disposal alternatives, waste concentrate treatment may be required before discharge. This is particularly common with surface water disposal when hydrogen sulfide is present in the concentrate, necessitating sulfide destruction and the addition of dissolved oxygen.

MEMBRANE PROCESS AND SYSTEM COMPONENT SELECTION

Membrane Process Selection

To properly select a membrane process for a given application, overall project goals must be identified and the treatment objectives well defined. Membrane feedwater quality after pretreatment should be compared with the established product water goals to determine the constituent(s) that must be removed by the membrane process and their required removal rates. Historical, current, and expected future water quality data and product water quality criteria should be considered during this evaluation.

Once the design removal requirements are known, generalized membrane process selection charts (Bergman and Lozier, 1993) and other available information can be used. The potential for using a split-treatment scheme, where some of the feedwater is bypassed around the membrane treatment and blended with the membrane product to produce the finished water, should also be considered. With split treatment, the capacity of the membrane treatment facilities can be reduced, which could reduce overall costs.

The potential for blending membrane product water with water from other sources should also be considered. This type of blending lowers required membrane capacity and reduces treatment costs. For example, new membrane facilities treating brackish ground water can be blended with product water from existing potable water treatment plants (WTPs), reducing the size of the membrane system or the membrane system treatment requirements for constituent removal. Such a blending approach is being used by the City of Melbourne.

For this investigation, it is assumed that only spiral-wound, pressure-driven membrane processes (RO and nanofiltration), which are commonly used in Florida, are appropriate. Electrodialysis, the other potential membrane desalting process, can be considered by designers for certain applications in the future. Including electrodialysis in this analysis would not affect the applicability of using brackish ground waters in SJRWMD, but would add unneeded complexity to the analyses.

Membrane System Component Selection

Ground waters are generally low in suspended solids, organics, and other potential membrane foulants, and typically allow the use of minimum pretreatment processes before the membranes. Figure 7 shows a typical membrane system that is applicable for desalting ground waters in SJRWMD. The pretreatment processes are as follows:

- Adding sulfuric acid to lower the feedwater pH, as required to protect the membrane system and control calcium carbonate scale
- Adding a scale inhibitor chemical for carbonate, sulfate, and silica scale control
- Using 5-micron-rated cartridge filtration for removal of small particulates that may be present

Membrane feed pump(s) can be used to boost the pretreated water pressure to feed the membrane train(s). Membrane permeate or product water passes to degasifier(s) for carbon dioxide and hydrogen sulfide removal, where blowers force air upward through packing material, stripping the gases from the permeate falling by gravity through the tower to a clearwell. Product transfer pump(s) transport the degasified water to the plant's finished water storage and pumping facilities.

Membrane product post-treatment chemical addition includes caustic for pH adjustment, chlorine (potentially ammonia) for disinfection, and inhibitors for corrosion control. Waste membrane concentrate treatment for sewer system or surface water discharge applications is assumed to be oxygen addition using a degasifier or, possibly, air injection prior to a static mixer in the disposal pipeline. For disposal to deep injection wells, no concentrate treatment is assumed to be required.

Membrane System Product Water Quality

The product water quality from an RO or nanofiltration membrane system depends on feedwater quality, membrane type and solute (salt) rejection characteristics, system recovery, the hydraulic loading rate (flux) and operating pressure, membrane age, and the presence of foulants and scale on the membranes.

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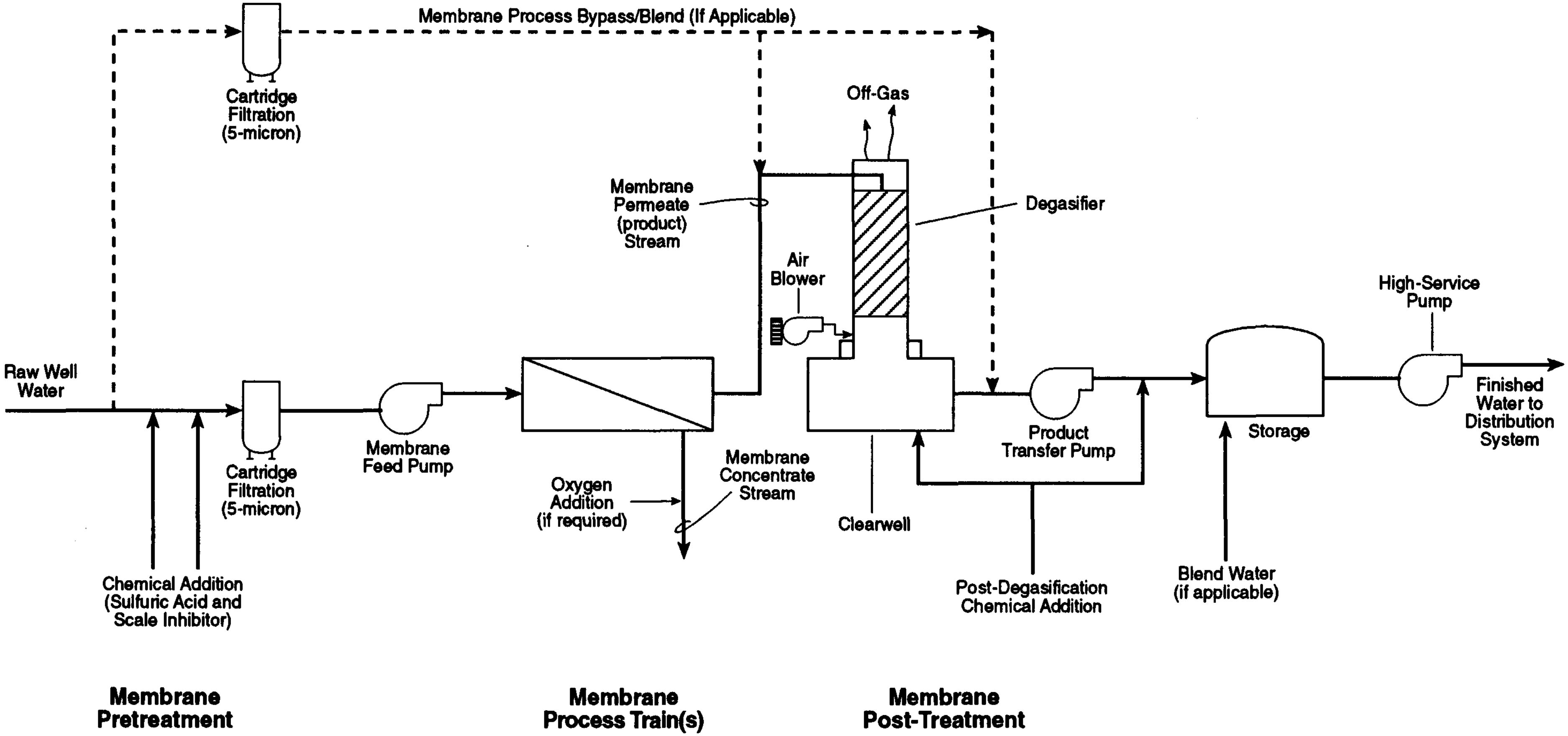

Figure 7. Typical Reverse Osmosis or Nanofiltration Membrane Treatment System for Ground Water Supply Applicable to the SJRWMD Planning Area

Definitions

Recovery, which is the fraction of feedwater volumetric flow that permeates the membrane element, vessel, or system, is expressed as a percent as follows:

$$Y = (Qp/Qf) \times 100$$

Where:

Y = recovery (percent)

Qp = permeate flow rate

Qf = feed flow rate

Solute (salt) passage, which is the fraction of solute present in the feed that is contained in the permeate, is expressed as follows:

$$SP = (Cp/Cf) * 100$$

Where:

SP = solute passage (percent)

Cp = concentration of solute in permeate stream (mg/L)

Cf = concentration of solute in feed stream (mg/L)

Solute (salt) rejection, which is the fraction of solute in the feedwater that remains in the concentrate stream, is expressed as a percent as follows:

$$SR = [1 - (Cp/Cf)] * 100 = 100 - SP$$

Where:

SR = solute rejection (percent)

SP = solute passage (percent)

Flux is the rate of water flow through a membrane, typically expressed in units of gallons per square foot of membrane area per day. For a given membrane system and application, higher applied pressure increases the flux rate. The design flux rate depends on the type of application. For a typical Florida ground water application, the average system flux rate is approximately 15 gallons per square foot (gallons/ft^2) of membrane area per day. When membrane hydraulic performance declines because of fouling or other factors, increased feed pressure is typically used to maintain targeted flux rate and desired product water output.

Projecting Product Water Quality

Typically, membrane manufacturer software is used to estimate the product water quality expected after a given period when operating at a specific set of conditions. The scaling potential of the feedwater constituents limits the maximum allowable recovery. The targeted flux rate in gallons/ft^2 of membrane area per day is determined from past experience in treating similar type waters. For example, a typical design flux rate for RO and nanofiltration systems for ground water applications is approximately 15 gallons/ft^2 of membrane area per day, which is the flux rate assumed for this investigation.

Based on feedwater quality and operating conditions, the permeate and concentrate qualities are projected. For a given permeate water flow rate, system type, and configuration, the projected feed pressure requirement also is determined by the program. Typically, feed pumps are sized to provide additional feed pressure to offset membrane performance decline over time for site-specific conditions, such as feedwater foulants. In practice, periodic membrane cleanings are used to control the buildup of unwanted materials on the membranes.

Virtually any product water quality goal can be met using appropriate membrane and other technologies. Volatile compounds and gases such as hydrogen sulfide, which are not removed using RO or nanofiltration, can be removed by membrane post-treatment degasification, also called air-stripping. Although membrane treatment facilities can meet treatment requirements, the residual waste concentrate must be disposed of, which is discussed later in this report. Therefore, the technical feasibility of using brackish ground waters is controlled not only by treatment capabilities but also by concentrate disposal.

PRODUCT WATER QUALITY CRITERIA

Treatment Plant Finished Water Quality Goals

Water quality requirements for WTP finished water pumped to the distribution system are dictated by state DWS and, possibly, more stringent utility water quality goals.

For this investigation, critical product water quality criteria include TDS, chloride, sulfate, and sodium. It is assumed that the targeted finished water quality after membrane post-treatment and possible blending with other waters will be 90 percent of the maximum levels specified in the DWS. Therefore, finished water quality goals for TDS, chloride, sulfate, and sodium are assumed to be 450, 225, 225, and 144 mg/L, respectively. Furthermore, when membrane performance projections are run to estimate permeate water quality, a 5-year membrane operating time will be used. This value is also the estimated service life for the type of membranes assumed for this application.

Comparison of Membrane Treatment Product Quality with Finished Water Quality Goals

There are several options for required treatment, based on raw water salinity, finished water quality goals, the membrane process selected, and availability of blend waters. These options can be categorized by salinity of the raw water source, and can be further divided into either full treatment or partial treatment. Full membrane treatment assumes all plant finished water has passed through the membrane system (that is, no bypass/blend flow). Split treatment assumes that only a portion of the WTP's finished water pumped to the distribution system is treated with all plant processes.

Saline Waters (TDS > 10,000 mg/L or Cl > 5,000 mg/L)

Full membrane treatment using seawater RO is required for high salinity ground waters with TDS concentrations of 10,000 mg/L and above. Seawater RO is required because of the significant levels of desalting needed to meet finished water quality goals. These systems typically reject about 99 percent of the TDS. (Permeate TDS is approximately 1 percent of the feed TDS.) Also, these systems typically operate at about 45 percent recovery (that is, about 45 percent of the feedwater becomes permeate and 55 percent is waste concentrate).

Highly Brackish Waters (TDS of 4,000 to 10,000 mg/L or Cl of 2,000 to 5,000 mg/L)

Full treatment with standard-pressure brackish water RO membranes is required for highly brackish waters. This type of treatment typically results in an overall rejection of 90 percent at a recovery of 70 percent. The actual rejection and recovery for a specific application depends on feedwater quality characteristics and membrane system design, but for planning purposes can be considered to exhibit these general values.

Moderately Brackish Waters (TDS of 1,000 to 4,000 mg/L or Cl of 500 to 2,000 mg/L)

Full or split treatment using low-pressure RO may be considered for lower salinity raw waters ranging from 1,000 to 4,000 mg/L of TDS. This investigation assumes that membrane system rejection and recovery are 90 percent and 80 percent, respectively.

Slightly Brackish Waters (TDS of 500 to 1,000 mg/L or Cl < 500 mg/L)

The available options increase significantly for slightly brackish waters. Desalting may not be needed if adequate quantities of good-quality (low TDS) water from other sources are available for blending. If blended water is not available, then full or split treatment with RO or full treatment with nanofiltration may be considered. It is assumed that RO treatment facilities for these feedwaters using low-pressure membranes will remove approximately 90 percent of the TDS and operate at recoveries of about 85 percent. Nanofiltration systems are assumed to reject 50 percent of the TDS at recoveries of 85 percent.

Degree of Potential Blending

If the quality of the existing water supply for a utility meets or exceeds DWS, brackish ground water could be used for blending without desalting. The maximum allowable bypass/blend flow rate is controlled by the flow rate of the existing facility, the qualities of both waters, and the finished water quality goals. As mentioned previously, these water quality goals may be the same as the DWS or a more stringent goal dictated by the utility and its customers. For example, bypass and blending brackish water without desalting typically increase hardness and salinity, which may not be acceptable to utility customers. Where TDS is the limiting quality criteria and existing treatment includes lime softening, the potential lower quality water blend ratio can be increased without using desalting technologies because TDS could be reduced during lime softening.

The degree of potential blending, which can be determined using mass balance techniques, is calculated as follows:

$$Qp/Qfin = (Craw - Cgoal)/(Craw-Cp)$$

Where:

Qp = Membrane permeate flow rate

Qfin = Finished water flow rate

Craw = Concentration of raw water (e.g., TDS, chloride, sodium)

Cgoal = Concentration of finished water quality goal

Cp = Concentration of membrane permeate

The resulting bypass/blend flow rate equals:

$$Qbyp = Qfin - Qp$$

Where Qbyp is the membrane bypass flow rate that is blended with the membrane permeate to form the finished water.

The required raw well water flow rate can be calculated as follows:

$$Qwell = Qfin * (BR/Y + 1 - BR)$$

Where:

Qwell = Raw well water flow rate

BR = Blend ratio = Qp/Qfin

Y = Membrane system recovery = Qp/Qf

and where Qf is the membrane feed flow rate.

REJECT CONCENTRATE DISPOSAL

Membrane Concentrate Quantity and Quality

The quantity and quality of reject concentrate from a membrane treatment plant can be determined with membrane system design computer programs. Input data include (1) membrane type, (2) desired permeate flow rate for the individual process train,

(3) number of membranes and hydraulic arrangement (design flux rate and staging), (4) raw water quality characteristics, (5) desired feedwater pH adjustment with acid, (6) operating time (membrane age), and (7) recovery rate. The model projects estimated membrane train concentrate quality (TDS and major ions) and quantity (flow rate).

The total reject concentrate flow rate to be disposed of depends on the number of membrane process trains desired to meet the overall treatment product water output.

The concentrate quality (for example, TDS) from an RO or nanofiltration system can be estimated without computer modeling by assuming a specific recovery and solute (salt) passage. The concentrate concentration can be calculated as follows:

$$Cc = Cf * [(1 - Y * SP)/(1 - Y)]$$

Where:

Cc = Concentrate concentration (mg/L)

Cf = Membrane feedwater concentration (mg/L)

Y = Recovery (ratio permeate:feed flow rates)

SP = Solute (salt) passage, expressed as a decimal

Concentrate Disposal Options

Membrane concentrate is classified as an industrial waste. The major membrane concentrate disposal options in Florida include (1) discharge to surface water or ocean outfall, (2) discharge to a sanitary sewer system and wastewater treatment plant (WWTP), (3) deep well injection, and (4) land application, including irrigation and reuse. Major factors affecting the selection of concentrate disposal methods and sites include concentrate characteristics (quantity and quality), availability of blending waters, permittability, public acceptance, and cost.

Discharge to Surface Water. The following factors should be considered for surface water discharge:

- **Classification of the surface water**. Permitting a concentrate discharge to a Class I (potable water supplies) surface water body would be extremely difficult. Some potential exists for discharge to Class II (shellfish propagation or harvesting), Class III (recreation), Class IV (agricultural), or Class V (navigation, utility, and industrial use) water.

- **Flow ratio of receiving surface water and concentrate.** Receiving waters with large average flow, low flow, or tidal flow rates, or all of these characteristics, are better candidates for concentrate disposal than receiving waters with limited flow.
- **Relative water quality of the surface water and concentrate.** Receiving water bodies with salinities similar to the salinity of the concentrate are the best candidates for concentrate discharge. The potential for toxicity of the discharge must also be considered, as well as the concentration of radionuclides.
- **Availability of blend waters.** If the differences in salinity between the concentrate and the candidate receiving water are too great for direct discharge, the potential for blending with another treated waste stream, such as WWTP effluent, may be explored.
- **Availability of an existing ocean outfall with excess capacity.** If an existing ocean outfall with excess hydraulic capacity sufficient to accept the concentrate stream is available, this outfall might provide cost-effective concentrate disposal.

Discharge to Sewer System. Factors that should be considered for discharge to a municipal WWTP through the sanitary sewer system include the following:

- **Available capacity of the sewer system and WWTP.** Existing excess transport and treatment capacity to accommodate the membrane concentrate must be available. Effects on the WWTP expansion schedule should also be considered.
- **Discharge limitations.** Current WWTP discharge method and National Pollutant Discharge Elimination System (NPDES) permit limitations and their compatibility with the potential addition of membrane concentrate must be considered.
- **Potential for retrofitting.** Evaluate the potential for retrofitting an injection well being used for WWTP effluent disposal to accommodate the concentrate (classified as an industrial waste) without unacceptable loss of capacity.

- **Type of wastewater treatment process.** Evaluate the potential for adversely affecting the existing WWTP unit processes. A significant increase in influent salinity or variability could upset existing biological treatment processes.

Deep Well Injection. The following factors should be considered for the deep well injection disposal option:

- **Geologic conditions.** An acceptable concentrate injection zone at an appropriate depth must be available.
- **Planned back-up disposal.** A back-up disposal method is usually required for deep well disposal systems. Any disposal option, including an additional injection well, could be considered.

Land Application. The following factors should be considered for the land application (reuse) option:

- **Availability of blend water, such as WWTP effluent.** Land application will require blending with another less saline reclaimed waste stream.
- **Potential land application sites and their geohydrologic conditions.** Are suitable sites available near the brackish WTP?
- **Types of land application systems.** Possible applications may include slow-rate systems in restricted public access areas; irrigation opportunities in public access areas; or rapid-rate application systems, such as percolation ponds, absorption fields, overland flow systems, and wetland application.
- **Land use at the potential site.** Existing and proposed land use must be compatible with water reuse.
- **Water qualities of the subsurface aquifers.** The potential for ground water degradation, including the shallow water table aquifer, should be assessed.
- **Wet-weather storage requirements.** Any land application system will require offline storage of the concentrate during wet weather when application rates are restricted.

In summary, the concentrate disposal methods are as follows, from most desirable to least desirable:

1. **Discharge to sewer system.** If the concentrate flow rate is less than or equal to 5 percent of the WWTP's average annual flow rate and the site is near a sewer system, or if the WWTP has a disposal well that can be retrofitted to accommodate the concentrate and still have adequate capacity (current and future), sewer system discharge is feasible.
2. **Discharge to surface water.** If a surface water body is within 1 mile of a potential membrane plant site and is classified as Class V, for direct discharge, or Classes II through IV, and if adequate blend water is available, then discharge to surface waters should be considered. The receiving water should also have an average TDS greater than the blended concentrate TDS.
3. **Land application.** If the potential membrane plant is within 1 mile of a golf course currently using municipal water for irrigation and the "whole" concentrate or "blended" concentrate TDS is less than 1,000 mg/L, golf course irrigation may be technically feasible. The golf course must be large enough to accommodate the available concentrate, including blended water, and construction of wet weather storage facilities must also be feasible.
4. **Deep injection well.** If a suitable injection zone is available (assumed to be where there is "confined" ground water with TDS greater than 10, 000 mg/L between 1,000 and 3,000 feet deep), or if the membrane concentrate can be blended with domestic wastewater and disposed of in an existing retrofitted municipal disposal well, deep well disposal is a feasible option.

For the purposes of the planning-level cost estimate, it is assumed that deep injection well concentrate disposal will be used. Deep wells are assumed for several reasons. First, deep disposal wells are the most generally applicable technology, especially for larger concentrate flow rates and TDS concentrations. Other methods, including discharge to surface waters, discharge to the sewer system, and land application, are opportunity specific. These technologies should be considered in detailed, site-specific planning, but are less universally applicable. Therefore, they should not be relied on for regional planning purposes. Also, deep disposal wells are relatively expensive. Therefore, planning-level cost estimates developed on the assumption of deep wells should represent the upper end of the expected value range. Such a costing approach is appropriate for regional planning purposes.

Permitting concentrate disposal is likely to be one of the more difficult tasks associated with development of brackish ground water resources, regardless of available concentrate disposal technologies and the final technology selected.

EXAMPLES OF BRACKISH WATER SUPPLY AND MEMBRANE TREATMENT

Using brackish ground water to augment drinking water supply is not a new practice. In fact, blending brackish ground water with potable water so that the mixed water meets DWS has been used within SJRWMD and worldwide for years. Also, membrane technologies are used throughout the world to treat brackish water, both to blend with existing water sources and provide an independent water source.

According to Morin (1994), as of December 1993, municipal utilities in North America had over 190 membrane plants with capacities of more than 25,000 gallons per day (gpd). Table 2 presents a partial list of brackish water RO desalting plants located in Florida, as reported by Morin (1994). The RO plants listed in Table 2 are those that responded to Morin's survey and that were constructed for brackish water desalting for drinking water purposes. Membrane softening plants were not included. Thirty brackish water RO treatment plants, with a total capacity of 47.45 mgd, are identified.

Bergman (1995) summarized design and operating data for membrane softening WTPs in Florida (Table 3). In addition to providing examples of membrane treatment in Florida, Table 3 demonstrates the range of concentrate disposal options used by existing membrane facilities in Florida. Concentrate disposal methods in use include deep injection wells, ocean outfalls, discharge to wastewater treatment plants, and irrigation ponds.

Table 4 presents a list of membrane water treatment plants currently operating within SJRWMD, based on a review of District consumptive use permit (CUP) files. Ten currently operational membrane plants are identified, with a total permitted capacity of about 34 mgd. Nearly half of the District-wide total capacity is provided by the City of Melbourne facility.

Table 2. Partial List of Reverse Osmosis Desalting Plants In Florida (Morin 1994)

Plant	Location	Start-Up Year	Capacity [mgd]
Marineland Inc.	St. Augustine	1972	0.10
Kinston Shores	Ormond Beach	1972	0.06
Rotunda West	Rotunda West	1974	0.50
Greater Pine Island	Bokeelia	1975	1.50
Cape Coral RO Plant	Cape Coral	1976	14.00
Southbay Utilities	Sarasota	1976	0.23
Indian River Plantation	Stuart	1977	0.40
Myakka River State Park	Sarasota	1977	0.05
Kings Gate Club	Nokomis	1978	0.06
Charlotte Harbor	Charlotte Harbor	1978	0.45
Island Water	Sanibel	1980	3.60
Englewood Water District	Englewood	1981	2.00
City of Sarasota	Sarasota	1982	4.50
Indian River County	Vero Beach	1983	2.00
Windward Isle	Sarasota	1983	0.06
Tippecanoe	Sarasota	1984	0.04
Aquaria Service Management System	Melbourne Beach	1984	0.08
Sarasota County Plantation	Venice	1984	0.25
Bocila Utilities	Englewood	1985	0.03
North Beach	Wabasso	1985	1.00
Seaside Services System	Grove City	1986	0.02
Holiday Pines Service Corp.	Lutz	1989	0.24
Gasparilla Island Water	Boca Grande	1990	0.50
Jupiter	Jupiter	1990	6.00
Sarasota County Plantation	Venice	1990	0.25
Acme Improvement District	Wellington	1990	1.80
Bay Lakes Estates	Nokomis	1990	0.05
Venice	Venice	1990	4.00
North Beach	Wabasso	1991	3.00
Sorrento	Nokomis	1991	0.68
Total			47.45

Table 3. Membrane Softening Water Treatment Plant Design and Operating Data (Bergman 1995)

Plant Name	Membrane Manufacturer	Membrane Type	Ground Water Aquifer	Recovery (%)	Feed Pressure (psi)	TDS (mg/L)[a]		Hardness (mg/L as $CaCO_3$)		Color (CU)		Concentrate Disposal
						Feed	Permeate	Feed	Permeate	Feed	Permeate	
Plantation	Fluid Systems	NF, RO	Biscayne	85	130	480	35	310	20	65	<5	Deep injection well
Fort Myers	Hydranautics	NF, RO	Shallow wells near river	90	155	480	285	230	130	75	<5	Irrigation pond
Collier Co.	Hydranautics	NF	Lower Tamiami	90	110	420	140	260	80	17	<4	Deep injection well
Indian River Co. South	Hydranautics and Fluid Systems	NF, RO	Floridan	85	110-120	910	230	310	30			Canal to ocean
Dunedin	Hydranautics	NF	Upper Floridan	83	105	450	300	240	90	30	<5	To WWTP
Boynton Beach	FilmTec	NF	Surficial	85	105	360	90	255	50	45	<1	Deep injection well
Village of Royal Palm Beach	FilmTec	NF	Surficial	80	95	800	250	350	60	35	<5	To WWTP
St. Lucie West Development	Hydranautics	NF	Shallow wells	85	100	500	170	250	70	70	<5	WWTP and irrigation pond
Hollywood	Hydranautics	NF[b]	Biscayne	90 (NF)[c]	130[c]	585	210[c]	350	120[c]	30[c]	<1[c]	Ocean outfall
Miramar	FilmTec	NF	Surficial	80[c]	95[c]	400	--	265	--	115	<5[c]	Two deep injection wells

[a] Membrane feed after treatment.

[b] Plant includes 4 mgd of reverse osmosis treating brackish Floridan aquifer water.

[c] Projected values.

Table 4. Permitted Membrane Water Treatment Plants Currently Operating Within SJRWMD.

Owner	Permitted Capacity - mgd	Comments
Indian River County		North Plant scheduled to be decommissioned due to water quality deterioration. Maximum permitted capacity for all 3 plants not to exceed 7.8 mgd.
North Plant	NA	
South Plant	7.30	
Hobart Plant	4.28	
City of Vero Beach	3.65	
Vero Beach Countryside	0.17	Current CUP has expired. Plant is operating.
City of Melbourne	15.90	
Aquarina	0.21	
South Brevard Water Coop, Inc. (Sunnyland)	0.18	
Light House Cove Condo Assoc.	0.01	
Palm Coast Utility Corp.	2.00	Membrane softening plant. Design capacity is 2 mgd; currently operating at 1 mgd.

Source: SJRWMD Consumptive Use Permit files.

As can be seen from the summaries presented in Tables 2, 3, and 4, membrane treatment, both for brackish water desalting and water softening, is an accepted and growing water treatment technology. This technology is currently applied in SJRWMD, as well as throughout Florida.

SOURCE AREA CHARACTERISTIC DATA

As previously discussed, SJRWMD will identify potential brackish ground water sources and provide the following characteristics for each source area:

- Total maximum developable yield (mgd)
- Raw water quality (chloride concentration in mg/L)
- Maximum allowable withdrawal rate per well
- Typical wellfield configuration, including well depth

Of these potential sources, up to six will be identified as candidate brackish ground water sources in TM D.1.c. Cost estimates will be developed for these sources in TM D.3.b.

PROPOSED COST ESTIMATION PROCEDURE

The brackish ground water cost estimates will include developing planning-level cost estimates for up to six candidate source areas identified in TM D.1.c. Cost functions for each withdrawal site, expressed as a function of water supply yield and finished water quality, will also be developed. TM D.3.b will report the methods used and results obtained.

COST PARAMETERS AND CRITERIA

Cost parameters to be considered have been previously established by the project team and include the following:

- Construction cost
- Non-construction capital cost
- Land cost
- Land acquisition cost
- Total capital cost
- Operation and maintenance (O&M)
- Equivalent annual cost
- Annualized set-up cost
- Annualized unit cost

Economic criteria, including cost basis, non-construction capital cost factor, unit land costs, interest rate, and facilities life expectancies, have been previously established for all cost estimates developed as part of SJRWMD's alternative water supply strategies investigations. These previously established criteria will be used to develop the required cost estimates for the brackish water facilities.

CONSTRUCTION AND O&M COST COMPONENT

Construction and O&M cost estimates will be developed at the preliminary planning or cost curve level for the major components required. Major components required for each candidate brackish ground water source area may include the following:

- Raw water wellfields
    - Wells
    - Pumps
    - Piping and instrumentation and controls (I&C)

- Membrane pretreatment
    - Sulfuric acid addition
    - Scale inhibitor addition
    - Five-micron cartridge filtration
- Membrane process train
    - Membrane feed pump
    - Membrane module(s)
- Membrane post-treatment
    - Degasifier (air stripping tower with blowers)
    - Product transfer pump
    - Chemical addition (caustic, chlorine, inhibitors)
    - Ozone disinfection
    - Storage
    - Pumping facilities
    - Blending facilities
- Waste concentrate disposal
    - Deep injection well

Applicable cost curves or equations defining cost as a function of capacity and other data will be identified in the literature. Cost information presented in TM B.2.b, Water Supply and Wastewater Systems Component Cost Information (Law Engineering 1996), will be used to the greatest extent possible. Where necessary, cost curves or unit costs for individual items (e.g., pumps) or major systems (e.g., complete RO treatment plant) will be developed using the identified or developed construction and O&M cost curves. The curves will be applied to the identified brackish ground water sources.

LAND COSTS

Land requirements will be estimated for the raw water wellfields and membrane treatment plant. Total land costs, including the cost of acquisition, will then be estimated on the basis of estimated total land requirement for each of the facilities considered.

OTHER COST ESTIMATES

Other cost parameters, including total capital cost, equivalent annual cost, set-up cost, and unit cost, will be estimated on the basis of construction, land, and O&M costs computed for each facility. These cost estimates will be developed in accordance with the cost estimating guidelines and economic criteria established for this alternative water supply investigation.

COST FUNCTIONS

The cost analysis will result in the development of estimated costs for each of the eight cost parameters for the up to six candidate brackish ground water supply source areas. These individual cost estimates will be used to develop cost equations for each cost parameter applicable to the individual withdrawal sites. The resulting cost equation for a complete brackish ground water supply system will likely have the following general form:

$$COST_{(p,l)} = f(WSY_{(p,l)}, PWQ_{(p,l)})$$

Where:

$COST_{(p,l)}$ = estimated cost of parameter p, at source area location l, in total dollars or dollars per year, depending on the units of the cost parameter.

$WSY_{(p,l)}$ = water supply yield expressed as average daily flow in mgd.

$PWQ_{(p,l)}$ = product water quality in terms of chloride concentration (mg/L)

The cost equations will be used in the University of Florida Decision Model to define the cost characteristics of the brackish ground water supply alternative.

TECHNICAL MEMORANDUM PREPARATION

TM D.3.b will report on the methods and results of the brackish ground water supply cost estimating and cost equation development.

SUMMARY AND RECOMMENDATIONS

SUMMARY

Brackish ground water is one of several alternative water supply sources being evaluated by SJRWMD. This TM is the second of three that addresses the technical feasibility and costs of developing brackish ground water resources to help meet future water supply needs for selected water supply source areas located within the Water Resource Caution Area. This TM reviews available information on brackish ground water treatment technologies and brackish ground water characteristics. Based on this review, the TM presents a methodology to be used in establishing planning-level cost estimates.

RECOMMENDATIONS

It is recommended that the cost estimating procedure presented in this TM be approved and applied to the candidate source areas identified in TM D.1.c.

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