# *Desalination in Florida: Technology, Implementation, and Environmental Issues*

**Division of Water Resource Management**
**Florida Department of Environmental Protection**
**April, 2010**

3900 Commonwealth Boulevard, MS 41
Tallahassee, Florida 32399-3000
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***Desalination in Florida: A Brief Review of the Technology, Environmental Issues and its Implementation.***

This report was prepared in response to the interest in the development of alternative water supplies and specifically desalination in Florida. It is an assessment of current technologies and its application in the state. Recommendations are provided to effectively implement environmentally and fiscally sound desalination technologies that will hopefully help meet current and long-term potable water supply demands of the state's growing population.

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# EXECUTIVE SUMMARY

Florida cannot meet its future demand for water by relying solely on the development of traditional ground and surface water sources. The state's water demand is expected to grow by greater than 25% to about 8.7 billion gallons per day by the year 2025. To meet this demand, we must continue to diversify our sources of water to include environmentally sound use of saltwater, brackish surface and ground waters, the collection of wet-weather river flows, and reuse of reclaimed water and stormwater. Water conservation, though not typically thought of as an alternative water supply, is also critical to our water supply strategy as a cost effective means of achieving efficient utilization of water and ensuring the sustainability of the diverse water resources of the state. Desalination, or the removal of salts from seawater and brackish water sources, is one of several alternative water supplies identified by Florida's water managers as needed to meet the projected increase in demand. The "drought resistant" nature of desalination makes it an attractive alternative to those water sources that rely on rainfall.

Florida leads the nation in the use of desalination technology, in both the number of facilities using the process (more than 140) and the gallons of potable water produced each day (about 515 million gallons). This is reflective of efforts to meet the needs of the state's increasing population while avoiding overuse of traditional drinking water sources, particularly in coastal areas of central and south Florida. The majority of the source water treated at desalination plants in Florida is not saltwater, but brackish ground and surface waters. Today, only a few Florida plants draw their source water from coastal seawater. The Tampa Bay Seawater Desalination Facility is the only large-scale reverse osmosis facility in the state using a coastal surface water source. However, seawater desalination technology is being considered for application to other areas such as the Coquina Coast project in Flagler County in Northeast Florida where land-based and novel ship-based approaches are being considered.

Desalination can be accomplished by distillation, electrodialysis, and reverse osmosis technologies. In Florida, as in much of the United States, reverse osmosis (RO) is by far the dominant technology used. This is primarily due to the higher energy costs of the other technologies. The prevalence of RO, as a stand-alone technology, may evolve to combination systems, where membrane technology (like RO) is linked to a distillation process, lowering energy requirements of either stand-alone technology. Modifications of the traditional RO process, including more energy efficient pumps, longer lasting membranes, and blending of existing technologies like distillation are reducing the costs of desalination. The increasing costs of traditional water supply and the reduction in costs of RO technology result in desalination becoming more cost competitive.

The type of source water (surface or ground, salt or brackish), the desalination technology employed, and the concentrate management method used are significant factors affecting the environmental evaluation and regulation of these facilities. In addition, desalination technologies have greater energy consumption and associated greenhouse emissions compared to other traditional water supplies. As the salt content of the source water increases from brackish water to seawater, there is a proportional increase in the energy usage and greenhouse gas emissions. The use of alternative energy sources like waste heat or solar can reduce the need for fossil fuel based energy. Co-location of desalination facilities at or near existing power plants or large municipal wastewater treatment plants can minimize environmental impacts through the use of existing intake and outfall structures and the blending of desalination brine and power plant heated effluents. In addition, co-location can reduce energy needs (heated source water improves the efficiency of the desalination membranes), reduce capital cost (use of existing intake and outfall structures, reduced power line connection costs, and reduced property and zoning costs from the use of an existing industrial site footprint) and reduce operational costs (heated source water reduces degradation of membranes and efficiency of salt removal).

Given the large number of desalination plants in Florida, and the anticipated development of new facilities over the next 10 years, desalination has already been determined to be a feasible and cost- effective supply alternative by water supply utilities. Technological improvements and continued cost-sharing of alternative water supply development by the water management districts and the State could hasten the wider application of desalination technology.

## ***Acknowledgements***

Many individuals assisted in the development of this report, either through contributions, reviews, or both. David Trimble, Ken Carter, Dan Peterson, Bonnie Hall, Al Hubbard, Jeffrey Lawson, and Kevin Ledbetter of the Department of Environmental Protection contributed significantly to the writing of several sections of the report and researching the current and growing field of desalination. The St. Johns River, Southwest Florida, and South Florida Water Management Districts and specifically Barbara Vergara, Ken Herd, and Ashie Akpoji, Mark Elsner, and Marjorie Craig all provided critical review and valuable suggestions. Each of these water management districts is a valuable resource on the subject of desalination in Florida, providing a wealth of information.

In addition to Florida-specific information provided by the water management districts, the development of this report was greatly aided by the recent and comprehensive examination of desalination in the United States, crafted by the National Research Council, of the National Academies, "Desalination, A National Perspective". Anyone wanting to understand the subject and the rapidly growing field of knowledge is encouraged to read this report.

Finally, as editor of this report, I take full responsibility for errors and mistakes, and place full credit on what is good on those listed above.

Richard Drew, Chief, Bureau of Water Facilities Regulation, Division of Water Resource Management, Florida Department of Environmental Protection

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*List of Abbreviations and Acronyms*

ASR: aquifer storage and recovery system

BGD: billion gallons per day

°C: degrees Celsius

CAB: cellulose acetate

CPA: composite polyamide

CWA: Clean Water Act

EDR: electrodialysis reversal

FDEP: Florida Department of Environmental Protection

kgal: one thousand gallons

kgal/d: thousand gallons per day

kJ/kg: kilojoules per kilogram

kWh: kilowatt-hour

$m^3$: cubic meters

MGD: million gallons per day

MED: multiple effect distillation

mg/L: milligrams per liter

MSF: multistage flash distillation

MVC: mechanical vapor compression

NaOH: sodium hydroxide

NF: nanofiltration

NPDES: National Pollutant Discharge Elimination System

O&M: operation and maintenance

ppt: parts per thousand (g/L)

ppm: parts per million

psi: pounds per square inch

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| | |
|---|---|
| PWS: | public water systems |
| RO: | reverse osmosis |
| SDV: | Seawater Desalination Vessel |
| SFWMD: | South Florida Water Management District |
| SJRWMD: | St. Johns River Water Management District |
| SRWMD: | Suwannee River Water Management District |
| SWFWMD: | Southwest Florida Water Management District |
| TDS: | total dissolved solid |
| TFC: | thin film composite |
| TVC: | thermal vapor compression |
| UIC: | Underground Injection Control |
| USDW: | Underground Source of Drinking Water |
| USEPA: | United States Environmental Protection Agency |
| VC: | vapor compression |
| VVC: | vacuum vapor compression |
| WWTP: | wastewater treatment plant |

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# *SECTION ONE: Introduction*

**Figure 1-1. Lake Region Water Treatment Plant, Belle Glade, Florida (SFWMD, 2009)**

During the 2008 Florida Legislative session, House Bill 199 recognized the treatment of saltwater to produce potable water, or desalination, to be a proven technology advanced around the world. The bill directed the Department of Environmental Protection to work with the Water Management Districts to examine this technology's usefulness to Florida. While the bill did not pass, the Department agreed to undertake the tasks outlined in the proposed legislation. To that end this report will:

- Examine current and available desalination technologies,
- Provide an analysis of existing desalination projects in the state, and
- Provide recommendations to effectively implement desalination in an environmentally safe and cost effective manner.

Until the last few decades, Floridians have enjoyed what appeared to be a limitless supply of freshwater, mostly contained in readily-accessible shallow aquifers under most of the land surface area of the state. This was evidenced by the presence of springs from Miami to the Panhandle. As the population grew, its water use grew. Just as the presence of springs exemplified the abundance of water in the early part of the twentieth century, the disappearance of springs along the southeastern and southwestern coasts provided the early warning signs of diminishing groundwater supplies (Ferguson, et al., 1947).

Today, we face saltwater intrusion along the coastlines, as well as intrusion of more salty deep aquifer waters into shallower freshwater aquifers (Causseaux and Fretwell, 1983; Koszalka, 1994; Tihansky, 2005). Growth, particularly along the central and southern Florida coasts, has caused some drinking water utilities to change treatment to deal with a decline in existing water sources and treat poorer quality source waters to meet increasing water needs (Merejo, et al., 2005; Elarde, et al., 2005).

In a number of locations around the state, dwindling groundwater supplies have resulted in the designation of areas of critical water supply, water use caution areas, water resource caution areas, and priority water resource caution areas by the state's water management districts. These designations typically result in greater limitations on water use and more stringent conditions for obtaining, renewing, or increasing the allocation authorized by consumptive use permits. For example, in the Central Florida region the water management districts, through water supply planning and individual permit actions, have determined that growth in public water supply over the next 20 years from traditional groundwater sources is not sustainable. In some instances, groundwater withdrawals have already resulted in impacts to wetlands and spring flows. As a result, the South Florida, Southwest Florida, and St. Johns River water management districts are working together to determine the limit of available groundwater supplies in the area and identify alternative sources of water to meet Central Florida's water demands. The districts are also working together to develop long-term rules for the area by 2013 (SJRWMD, 2009). These efforts are described in Section 2 of this report.

Clearly, Florida cannot meet its future demand for water solely through traditional ground and surface water sources. Florida must continue to diversify its water supply sources to include a range of environmentally sound alternative supplies including saltwater, brackish surface and ground waters, surface water collected primarily from wet-weather flows, reuse of reclaimed water and stormwater, and conservation (AWWA, 2008; Henthorne, 2008; Heimlich, et al., 2009). Section 2 of this report will provide a more detailed look at the present and future water needs of the state and the specific efforts to develop desalination.

While most of the state has had, until recently, an adequate water supply, there were areas, such as the Florida Keys and some barrier islands, where freshwater was never plentiful. It wasn't unusual, in the early 1900's, to find cisterns to collect rainwater in coastal and barrier island homes. A shallow lens of freshwater in the surficial aquifer system floated on top of the saltwater in the barrier islands, providing an additional but very limited supply of freshwater.

It was in these areas of limited freshwater that the first attempts were made to extract freshwater from saltwater (desalting or desalination) using distillation (the process of heating water to a boil and condensing the water vapor through cooling tubes).

Distillation is an old technology used on the open seas. Sir Richard Hawkins reported in 1662 that, during his voyages to the South Seas, he was able to supply his men with freshwater by means of shipboard distillation (Birkett, 2003). Thomas Jefferson, as Secretary of State, encouraged research on the concept of desalination in the 1790s and was responsible for having desalination methods printed on the back of every permit issued for vessels sailing from U.S. ports (Wilson, 2001).

Distillation was used to produce the first land-based water supply facilities in the 1920s and 1930s in the Caribbean and Mideast. In the U.S. at the 1961 dedication of a vertical distillation plant in Texas, President Kennedy, made an insightful statement on the importance of desalination then and for the future, "*No water resources program is of greater long-range importance than our efforts to convert water from the world's greatest and cheapest natural resources – our oceans – into water fit for our homes and industry. Such a break-through would end bitter struggles between neighbors, states, and nations.*"

As with the Texas facility, various forms of distillation were the mainstay of the desalination industry, until a few decades ago, when innovations in reverse osmosis (RO) technology lowered its costs. Since then, RO use has expanded exponentially. Today, distillation technologies still generate 43% of the world's desalinated waters (NRC, 2008). However, in the United States, distillation or 'thermal' technology represents only 3% of the water production, whereas RO, a membrane filtration technique, produces 96% of the nation's desalinated water.

Reverse osmosis is a process that uses pressure on a salty source water to push the water molecules through a membrane. The salts remain behind the membrane in a saltier concentrate for later disposal. More than 12,000 desalination plants operate around the world today and have the capacity of producing 11 billion gallons of water each day (See Figure 1-2). In 2005, the U.S. contained more than 1,100 facilities with the capacity of about 1.5 billion gallons per day. Today, almost 100% of the municipal desalination facilities in the country use reverse osmosis and other similar membrane treatment technologies.

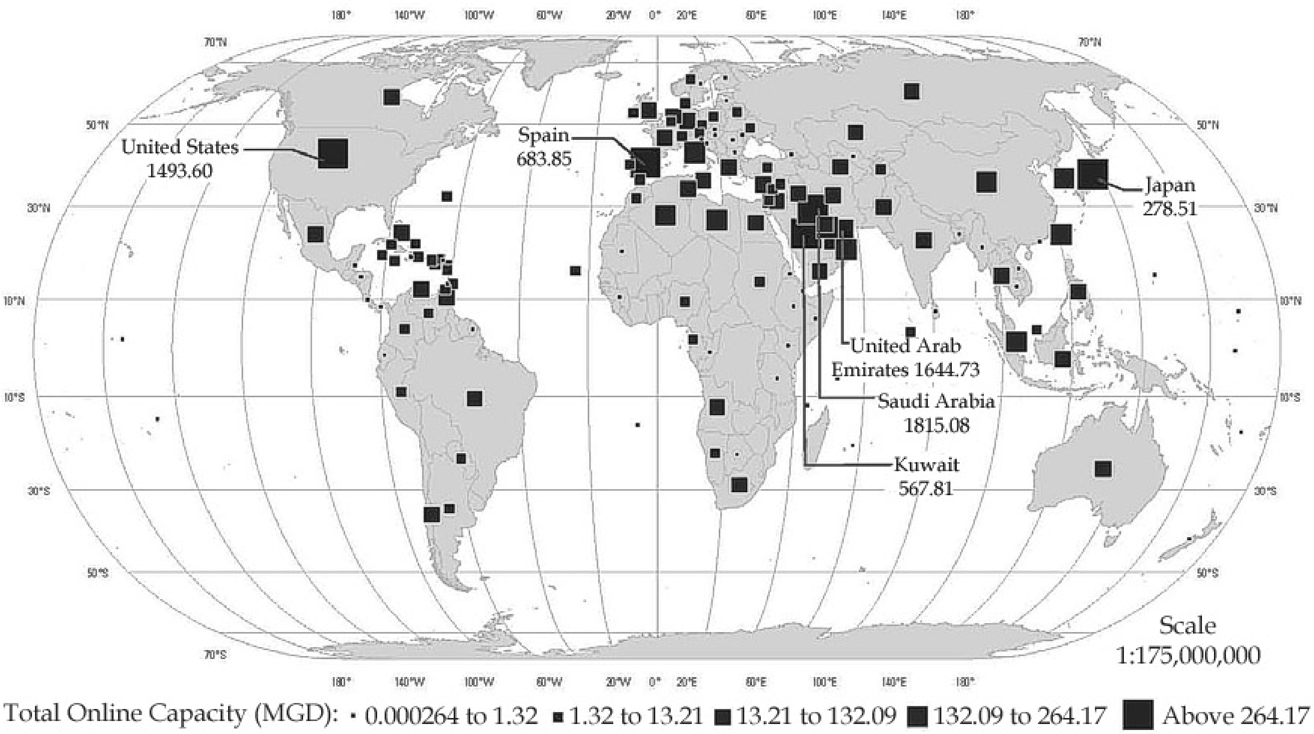


**Figure 1-2. Total Desalination Capacity by Country (Adapted from GWI, 2006)**

These and other desalination technologies are described in more detail in Section 3 of this report.

In addition to a brief description of existing and new technologies, Section 3 also includes a discussion of the Florida-specific facilities. Florida has set the pace in the use of desalination technology in this country. The production of potable drinking water here is more than twice that generated in the second highest production state, California (Figure 1-3; NRC, 2008). This is reflective of the state's increasing population, especially along the central and southern coastal regions of the state and the finite availability of freshwater, as illustrated by the location of the desalination facilities shown in Figure 1-4. As the well fields serving these areas moved inland, the economics of transporting freshwater ever increasing distances to the point of use made membrane filtration of lower quality nearby water more cost effective. For the most part, the source water treated at desalination plants in Florida is not saltwater as the name would suggest, but mainly less salty brackish ground and surface waters (full strength seawater contains about 35,000 mg/l of total dissolved solids [TDS] - various salts, chiefly sodium and chloride; brackish water will typically range from 1,000 to 20,000 mg/l TDS). Today, only a few sites draw their source water from coastal seawater. However, one of those, the Tampa Bay Water desalination facility, is the largest reverse osmosis facility east of the Mississippi River. Future development and application of seawater desalination technology is being studied for application to other areas in the state. The Coquina Coast desalination project in Flagler County, northeast Florida, is one example of a potential regional system being explored, and is described in more detail in Section 3 and at the St. Johns Water Management District (SJRWMD) web site, http://sjr.state.fl.us/coquinacoast/index.html.

As mentioned earlier, the by-product of desalination is a brine or concentrate that must be safely managed. Management options depend on the source water chemicals that will be concentrated, the degree of concentration, and the disposal alternatives (surface waters, underground injection, and land application) available to the facility's specific location. Section 4 provides a discussion of the environmental considerations tied to concentrate management.

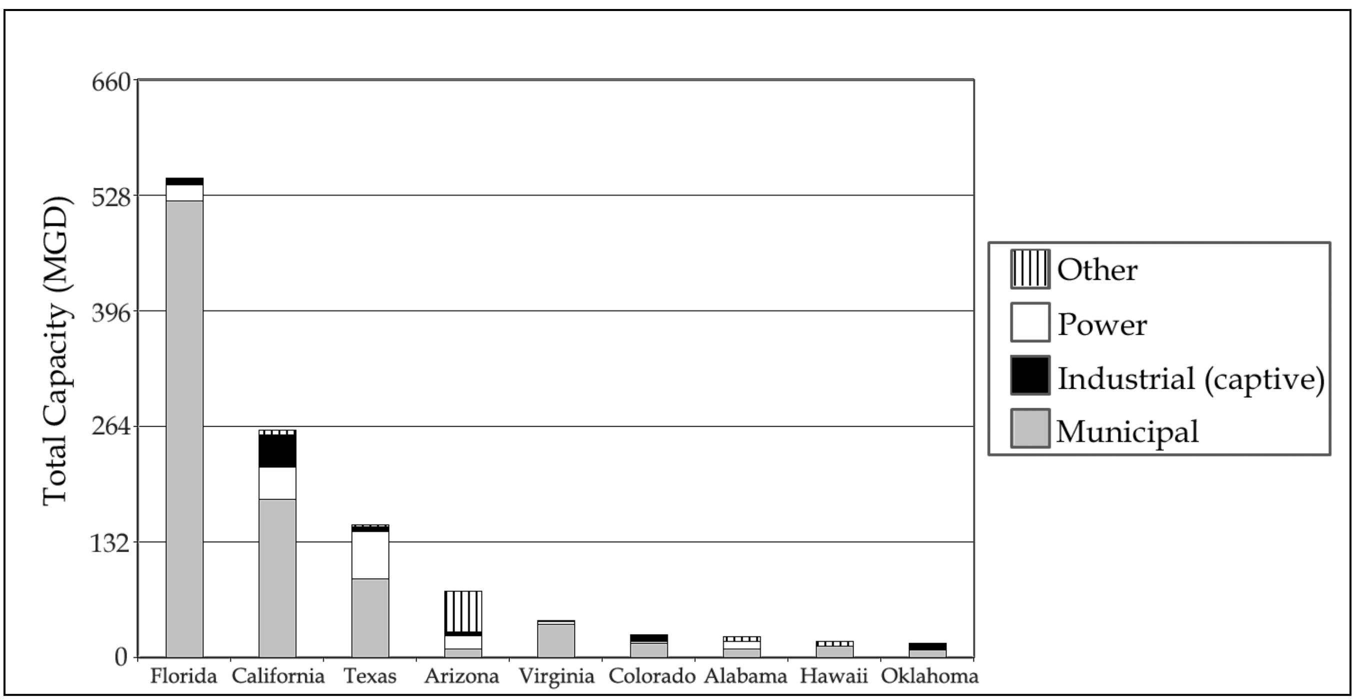


**Figure 1-3. States with the Highest Desalination Production (Adapted from GWI, 2006)**

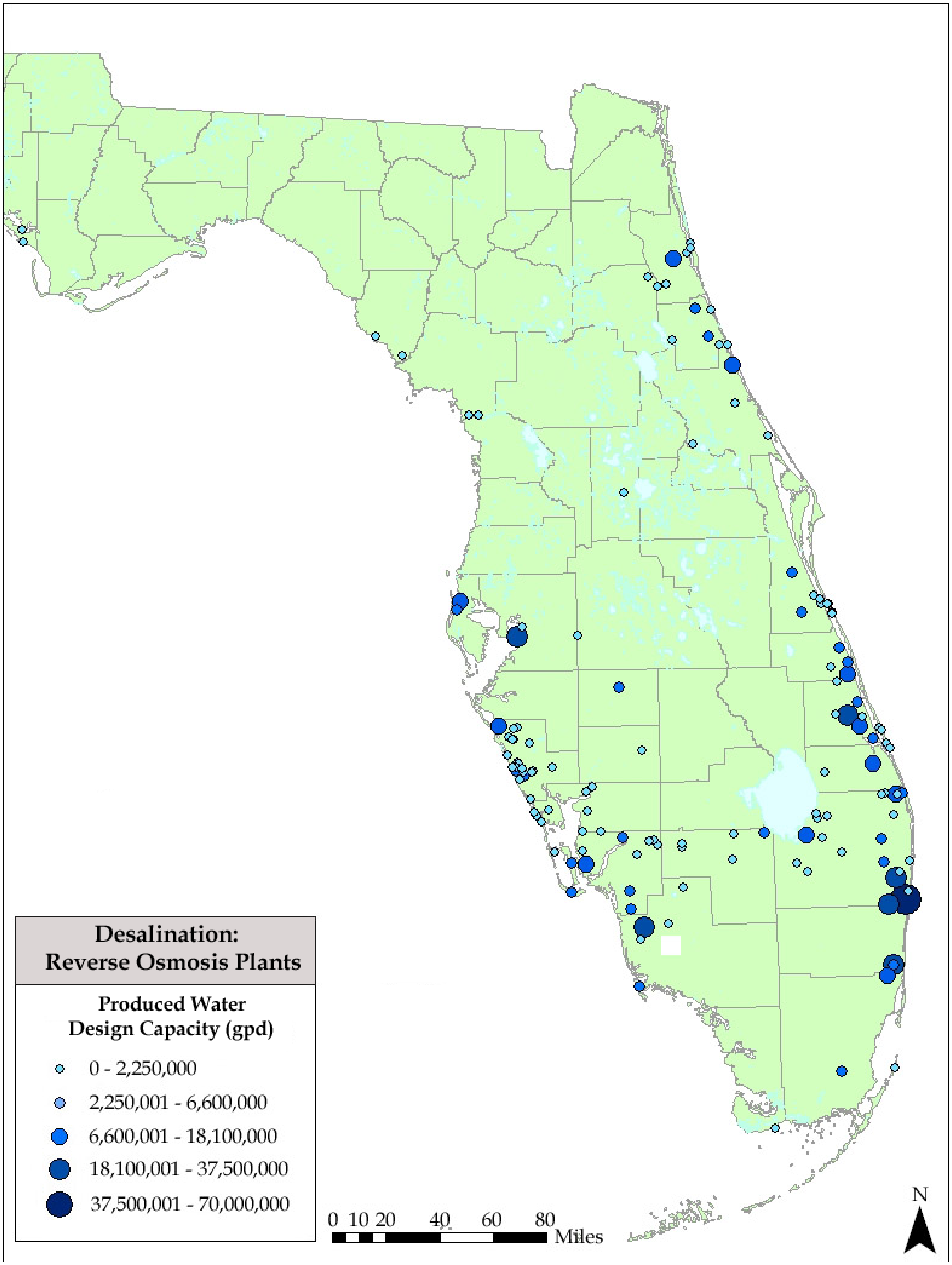


**Figure 1-4. Desalination Facilities in Florida (FDEP, 2009)**

# *SECTION TWO: Water for the Future*

Clean and plentiful water is critical to Florida's economy and quality of life. Florida is a water rich state, with over fifty inches of rainfall per year, and some of the most prolific aquifers in the nation. However, Florida's growing population and cyclical patterns of drought and flood make meeting the needs of all existing and future water users, while also protecting the state's diverse natural resources, a challenge. Florida's five water management districts (Figure 2-1) are charged with identifying adequate sources of water to meet Florida's 20-year demands.

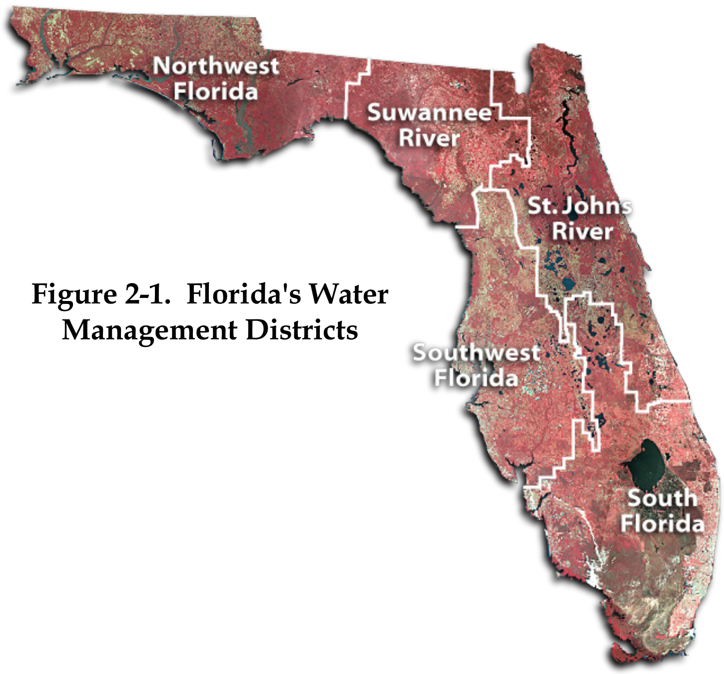


**Figure 2-1. Florida's Water Management Districts**

Chapter 373, Florida Statutes, requires the districts to develop regional water supply plans for any area where existing sources are deemed inadequate to meet projected 20-year demands without harm to the environment or existing legal users of water. Four of the five districts have identified such areas and have developed regional water supply plans that identify sources to meet foreseeable demands through the year 2025. These include alternative sources such as surface water, brackish groundwater, reclaimed wastewater, stormwater, or desalinated seawater, and increased water use efficiency.

This section of the report provides information on statewide water use trends and projections, planning efforts to meet future water use needs, and the role that desalination is expected to play in the state's water supply strategy.

### *Water Use Trends*

Floridians used an estimated 6.8 billion gallons per day (BGD) of freshwater in 2005. The most recent projections performed by the water management districts (2007–2008) forecast water demands of about 8.7 BGD in 2025 (Figure 2-2). Projections out to 2030 are currently being developed.

To understand trends in water withdrawals, it is important to look both within water use sectors and within regions of the state. Figure 2-3 shows the distribution of freshwater withdrawn in each water management district since 1975. In the northern part of the state, total freshwater withdrawn since 1975 has remained relatively stable. Water withdrawals in the South Florida Water Management District (SFWMD) show an increasing trend, and represent about 50 percent of all withdrawals in the state.

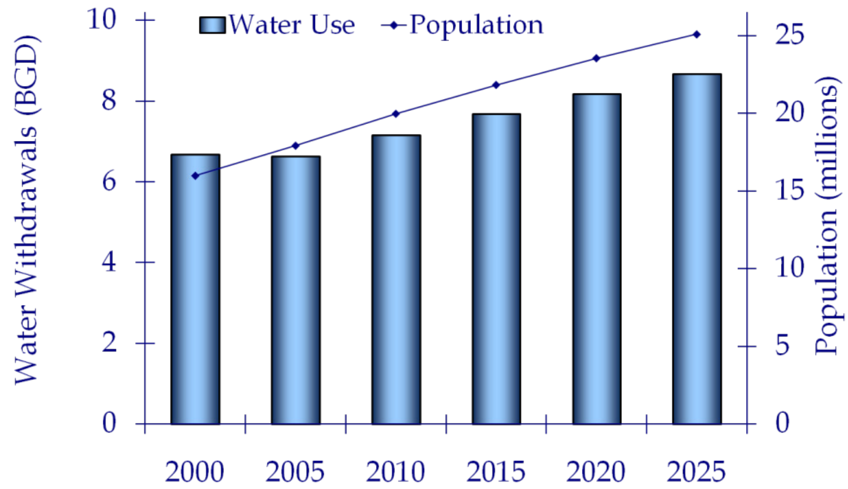


**Figure 2-2. Statewide Freshwater Withdrawals and Population Growth (FDEP, 2008a)**

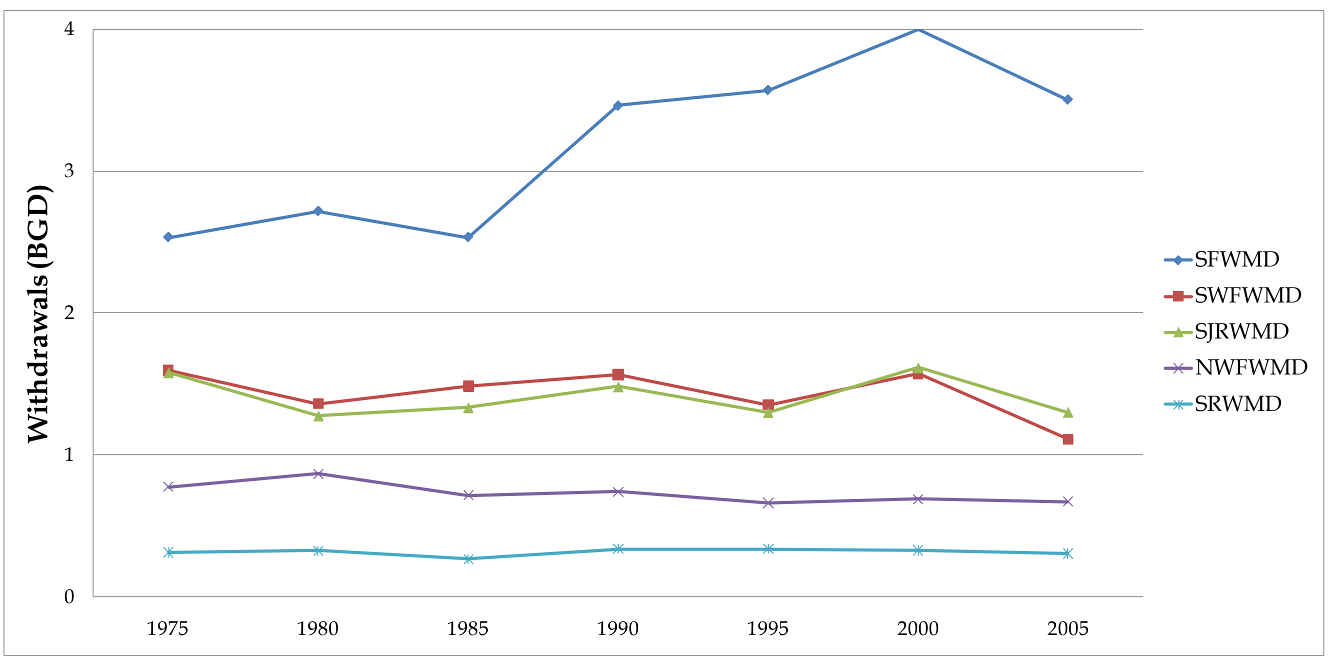


**Figure 2-3. Total Freshwater Use by Water Management District (FDEP, 2008a)**

Use also varies by sector. Agriculture currently is the largest user of freshwater in the state; however, public water supply is projected to become the largest user by 2010 (Figure 2-4).

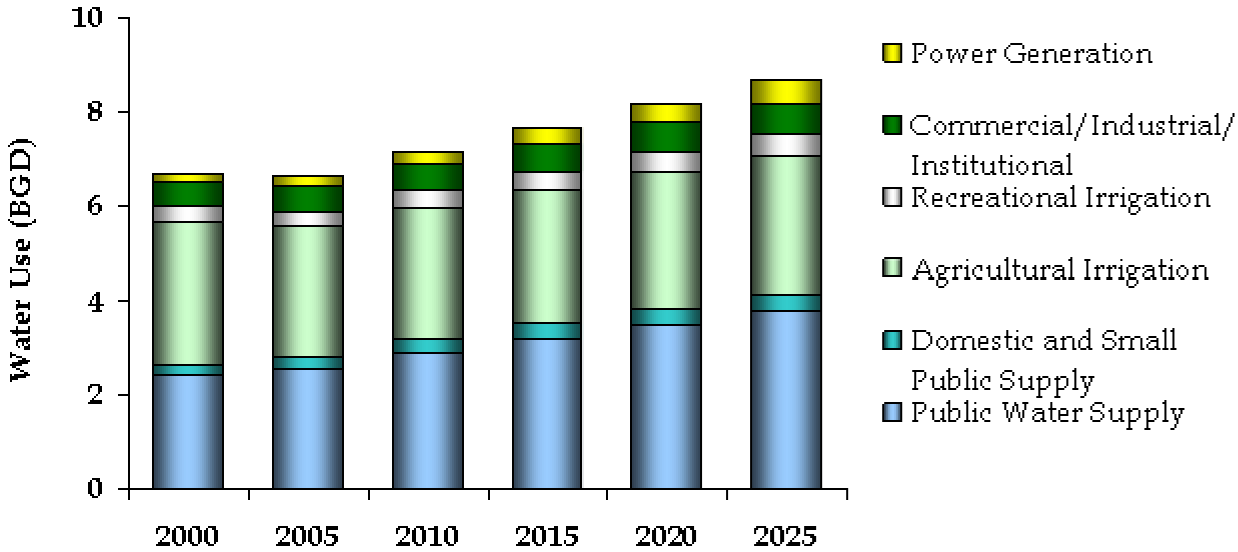


**Figure 2-4. Statewide Freshwater Demand Projections and Water Use Categories (FDEP, 2008a)**

Based upon water management district projections, public water supply will account for the majority of overall growth in statewide demand between 2005 and 2025. The regional water supply plans estimate that, by 2025, demands in public water supply will increase by about 49% and account for about 43% of the total estimated use of 8.7 BGD. Agriculture will be the second largest use, but will only increase by about 6%.

Figure 2-5 shows the amount of water historically used for public water supply and the population served. It shows a large overall increase in water withdrawn since 1950, and also that water use has been increasing in direct proportion to population growth. This trend could be altered by more emphasis on water conservation and by greater use of reclaimed water.

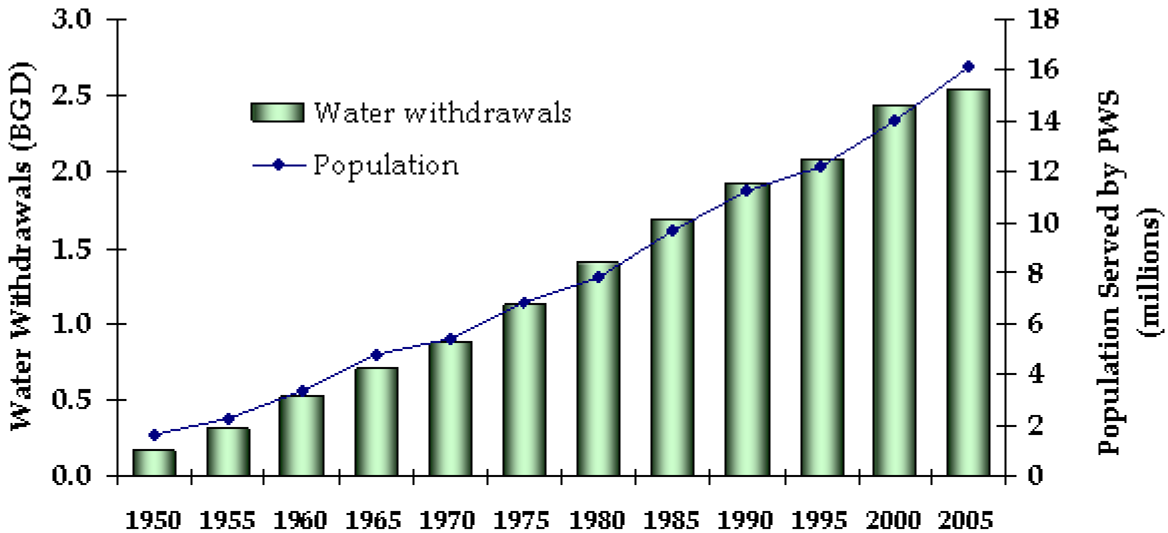


**Figure 2-5. Historic Public Water Supply Withdrawals and Population Served (FDEP, 2008a)**

Water use and demographic trends in Florida suggest that source diversification is an important consideration in meeting future needs. As shown in Figure 2-6, since 1975, Florida has relied more heavily on fresh groundwater than surface water to meet water supply needs. In 2005, groundwater withdrawals accounted for about 62% of all freshwater withdrawals in the state. More significantly, about 90% of water withdrawals for public supply, the use sector which will account for most of the anticipated growth in water use, have historically come from groundwater. Supplies of fresh, inexpensively treated groundwater are increasingly limited in many parts of the state, prompting water planners and suppliers to put increasing focus on the development of alternative water supplies to use in conjunction with existing groundwater sources. A mix of water supply sources, that can be

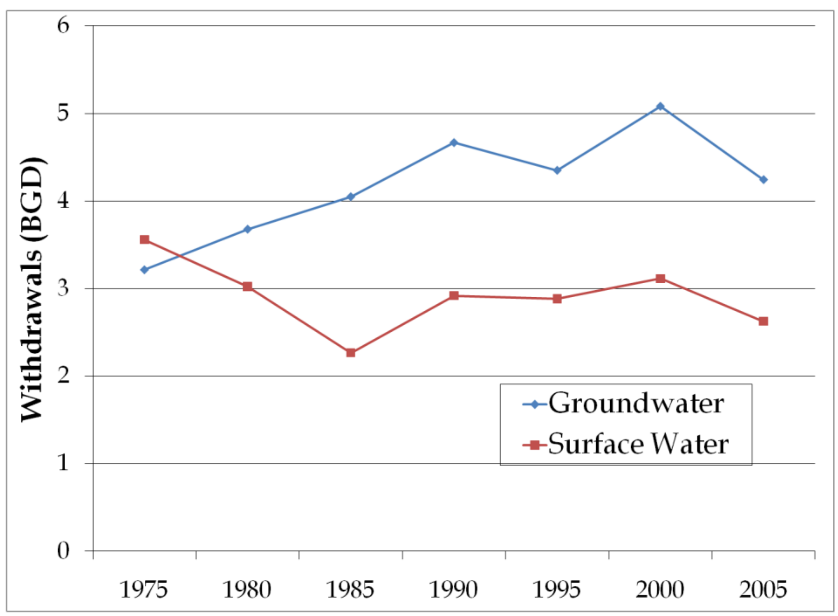


**Figure 2-6. Statewide Total Freshwater Use (USGS, 2008)**

combined or rotated depending on conditions and needs, offers many benefits. A diversified supply source affords a better ability to protect natural resources, deal with drought and flood periods (and potential effects of climate change), and provide more reliable water delivery to users. Desalination is expected to play an important role in Florida's diversified water supply portfolio.

### *Water Protection and Sustainability Program*

In 2005, the Florida Legislature created the Water Protection and Sustainability Program to encourage the development of alternative water supplies as a way to meet future needs. This program provides state funds to the water management districts for alternative water supply project construction as shown in Table 2-1. These funds, along with matching district funds, are awarded as grants to local water suppliers.

| Water Management District | FY 2005 – 2006 ($ millions) | FY 2006 – 2007 ($ millions) | FY 2007– 2008 ($ millions) | FY 2008 – 2009 ($ millions) |
|---|---|---|---|---|
| South Florida | 30 | 18 | 15.6 | 4.25 |
| Southwest Florida | 25 | 15 | 13 | 0.75 |
| St. Johns River | 25 | 15 | 13 | 0 |
| Suwannee River | 10 | 6 | 5.2 | 0.27 |
| Northwest Florida | 10 | 6 | 5.2 | 0.27 |
| Total | 100 | 60 | 52 | 5.54 |

**Table 2-1. Funding Distributions for Alternative Water Supply through the Water Protection and Sustainability Program (FDEP, 2010)**

Between 2005 and 2008, the water management districts provided funding assistance to local water suppliers for the construction of 327 projects. Figure 2-7 shows that approximately 63% of the projects funded were reclaimed water projects. The next most common group of projects funded were brackish groundwater desalination projects, which comprised approximately 22% of the total.

The districts estimate that when construction of these projects is complete they will help create approximately 761 MGD of "new water," which is about 38% of the 2 BGD of water needed by 2025. Figure 2-8 shows that reclaimed water projects are expected to produce the largest amount of water, approximately 267 MGD, which is about 13% of the additional water needed by 2025.

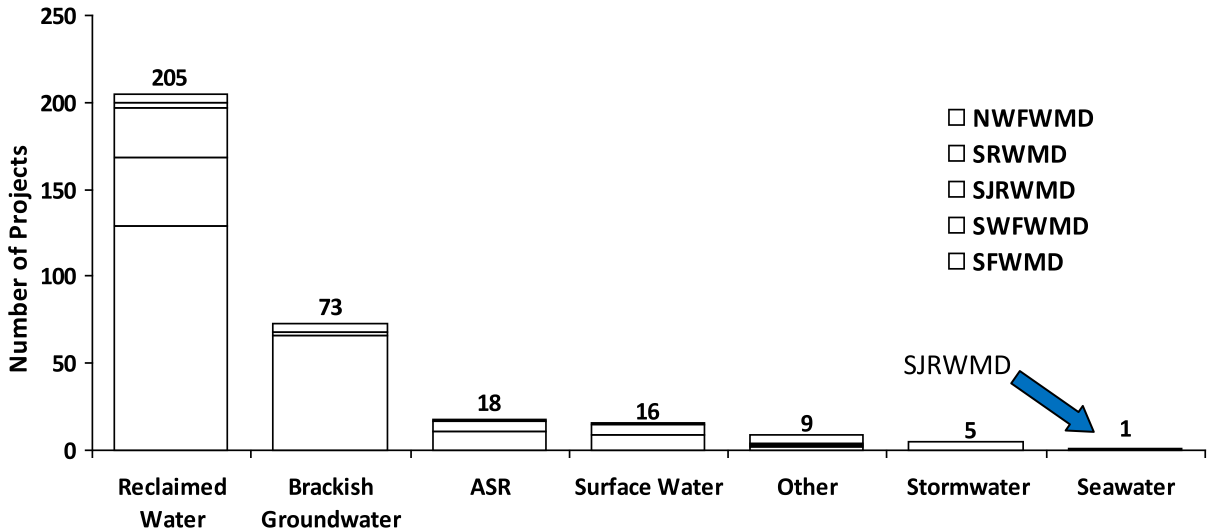


**Figure 2-7. Statewide Summary of Types of Alternative Water Supply Projects Funded (FDEP, 2010)[1]**

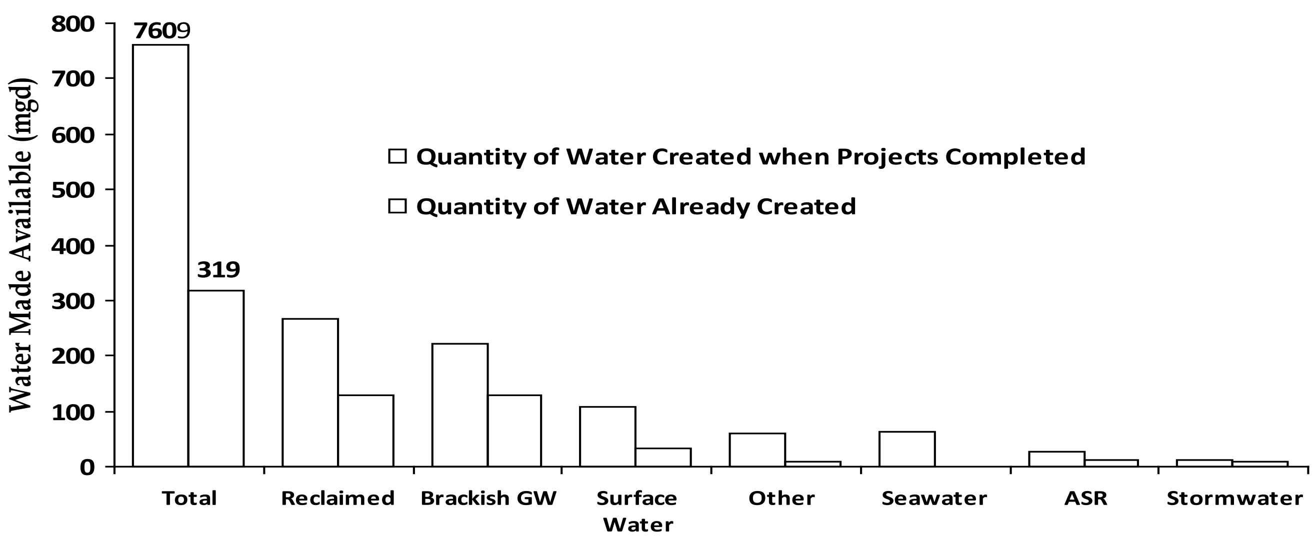


**Figure 2-8. Quantity of Water Created by Alternative Water Supply Projects (FDEP, 2010)**

[1] ASR: aquifer storage and recovery system

Brackish groundwater desalination projects are expected to produce the next largest amount of water, approximately 223 MGD, or about 11% of the additional water needed by 2025. The program has provided funding for only one new seawater desalination project to date, the Coquina Coast project in Flagler County. Funding for the Water Protection and Sustainability Program was discontinued in fiscal year 2009-2910, eliminating state-level participation in the funding of alternative water supply projects.

### *Desalination for Future Water Supply*

Florida has significant future needs for additional water, a portion of which will be met through desalination. The water management districts have been active in evaluating opportunities for both seawater and brackish water desalination. The Southwest Florida Water Management District (SWFWMD) assisted in the development of the seawater desalination facility operated by Tampa Bay Water. Three other seawater sites in that region have been studied, which together with the existing Tampa Bay Water desalination facility, have the potential to bring the total production from seawater desalination to 75 MGD. The district's Regional Water Supply Plan also identifies a considerable number of existing and proposed brackish water desalination projects within the 10-county planning region, primarily in Charlotte, Pinellas and Sarasota Counties.

The St. Johns River Water Management District (SJRWMD) is assisting a consortium of utilities in planning the development of the Coquina Coast seawater facility in Flagler County (http://www.sjrwmd.com/coquinacoast/index.html). The partners include Volusia, Flagler, Marion and St. Johns counties, the Dunes Community Development District, and the cities of Palm Coast, Deland, Mount Dora, Leesburg, Bunnell, and Flagler Beach. Eleven other potential sites were identified, three of which remain under consideration, though none have been selected for implementation at this time. As with the Southwest and South Florida districts, brackish water desalination is a significant component of water supply within the St. Johns River district.

In the South Florida district, investments by utilities in desalination, assisted by grants from the district, have resulted in doubling the amount of desalinated water and number of plants in the last 10 years. Currently, there are 29 brackish water and two seawater plants in operation. Eight brackish water plants are under construction and are expected to be completed before 2012. Total capacity is expected to reach 250 MGD by 2012 (SFWMD, 2009).

## *SECTION THREE: Desalination - The Technology and Application in Florida*

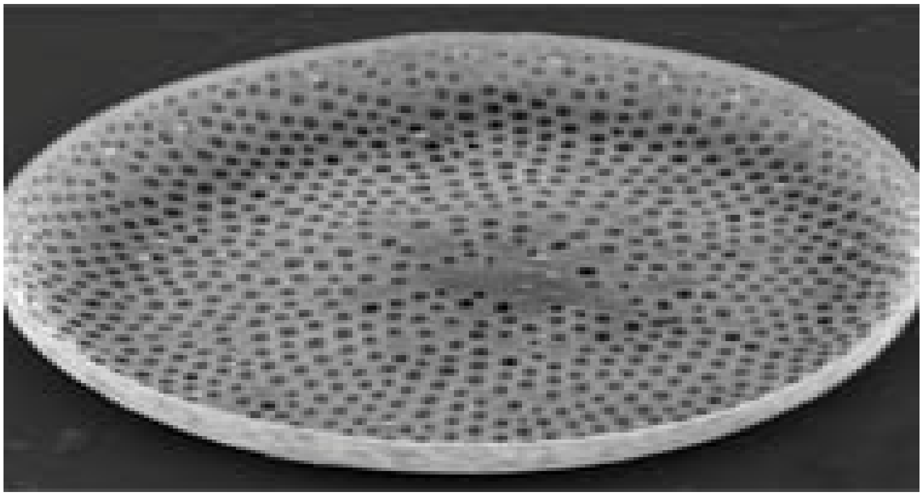

**Figure 3-1. The Structure of the Diatom Algae Being Reproduced Using Nanotechnology to Create More Efficient Membranes for Desalination (Copyright CSIRO Australia, 2009)**

### 3.1 A Brief History

As mentioned previously, the history of desalination in the United States can be traced back to the 1790's when Secretary of State Thomas Jefferson evaluated a proposal to provide affordable, freshwater to a fledgling US Navy. In Florida, the commercial use of modern desalination plants dates back to the latter part of the nineteenth century. Today Florida leads the nation in desalination, accounting for about 40 percent of the country's freshwater produced from seawater and brackish ground and surface waters. In the South Florida Water Management District (SFWMD) boundaries alone, there are 29 brackish and two seawater desalination plants In that region, eight brackish water plants are under construction and collectively will produce 250 MGD of potable water by 2012 (SFWMD, 2009).

This section will provide a brief description of desalination technology used in the state and describe some new technologies being tested or recently implemented. It includes a 'walk-through' of the state's largest seawater desalination facility, a discussion of concentrate management, and, finally, a general discussion of cost.

### 3.2 Desalination Processes

Desalination is the removal of salts or dissolved substances from raw water (referred to as source water) to produce water that is suitable for its intended purpose, for example, human consumption, irrigation, or industrial use. For the purpose of this report, that intended purpose is for drinking (potable) water.

The most common technologies available for desalination around the world are membrane reverse osmosis (RO), thermal distillation (TD), and electrodialysis (ED). In this section we will focus on technologies currently in use in Florida, including reverse osmosis, and to a much lesser extent, electrodialysis. Later, in the discussion of newer technologies, thermal technologies will be presented, particularly where they are combined with membrane technologies to produce a hybrid system. While Florida has no existing thermal or distillation facilities, and they only compose 3% of the production in the U.S.A., they represent more than 40% of the world production.

The chart below (Table 3-1) provides a summary of conventional treatment technologies and the type of material the technology can remove from the source water. While only a few of these technologies are capable of removing salts, many are important methods of pre-treating the raw or source water prior to applying the desalination treatment. Barron (2006) provides another summary of desalination processes broken down into thermal, solar-driven, and non-thermal methods (shown in Figure 3-2). Figure 3-2 underscores an important point; some technologies have been available for some time, but costs to operate the process have deferred its use. Recent advances in membrane technology and other areas are making these cost-prohibitive processes more cost effective (Voutchkov, 2008). These include such processes as membrane distillation or thermal hydrate techniques, which will be described in the new technology discussion, below.

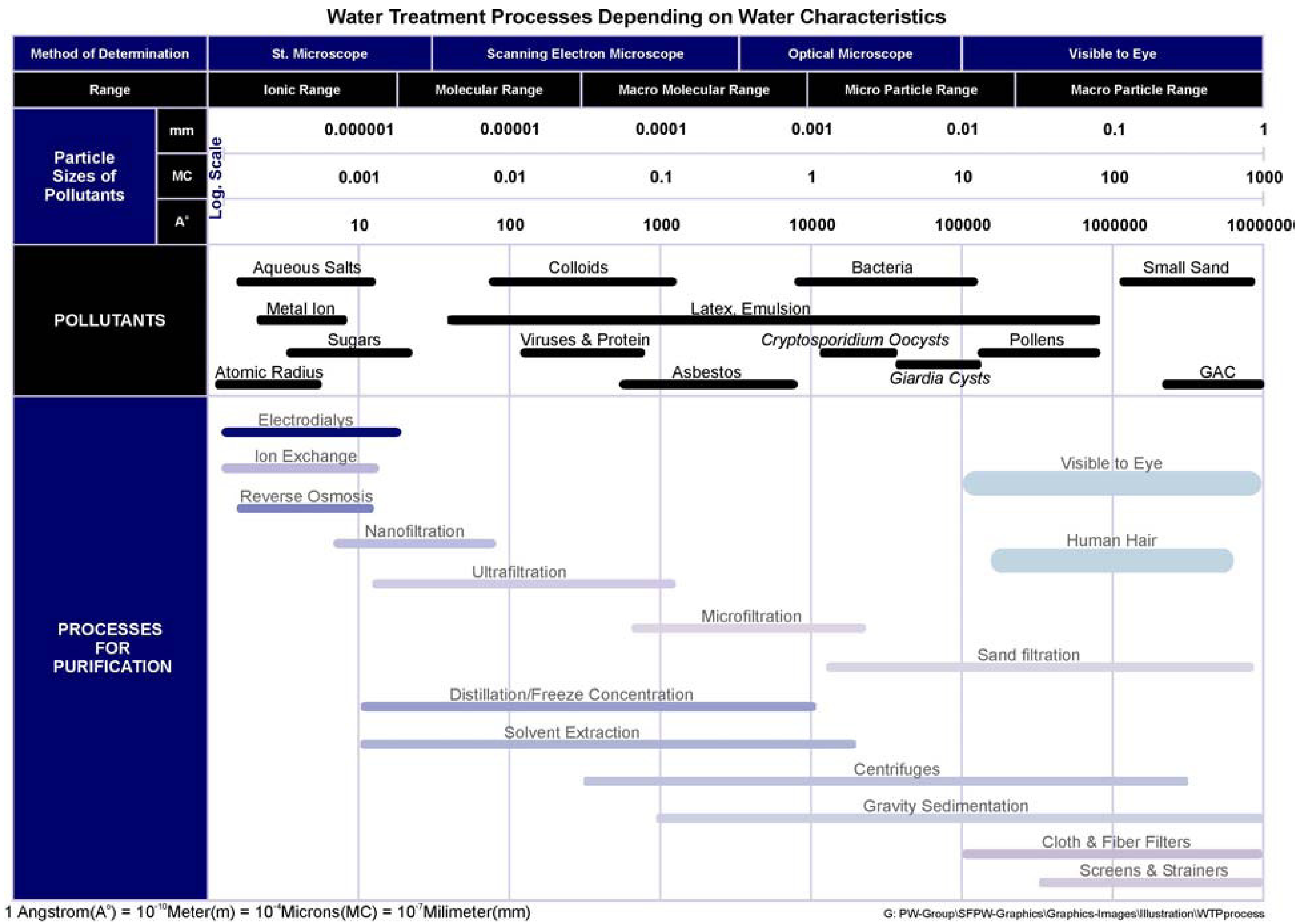


**Table 3-1. Filtration Treatment Processes and the Pollutants Removed (Adapted from Frenkel, et al., 2007)**

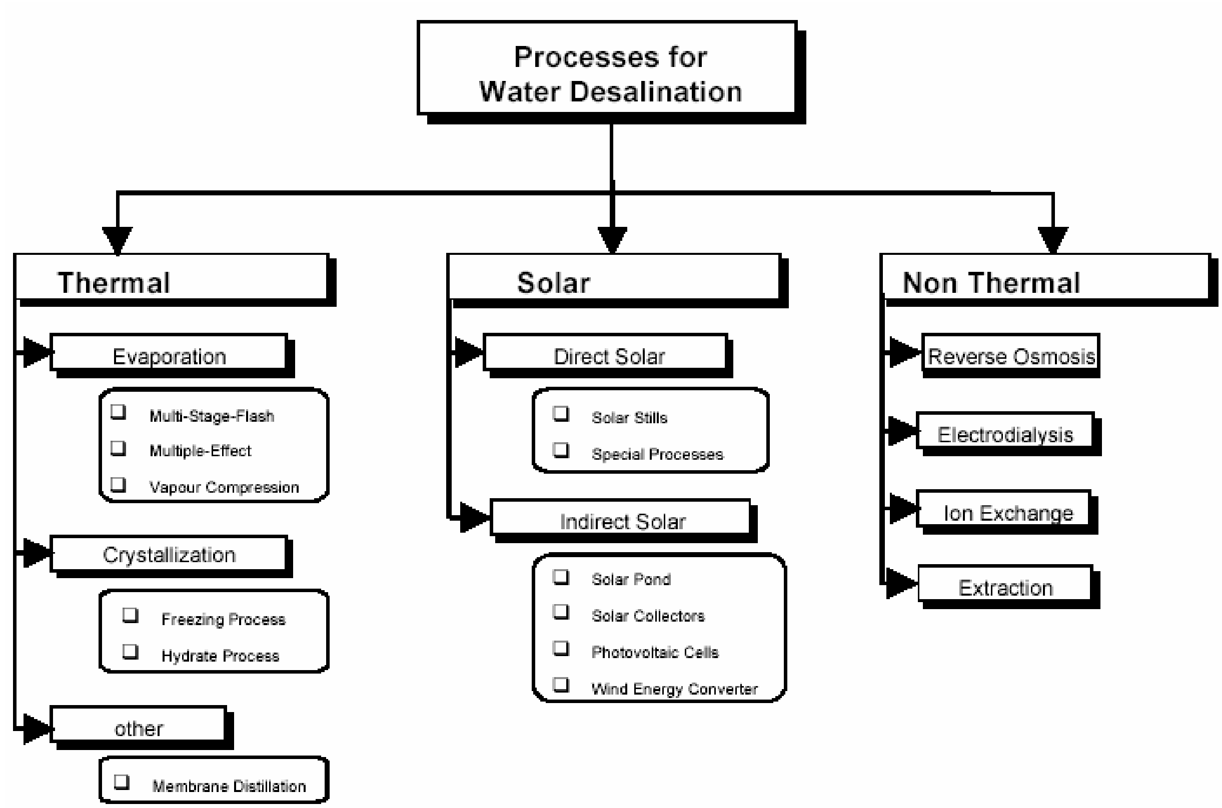


**Figure 3-2. A Summary of Water Desalination Processes (Barron, 2006)**

### *Reverse Osmosis*

Reverse osmosis (RO) uses pressure to force a solution through a membrane that will hold solute (waste concentrate) on one side while allowing solvent (potable water) to pass to the other side. It is the process of applying sufficient pressure to overcome natural osmotic pressure in order to force water from a region of high salt concentration through a membrane to a region of low salt concentration. Membranes used in this process are "semi-permeable," meaning the membrane will allow solvent (water) to pass, but not solutes such as salt ions. A more detailed description of RO is provided in Appendix A.

RO removes the broadest range of substances of the three technologies (RO, TD, ED), but in general it has been energy intensive and the operation and maintenance of the membranes has been costly. Recent membrane improvements have lowered the costs and improved the efficiency (NRC, 2008; ADC, 2008; MacHarg, et al., 2008; Voutchkov, 2008; Kucera, 2008; Fujiwara, 2009).

### *Electrodialysis Reversal (EDR)*

EDR desalination is a type of membrane process that has been commercially used since the early 1960s. The Sarasota County "Carlton" plant is the only plant using this form of desalination in the state. Built in 1995, the facility can generate 12 MGD and is one of the largest EDR plants in the world. An electric current draws dissolved salt ions through an electrodialysis stack consisting of alternating layers of cationic and anionic ion exchange membranes. The result is ion-charged salts and other chemicals are electrically pulled from the source water to produce the finished water.

Electrodialysis has the lowest energy requirement of the three primary desalination technologies, but it has inherent limitations. It works best at removing low molecular weight ionic components from a feed stream. Non-charged, higher molecular weight and less mobile ionic species will not often be removed. Also, in contrast to RO, electrodialysis becomes less economical when extremely low salt concentrations in the finished water are required (NRC, 2008).

### *Distillation*

The basic concept of thermal distillation is to heat a saline solution to generate water vapor and direct the vapor toward a cool surface where it will condense to liquid water. The condensate is mostly free of the salt. Thermal distillation is the oldest desalination method used and until recently provided the most worldwide production of water. According the 19th International Desalination Association plant inventory (GWI, 2006b), in 2006, thermal distillation technologies represented 43% of the total worldwide desalination capacity. Membrane technologies accounted for 56% of the capacity. However, it is very energy intensive and is less efficient at removing volatile substances (i.e. organic compounds, ammonia, etc). It is most efficient when treating higher salinity source waters. With the cost of RO-produced water coming down, the use of distillation technology is declining, although there is renewed interest in combining membrane and distillation technologies (NRC, 2008; Hsu, et al., 2002; Alklaibi and Lior, 2004; Lawson and Lloyd, 1997; Wong and Dentel, 2009).

Table 3-2 provides a summary of the characteristics of seawater reverse osmosis and three forms of thermal desalination technologies: multistage flash (MSF), multiple effect distillation (MED) with thermal vapor compression (TVC), and mechanical vapor compression (MVC). A description of these processes is provided in Appendix B. Table 3-3 continues the comparison for brackish water reverse osmosis, electrodialysis reversal, and nanofiltration (NF). Nanofiltration is used more as a pretreatment process because it is not effective at removing salts.

**Table 3-2. Comparison of Predominant Seawater Desalination Processes (NRC, 2008)**

**(Sources: Wangnick, 2002; Trieb, 2007; GWI, 2006a; USBR, 2003; Spiegler and El-Sayed, 1994)**

| Characteristic | Seawater RO | MSF | MED (with TVC) | MVC |
|---|---|---|---|---|
| Operating temperature (°C) | <45 | <120 | <70 | <70 |
| Pretreatment requirement | High | Low | Low | Very low |
| Main energy form | Mechanical (electrical) energy | Steam (heat) | Steam (heat and pressure) | Mechanical (electrical) energy |
| Heat consumption (kJ/kg) | NA | 250-330 | 145-390 | NA |
| Electrical energy use (kWh/kgal) | 9.5-26 | 11-19 | 5.7-9.5 | 30-57 |
| Current, typical single train capacity (kgal/d) | < 5,000 | < 20,080 | < 9,500 | < 800 |
| Product water quality (TDS mg/l) | 200-500*b* | < 10 | < 10 | < 10 |
| Typical water recovery | 35-50% | 35-45% | 35-45% | 23-41% |
| Reliability | Moderate | Very high | Very high | High |

RO: Reverse Osmosis
MSF: Multistage Flash
MED: Multiple Effect Distillation
TVC: Thermal Vapor Compression
MVC: Mechanical Vapor Compression

°C: Degrees Celsius
kJ/kg: Kilojoules per kilogram
kWh: Kilowatt-hour
kgal: 1000 gallons
TDS: Total Dissolved Solids
mg/l: Milligrams per liter
kgal/d: 1000 gallons per day

| Characteristic | Brackish water RO | ED/EDR | NF |
|---|---|---|---|
| Operating temperature (°C) | <45 | <43 | <45 |
| Pretreatment requirement | High | Medium | High |
| Electrical energy use (kWh/kgal) | 0.5-3 | ~2 kWh/kgal per 1,000 mg/l of ionic species removed | <1 |
| Current, typical single train capacity (kgal/d) | < 5,000 | < 3,200 | < 5,000 |
| Percent ion removal | 99-99.5% | 50-95% | 50-98% removal of divalent ions; 20-75% removal of monovalent ions |
| Water recovery | 50-90% | 50-90% | 50-90% |

RO: Reverse Osmosis
ED/EDR: Electrodialysis/Electrodialysis Reversal
NF: Nanofiltration

°C: Degrees Celsius
kWh: Kilowatt-hour
kgal: 1000 gallons
mg/l: Milligrams per liter
kgal/d: 1000 gallons per day

**Table 3-3. Comparison of Predominant Brackish Water Desalination Processes (NRC, 2008)**

**(Sources: Anne, et al., 2001; Wangnick, 2002; Kiernan and von Gottberg, 1998; Reahl, 2006 Sethi, et al., 2006b; USBR 2003; Semiat, 2008)**

### 3.3 Recent Technology

The 2008 National Research Council report, **"Desalination: A National Perspective,"** observed that the greatest potential for improvement in the field of desalination technology will be in reducing the costs to produce the membranes, identifying alternative energy sources to power the facilities (solar, geothermal, power plant co-location), developing passive pretreatment systems (in-bank filtration), and developing hybrids of existing technologies or improvement of old technologies using new developments. An example is the use of microbial desalination cells that create energy gradients to drive the desalination process (Cao, et al., 2009; Logan, 2009). Some of the newer technologies are presented below in Table 3-4, and described in greater detail in Appendix C. Some are in the pilot test stage. All show promise to reduce the cost of desalination as a means to produce potable water.

Some research efforts around the world provide models for the collaboration of industry, government, and the research sectors with a common goal of reducing the costs to produce water through desalination. One such group is the Affordable Desalination Collaboration (ADC) operating at the US Navy's Seawater Desalination Test Facility at Port Hueneme, California. At this site various membranes and other associated operational parameters are tested to determine the optimal process capabilities. The facility serves as a platform on which cutting edge technologies can be tested and measured for their ability to reduce the overall cost of the seawater RO treatment process (ADC, 2008).

Another example is the Australian Advanced Membrane Technologies for Water Treatment Research Cluster. Again, it is a collaborative effort of government, the industry, and universities (not only from Australia but also from the USA) to improve the use of nanotechnology, biomimetics and functional materials to deliver new innovations in membrane technology and cost-effective and highly efficient water recovery systems (www.csiro.au/partnerships/ps30e.html). This group is also building a national database of membrane technology that will improve information transfer between researchers and its practical application.

These and other organizations such as the American Membrane Technology Association (AMTA) and the International Desalination Association (IDA) represent examples of efforts to promote the development and implementation of desalination. Their work not only considers improvement of the technology but also the minimization of the environmental impacts. It is important for Florida to stay involved in these efforts.

| Innovation | Benefit | Citation |
|---|---|---|
| **Membrane Distillation**<br>- Improved membrane<br>- Hybrid system | High theoretical recovery rate (~80%)<br>Operates at normal pressures – reduces cost<br>Waste or low quality heat source can be used<br>Ability to work with near-saturated solutions | Dow, et al., 2008; Gunderson, 2008; Hsu, et al., 2002; Banat, et al., 2002; Lawson and Lloyd, 1997; Baltutis, 2009; El-Bourawi, et al., 2006; Wong and Dentel, 2009; Walton, et al., 2004; Dow, et al., 2008; Furukawa, 2008; Ludwig, 2004 |
| **Forward osmosis**<br>- New chemicals to drive process<br>- Hybrid system | Lower energy usage<br>High feed water recovery<br>Reduced brine discharge | McGinnis & Elimelech, 2007; Cath, et al., 2006; Teoh, et al., 2008; Adham, et al., 2007; McCutcheon, et al., 2006; Miller and Lindsey, 2006 |
| **Clathrate Desalination**<br>- "Trap" $H_2O$ in $CO_2$<br>- Recent advance in old technology improved yields | Operates at low pressures<br>Suitable for all qualities of water sources | Gunderson, 2008;<br>McCormack and Anderson, 1995;<br>Bradshaw, et al., 2006 |
| **Nanocomposite Membranes**<br>- Thin-film composite membranes with nano-structured material | Improved efficiency of extraction<br>Reduced biofouling & maintenance costs by repelling impurities<br>Reduced energy needs<br>Longer membrane life | Graham-Rowe, 2008; Gunderson, 2008; CSIRO, 2009; Jeong, et al., 2007; CNSI/UCLA and NanoH20, LLC., 2009; Dais Analytic 2009; Risbud, 2006 |
| **Energy Efficient Pumps**<br>- Axial piston pressure exchanger pump<br>- Rotary type energy recovery device | Improved consistency of pressure<br>Lower O&M costs<br>Use of "waste" heat to reduce costs | Gunderson, 2008<br>Ocean-Pacific Technology, 2008<br>CDWR, 2009b; Stover, 2009a; 2009b; Stover and Blanco, 2009 |
| **Dewvaporation**<br>- Old technology using newer energy sources<br>- "Waste" heat<br>- Solar | Energy efficient - uses recycled energy<br>Inexpensive to manufacture<br>Passive-lower O&M<br>Suitable for all qualities of water sources | NRC, 2008<br>Hamieh, et al., 2001<br>Banat, et al., 2002<br>Li, et al., 2006 |
| **Freeze Desalination**<br>- Old technique improved by washing of salts<br>- Use of density gradients | Improved energy efficiency compared to distillation processes<br>Minimal potential for corrosion<br>Little scaling or precipitation | Cooley, et al., 2006<br>NRC, 2008 |
| **Membrane Vapor Compression**<br>- Similar to membrane distillation<br>- Uses compression to reduce temperatures<br>- Improved membranes | Lower operating costs<br>Smaller equipment<br>Lower temperatures<br>Use of waste heat | Ruiz, 2005<br>Gunderson, 2008<br>Dais Analytic, 2009<br>Li, et al., 2006 |

**Table 3-4. Recent Desalination Innovations**

### 3.4 Key Components of Desalination Process

Primary components of the desalination process include intake and conveyance of raw source water, water treatment, residuals management, and concentrate disposal. The components of any desalination system will depend on the source water, the desalting process, and the disposal option chosen. The example below is the relatively new Tampa Bay Water desalination facility that came online at the end of 2007 and can produce up to 25 MGD. The plant is currently one of the largest desalination facilities in the United States. Figure 3-3 illustrates the flow of water through the facility. The source water is from Hillsborough Bay, where salinities range from 5 to 32 parts per thousand (ppt). It is co-located at a fossil fuel power plant and uses the heated once-through cooling water to improve the efficiency of the RO membrane extraction.

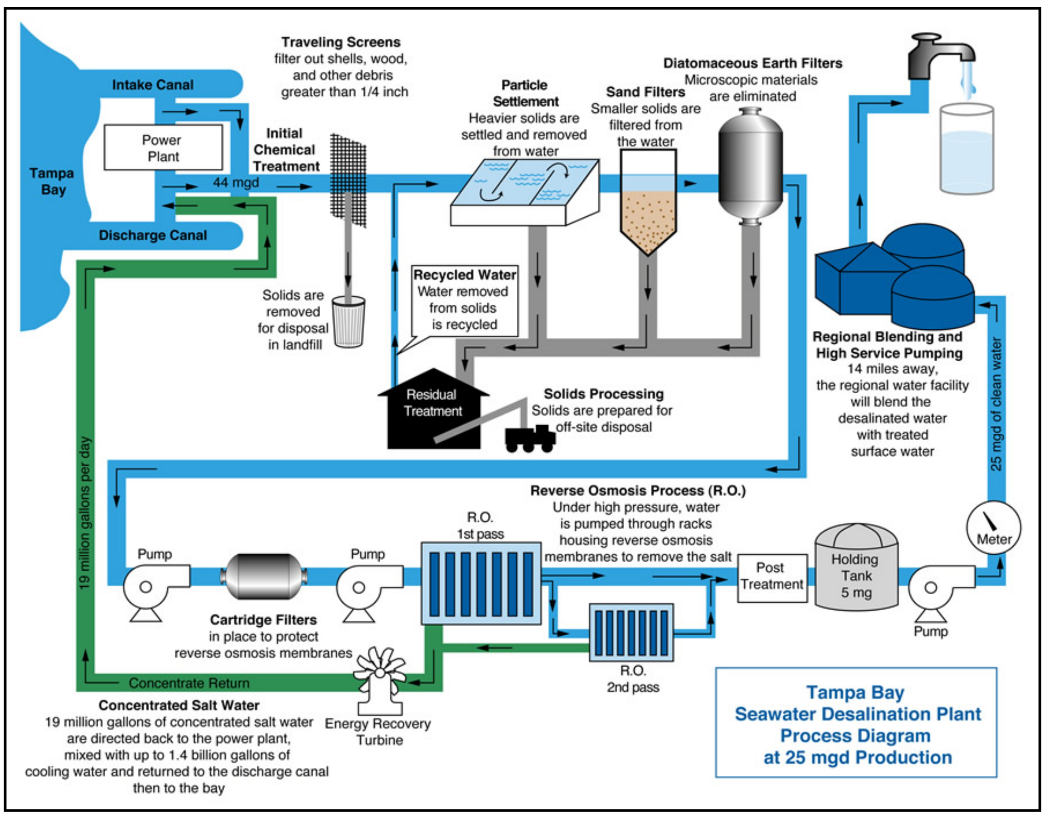


**Figure 3-3. Flow diagram of the Tampa Bay Water Seawater Desalination Facility (TBW, 2008)**

**Figure 3-4. Tampa Bay Water Desalinization Plant (TBW, 2008)**

### *Intakes Structures and Conveyance*

Intake and conveyance structures are used to transport source water to the treatment plant. Site specific source water quality and quantity often influence plant type, intake configuration and location feasibility. Surface water intake structures must be built to cope with varying flows, entrainment/impingement issues, and changes in physical, biological, and chemical characteristics of the influent. Estuarine intakes can potentially see significant changes in salinity over the tidal cycle. Groundwater influent provides a relatively chemically stable source of influent. In other words, the chemistry and physical characteristics, like temperature, in groundwater do not change quickly as surface water does. The groundwater is less likely to have other substances like organic plant material, algae, zooplankton, but the geology may restrict the amount of water that can be withdrawn (NRC, 2008; Cooley, at al., 2006; TWDB, 2008b; CDWR, 2009; Meyerhofer, 2008; Reynolds, 2009).

### *Pretreatment*

The feed or source water, depending on its origin, may contain various concentrations of suspended solids and dissolved matter. Therefore, pretreatment is a critical component of all desalination processes. During the RO process, the volume of feed water decreases, and the concentration of suspended particles and dissolved ions increases. A comprehensive pretreatment program will reduce scaling, control corrosion, remove suspended solids and prevent biological growth. A successfully implemented pretreatment program will ensure source water has minimal impact on performance of the desalination process.

Depending on the raw water quality, the pretreatment process may consist of all or some of the following treatment steps:

- Removal of large particles using a coarse strainer.
- Bio growth control with chlorine or other chemicals.
- Clarification with or without coagulation/flocculation.
- Clarification and hardness reduction using lime treatment.
- Media filtration.
- Reduction of alkalinity by pH adjustment.
- Addition of scale inhibitor.
- Reduction of free chlorine using sodium bisulfite or activated carbon filters.
- Water sterilization using UV radiation.
- Stabilization basins/chambers to minimize feed variation.

A more detailed description of the pretreatment process for a desalination facility is presented in Appendix D.

### *Reverse Osmosis Treatment*

The central component of the treatment train is the seawater reverse osmosis (SWRO) membrane. The Tampa Bay Water system, illustrated in Figure 3-5, is set up so that parallel trains of RO units can receive maintenance, while other units are operational. The layout of the membranes provides for easy access for maintenance, removal and replacement. Eight SWRO membranes sit in each of the 1,176 pressure vessels which comprise the central part of the desalination system. These are divided into seven separate treatment trains.

**Figure 3-5. Tampa Desalination Facility Reverse Osmosis Membranes (TBW, 2008)**

### *Post-Treatment*

Water from a desalination process is typically void of dissolved solids resulting in finish water with low hardness and low alkalinity. As a result, desalinated water without post-treatment is corrosive toward the metal and concrete surfaces of pipelines and other wetted surfaces. Without proper post-treatment this can release metal ions into finished water and can significantly degrade water-system infrastructure. The introduction of chemicals such as calcium hydroxide (slaked lime) is used to increase the hardness and alkalinity, while sodium hydroxide (caustic soda) and carbon dioxide are used to adjust the pH to stabilize desalinated water (Figure 3-6). Post-treatment of desalinated water is well understood, and methods for altering desalinated water are widely available. Customized post-treatment and its associated cost will depend upon factors such as the chemistry of the desalinated water and the complexity of infrastructure (NRC, 2008).

**Figure 3-6. Post Treatment Lime Softening Using Slaked Lime**

### *Concentrate Management*

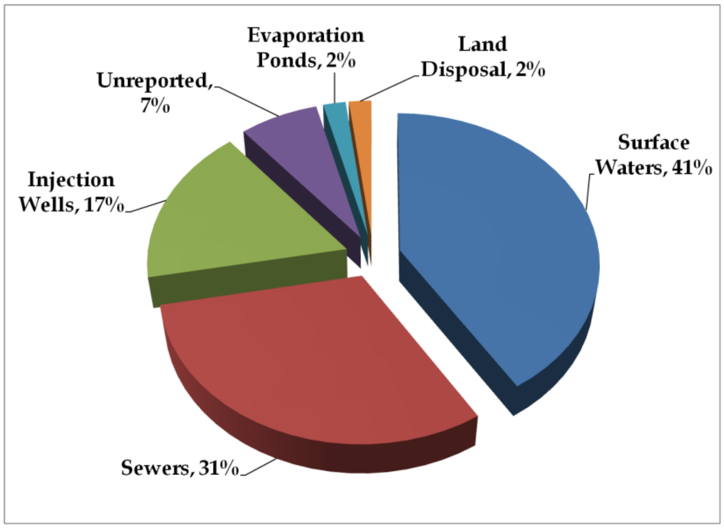


**Figure 3-7. A Summary of Desalination Concentrate Management Methods in the United States (Adapted from NRC, 2008)**

All desalination processes leave behind a concentrated salt solution that may also contain some pretreatment and process residuals. Concentrate and residuals management involves waste minimization, treatment, beneficial reuse, and disposal.

Each approach has its own set of costs, benefits, environmental impacts, and limitations (Sethi, et al., 2006a). A more detailed discussion of the potential environmental consequences of concentrate management is presented in Section 4 of this report. Because of the widely varying level of technology involved in concentrate management options, and site-specific factors and regulatory considerations that limit available alternatives, the cost of concentrate management can range from a relatively small fraction of the cost of the main desalination system to a significant portion of the project cost.

Figure 3-7 illustrates methods of concentrate management based on a survey of the 234 municipal desalination plants in the United States with output greater than 95 $m^3$/day (25,000 gallon per day) (Mickley, 2006). A summary of the challenges and limitations in the current state of concentrate management methods is also provided in Appendix E.

### *Offshore Desalination*

One recent and unique approach being considered in Florida and elsewhere is a Seawater Desalination Vessel (SDV).

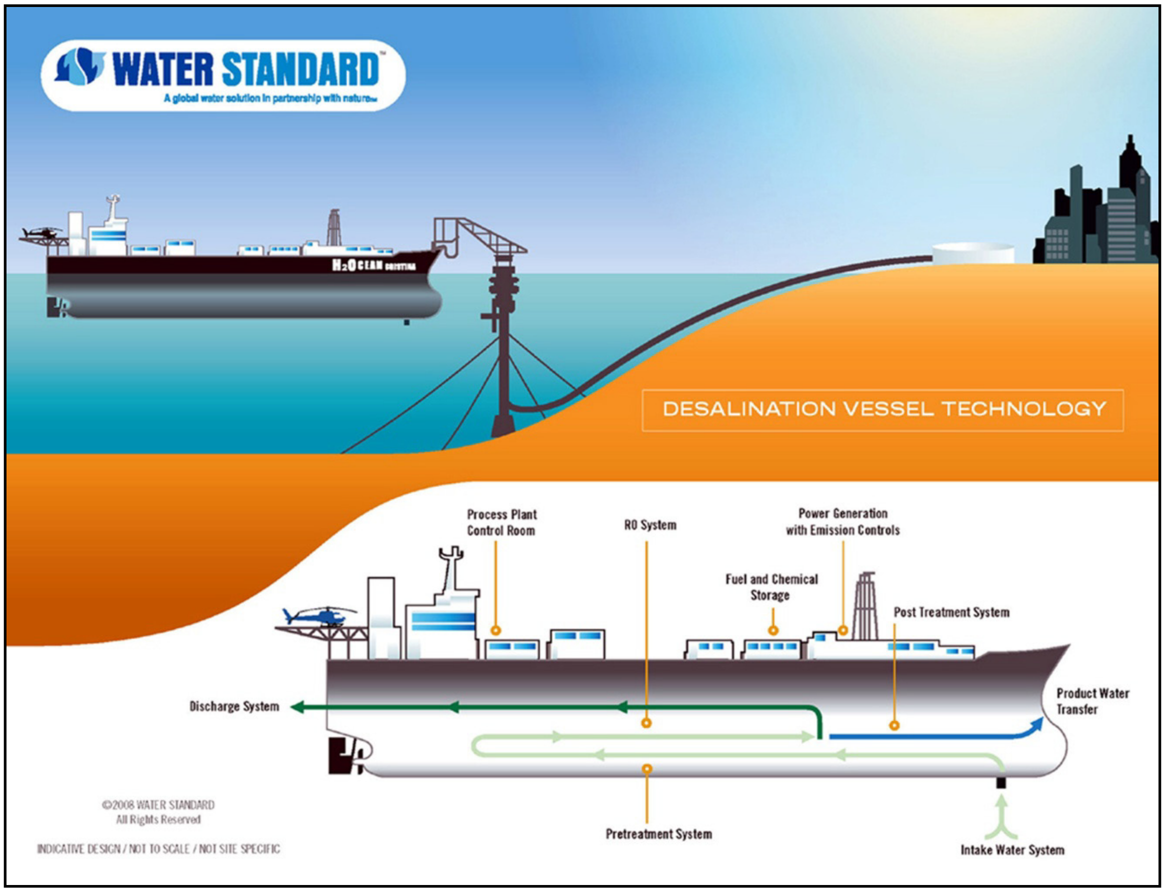


**Figure 3-8. Shipboard Desalination (WDR, 2008)**

A SDV is a vessel with conventional on-board desalination processes, like reverse osmosis, that military and cruise ships have used for years. SDV's are typically located offshore where the water quality is less affected by runoff causing fluctuations in salinity and other water quality parameters, therefore reducing pre-treatment needs and the costs to desalinate. Onboard a SDV, as the anchored ship points up-current, seawater is drawn through a passive intake system near the bow using low-velocity pumps to minimize the impact on sea life. Discharge water is diffused back into the ocean, from the down-current stern, at a rate sufficient to maintain the integrity of seawater temperature and salinity (Bluestein, 2008). Additional information on this project is available at the SJRWMD website: www.sjr.state.fl.us/coquinacoast/index.html.

Finished water transportation may include seabed pipelines, transfer stations with flex hoses or shuttle vessels for delivery to on shore storage facilities for distribution.

### 3.5 Cost

In decades past, the high costs of desalination limited its use in all but a few applications in the U.S. Today, the cost to desalinate has declined primarily due to increased membrane efficiency coupled with significant reductions in the cost of membranes. Costs have also been reduced through improved efficiency of treatment train processes, for example, the use of waste heat. These declining costs of desalination, coupled with increasing limitations on the use of fresh groundwater in some parts of the state and the high cost of building pipelines to transport water from distant well fields to areas of need, have made desalination more competitive as an alternative source of potable water supply (AWWA, 2008; Henthorne, 2008; Cooley, et al., 2006; CDWR, 2009; Voutchkov, 2007a; 2007b; Voutchkov, 2008, Heimlich, et al., 2009).

As the cost for desalination becomes more competitive with conventional water supply costs, another factor that will affect the cost and ultimately control the final choice of treatment for the utility, the origin or type of the source water. For example, the specific energy requirement for RO desalination varies with the treatment system used and the operational conditions, but the most important factor is generally the concentration of salt in the source water. For seawater RO, the specific energy usage is typically about 11-26 kWh/kgal with energy recovery devices (Alonitis, et al., 2003; Miller, 2003; see Table 3-2). For brackish water RO, energy usage is comparatively lower, about 2-11 kWh/kgal, because the energy required for desalination is proportional to the feedwater salinity (Sethi, et al., 2006b; see Table 3-3). In other words, it takes about 2 to 5 times as much energy to treat open ocean water as it does brackish water. Of course, other site specific factors, such as disposal options, can change the decision in favor of seawater desalination (NRC, 2008; Voutchkov, 2007b; 2008).

Two recent studies provided a range of Florida specific costs associated with the use of reverse osmosis membrane technologies. The first study looked at new stand alone systems with different types of source waters. The study compared relative total costs of RO using brackish groundwater, brackish surface water, and seawater as the source water (CDM, 2007). The cost curves associated with each option and are shown in the Figures 3-9, 3-10, and 3-11.

The basis for the groundwater cost estimates came from the following projects:

- City of Clewiston Low Pressure RO Water Treatment Plant, 3.0 MGD.
- Lake Region Water Treatment Plant, Palm Beach County, 10 MGD.
- Collier County, 12 MGD.
- El Paso, Texas, 28 MGD.
- Cape Coral, 3.1 MGD.
- Lake Worth, 4.5 MGD.
- Lee County Pine Woods, 2.3 MGD.
- North Miami Beach, 6.5 MGD.
- Alameda County Water, 6 MGD.

Fewer projects using seawater as the source water were available for the analysis. The curves for brackish surface water sources identified no project (as evidenced in Figure 3-10) and were extrapolated from information on the other projects. The estimated average production cost per 1,000 gallons from a 10 MGD facility ranges from about $3.20 (brackish groundwater) to $5.00 (seawater). These cost curves indicate that for all desalination facilities, the larger the plant, the lower the cost to produce the 1,000 gallons. However, for the brackish groundwater systems evaluated in the study, the cost differential between large and small facilities was not as great as it was for the seawater facilities, and remains near the $3.00 to $3.50 range even for the smaller plants near the 2 MGD production capacity.

As the study states, these figures should only be viewed in the most general way. Every site has unique factors that can dramatically affect the final production costs, but as previously noted, the salinity of the source water is a key indicator of energy costs. One of the projects used in the seawater cost curves is the Tampa Bay Water desalination facility. The costs at this site probably represent the lower end of the cost range for seawater desalination systems for two reasons. The source water is estuarine with salinities ranging from 5 to 32 ppt of total dissolved solids (TDS), lower than the 35 ppt of true seawater, thus requiring less energy to desalinate. Secondly, the plant is co-located at the TECO – Big Bend Power Plant and takes advantage of the 'waste heat' from the source water to improve efficiency of the membranes, an existing intake and disposal conveyance system, and proximity to the power grid to reduce the overall costs to construct and operate. Co-location is an attractive option for those reasons (Voutchkov, 2007b; 2008; CDWR, 2008a; 2008b).

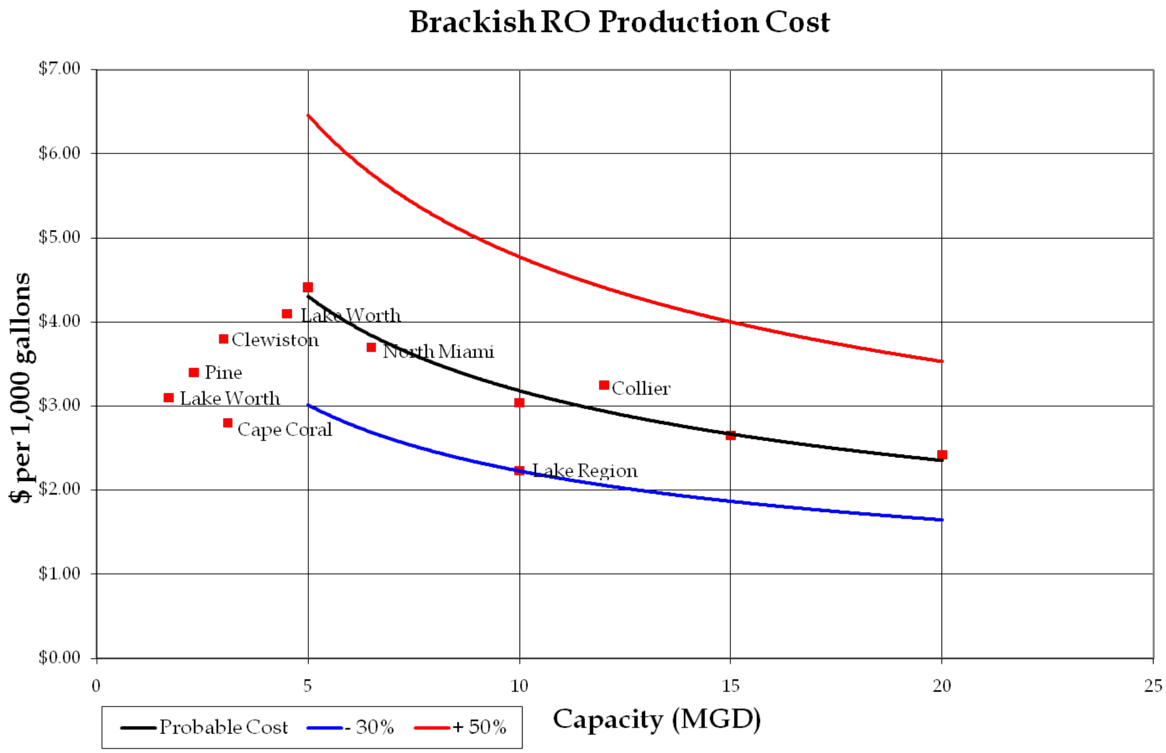


**Figure 3-9. Reverse Osmosis Production Cost Curves Using Brackish Groundwater as the Source Water (CDM, 2007)**

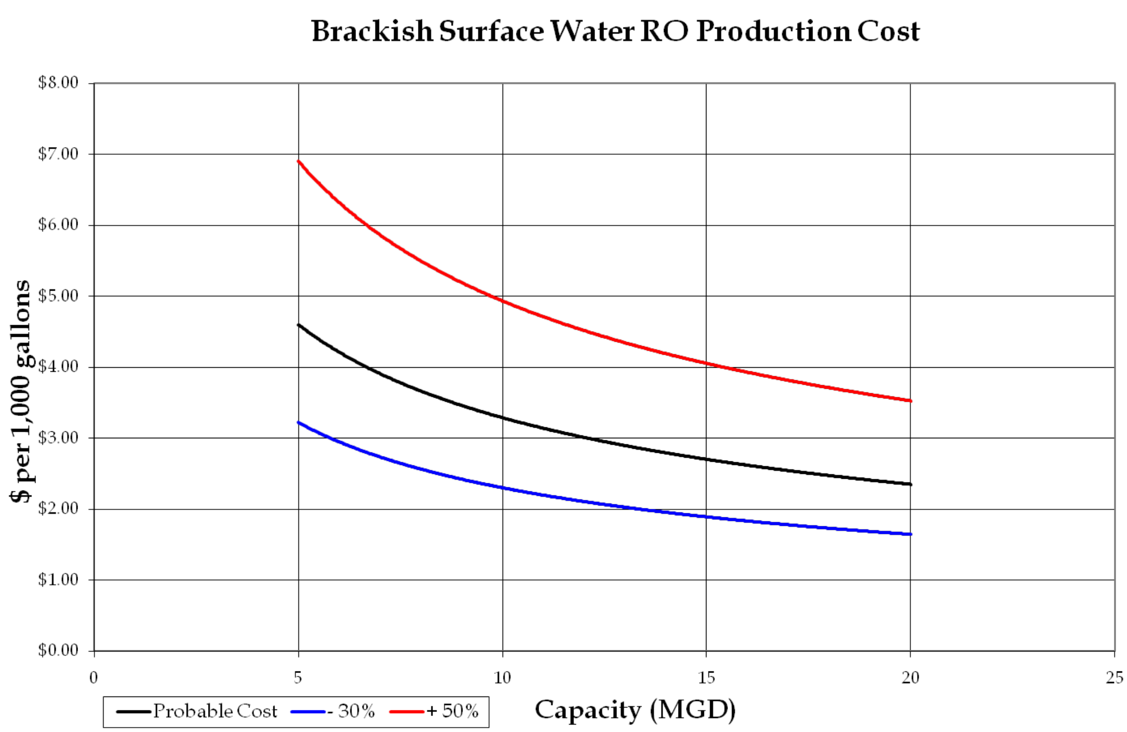


**Figure 3-10. Reverse Osmosis Production Cost Curves Using Brackish Surface Water as the Source Water (CDM, 2007)**

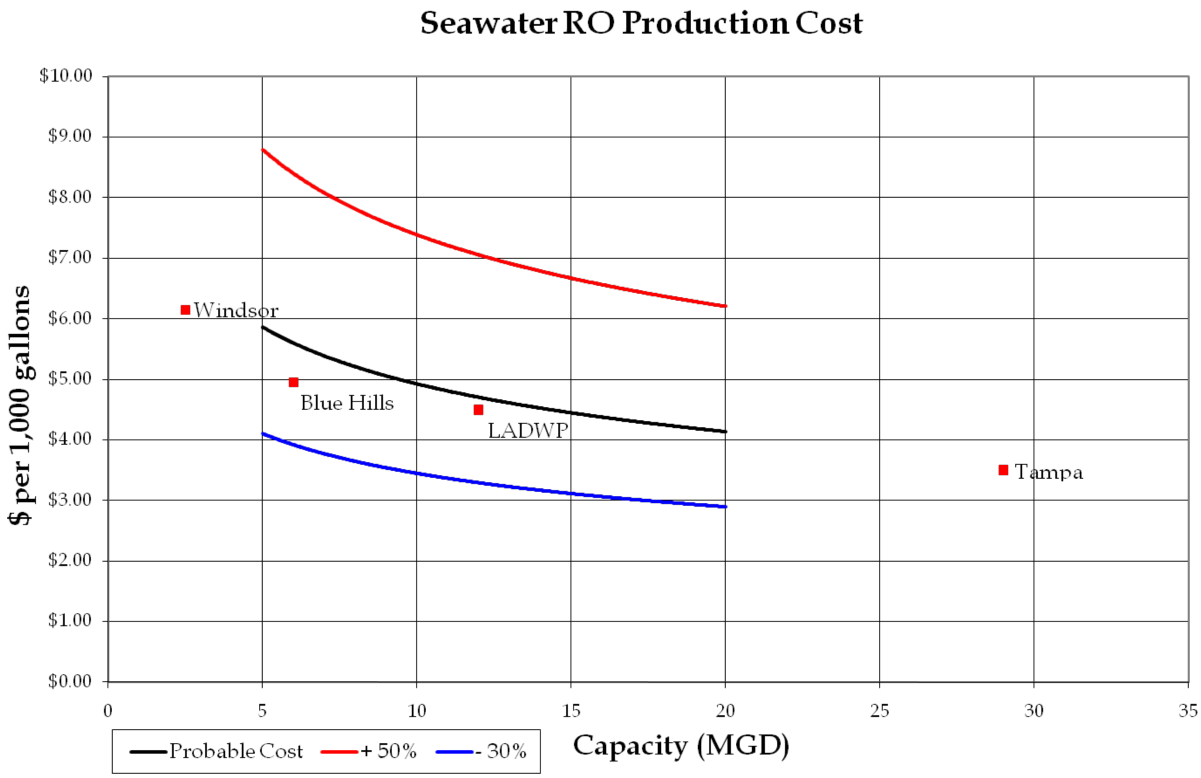


**Figure 3-11. Reverse Osmosis Production Cost Curves Using Seawater as the Source Water (CDM, 2007)**

### *Cost Estimates of Co-Located Desalination Facilities*

The second of the two studies, funded by the South Florida Water Management District, examined the feasibility of co-locating reverse osmosis treatment facilities with electric power plants (Metcalf & Eddy, 2006). As mentioned previously, this is the approach taken for the Tampa Bay Water desalination facility, which is co-located at the TECO – Big Bend Power Plant. The heated source water is taken from a small portion of the once-through cooling water after it has gone through the power plant. The heated source water increases the efficiency of the membranes to extract the freshwater. The study applied this concept to a number of potential sites along the southeast and southwest coast of Florida and narrowed the possibilities to three existing power plant sites. A summary of the estimated construction costs, O&M costs, and equivalent annual costs is presented in Table 3-5.

| Candidate Site | Plant Capacity (MGD) | Water Quality (TDS) (mg/l) | Total Construction Costs (millions) | Total Annual O&M Costs (millions) | Equiv. Annual Costs ($/1000 gallons) |
|---|---|---|---|---|---|
| **Port Everglades** | 35 | 33,000 | $275.90 | $21.30 | $4.16 |
| **Lauderdale** | 20 | 15,000 | $148.00 | $10.40 | $3.88 |
| **Fort Myers** | 10 | 15,000 | $91.10 | $6.40 | $4.66 |

**Table 3-5. Summary of Estimated Costs to Build and Operate RO Desalination Facilities at Port Everglades, Lauderdale, and Fort Myers Power Plant Sites (Metcalf & Eddy, 2006)**

These cost estimates are slightly higher than at the Tampa Bay Water desalination facility (probably because the salinity at these sites is higher), but are still in the lower part of the expected cost curve range for seawater desalination. The low cost is also partly attributable to co-location on pre-existing industrial sites, which minimizes the costs associated with any new site development.

Partnership discussions between the Florida Power & Light Company and the Lee County Utilities, facilitated by the SFWMD, started in early 2003, but no agreement on partnering to build the seawater desalination facility at the identified Fort Myers site was reached.

### 3.6 Florida's Membrane Plants

The last segment of this section describes the demographics of desalination facilities in Florida. The FDEP currently regulates more than 140 Public Water Systems (PWS) that utilize RO membrane technology in the production of drinking water. These public water systems, illustrated in Figure 1-4, provide a cumulative capacity in excess of 515 MGD to a population of greater than 4.2 million (see Table 3-6). The source water for all but three of the systems is either brackish ground or surface waters. The remaining three seawater systems are the Tampa Bay Water desalination facility, Marathon, and Stock Island (the latter two are located in the Florida Keys).

| ***FDEP Regulatory District*** | ***RO Plants*** | ***Population Served*** | ***Design Capacity (MGD)*** |
|---|---|---|---|
| Northwest | 2 | < 1000 | < 1 MGD |
| Northeast | 15 | ~ 240,000 | ~ 23 MGD |
| Central | 21 | ~730,000 | ~ 42 MGD |
| Southeast | 42 | ~1,985,000 | ~ 280 MGD |
| South | 31 | ~ 864,000 | ~ 81 MGD |
| Southwest | 29 | ~ 459,000 | ~ 89 MGD |
| **Totals** | **140** | **~ 4,279,000** | **~ 515 MGD** |

**Table 3-6. Characterization of Desalination Plants in Florida (FDEP, 2009)**

A complete listing of all FDEP regulated RO plants in Florida may be found in Appendix F. Figure 3-12, maps the location of the RO plants in the South Florida Water Management District. They typify the general pattern, statewide; that is, they are located in population centers, usually along the coastline, where freshwater resources have been depleted and the costs to transport inland water to the water treatment plant have increased to a point that using RO technology to treat local brackish water is more cost effective. Figure 3-13 illustrates the expected growth of potable water supplied by desalination facilities from 2008 to 2025 (SFWMD, 2008a).

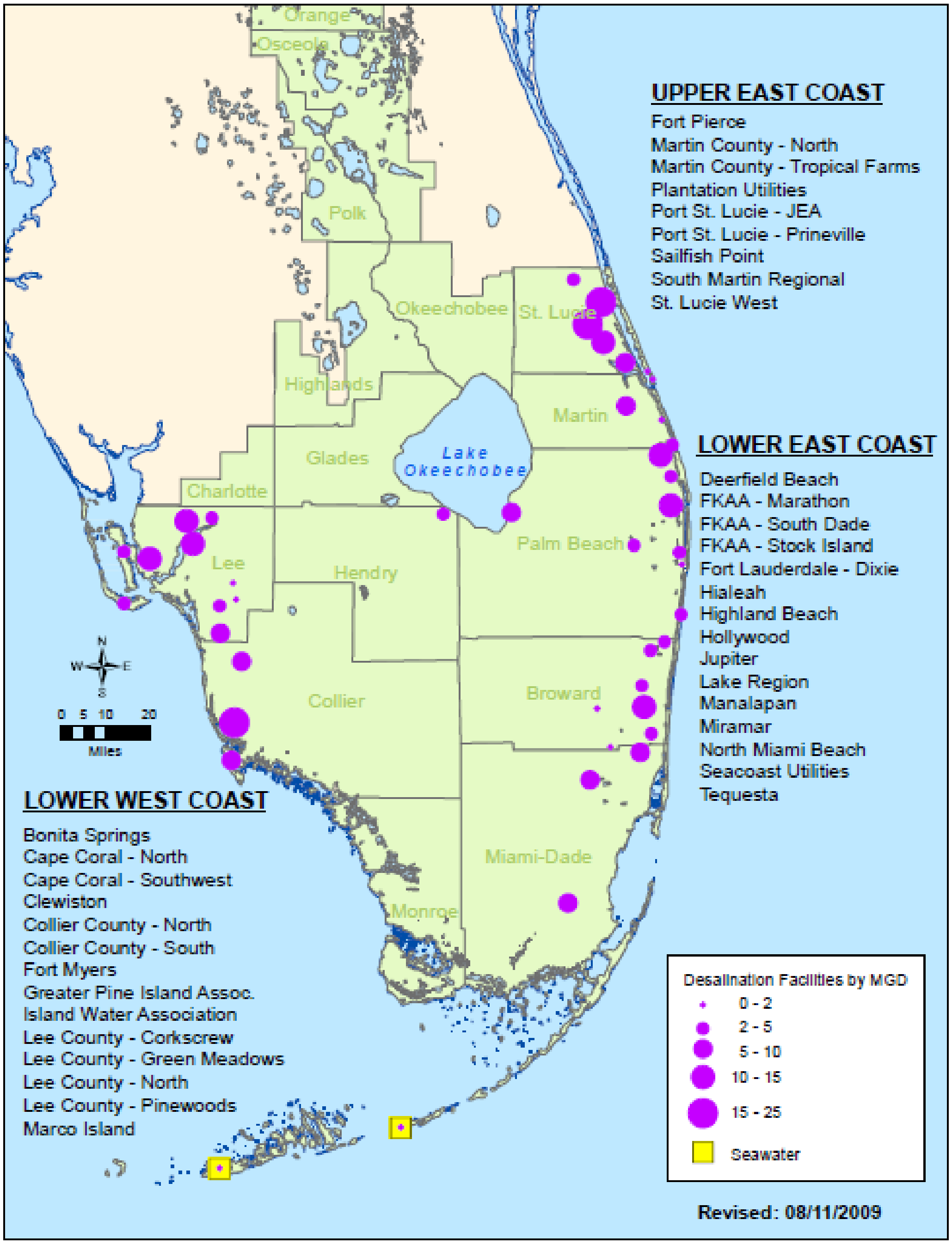


**Figure 3-12. 2009 Potable Water Desalination Plants in the South Florida Water Management District (SFWMD, 2009)**

*MGD = Millions Gallons per Day*

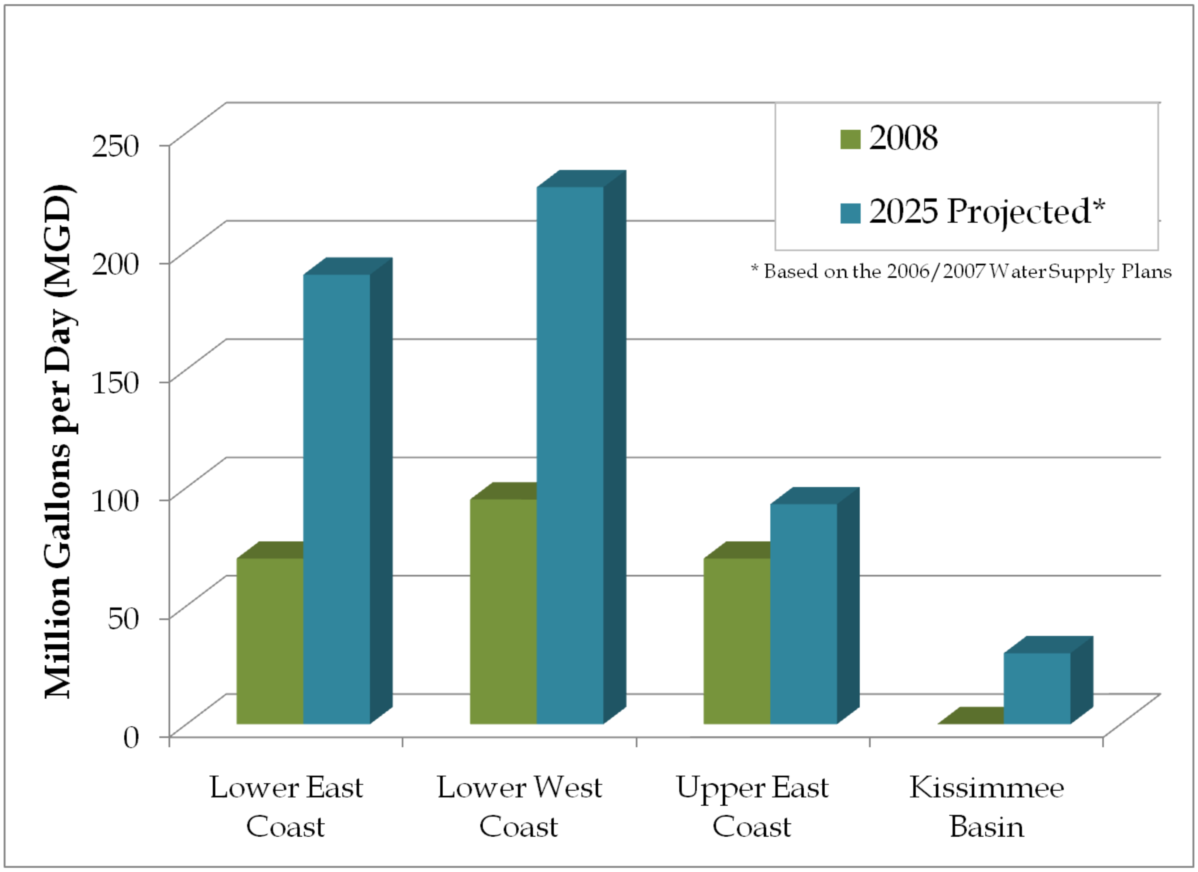


**Figure 3-13. Growth of Desalination Potable Water Production in the South Florida Water Management District (SFWMD, 2008a)**

Figure 3-14 provides a summary of the desalination flows and numbers of facilities within the jurisdiction of the South Florida Water Management District. Clearly there is a significant increase in facility numbers and flows in the last 20 years and the trend is projected to continue, as shown in Figure 3-13, particularly along the coastal regions of the District.

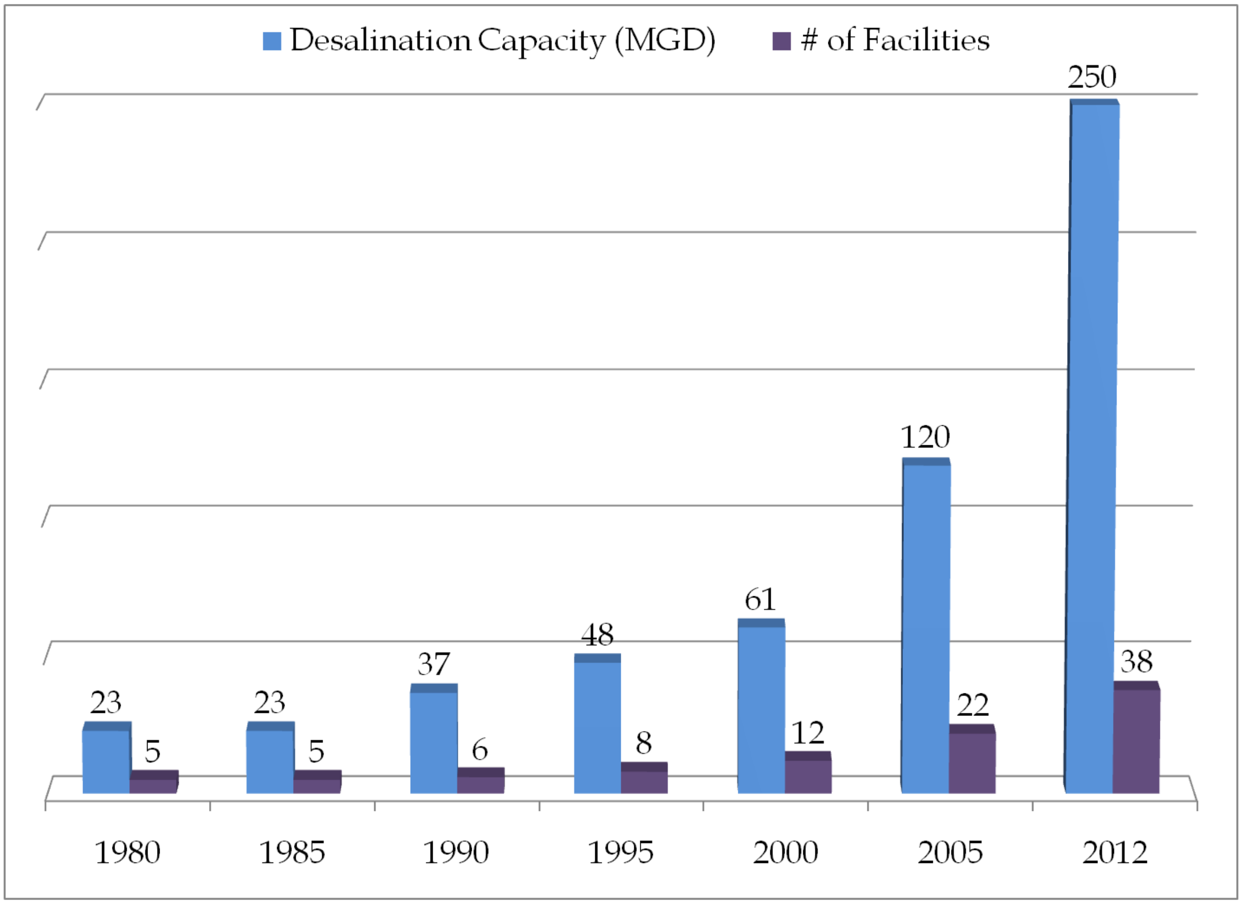


**Figure 3-14. Growth of Desalination in the South Florida Water Management District (SFWMD, 2008a)**

# *SECTION FOUR: Desalination Concentrate Management*

**Figure 4-1. Seawater Desalination Plant with Marine Discharge, Perth, Australia**
(http://www.water-technology.net/projects/perth/)

All desalination processes generate a concentrated salt or brine by-product that must be managed in an environmentally sound manner. The importance of its proper management will affect site selection for the facility, the costs to generate the water, and the public's acceptance of the project. This section will discuss Florida's regulatory controls, and how they are applied in the permitting process based on the source water, the desalination technology, and the brine concentrate management options.

## 4.1 The Regulations

Section 403.0882, F.S., encourages development of alternative water supplies using desalination to provide drinking water from lower quality sources that have been previously underutilized. The statute emphasizes environmental safeguards and efficient regulation through the development of consistent statewide permitting rules for desalination concentrate management. Based on this law, the Department has developed specific wastewater permitting rules for the desalination of seawater, brackish surface water from coastal estuaries and bays, brackish groundwater pumped from wells, and water from inland rivers. The rules acknowledge that under certain carefully defined circumstances, concentrate management is not problematic. They also create a streamlined authorization process for small utilities that use a desalination process and that present minimal environmental risk.

The rules acknowledge the importance of upfront planning for brine concentrate management: "During preliminary siting considerations, it is recommended that water supply utilities or entities that propose to operate demineralization facilities evaluate concentrate disposal options potentially available in the project area."

Wastewater permitting rules for concentrate management are found in Chapters 62-620 and 62-4.244, F.A.C. Discharge of concentrate via deep well requires an Underground Injection Control (UIC) permit from the Department under Chapter 62-528 F.A.C. These rules can be reviewed at: (http://www.dep.state.fl.us/water/rulesprog.htm#ww).

### 4.2 Source, Technology, and Management Options

In assessing the potential environmental effects of concentrate management, the three factors of source water type, desalination technique employed, and the concentrate management method must be considered. These factors shape the requirements or even the need for a regulatory permit.

Source waters can be from surface or ground waters, and those waters may be seawater strength (about 10 to 35 ppt of total dissolved solids) or brackish (from 1 to about 10 ppt). However, the types of salts found in groundwater are typically different from the salts in seawater, and this difference can become an issue when the concentrate brine from groundwater sources is discharged to the ocean or to brackish estuaries. Groundwater source quality is more chemically stable than surface waters, and ground waters do not typically contain algae and pathogens, or other biological components that must be removed. Open ocean seawater quality would generally be much more stable than estuary or river waters, where quality changes every tidal cycle. These differences in the chemistry of the source water will influence the desalination process selected (including pretreatment), the composition of the concentrate, and its management options. For example, a substance like radium, meeting water quality standards in the source water, may exceed water quality standards in the concentrate. An accurate chemical characterization of the source water allows the utility to design the desalination process treatment train and select a suitable management option that ensures compliance with the water quality standards.

The treatment technology used to reduce the salt content of the source water will affect the quality of the concentrate. For example, thermal technologies (very common around the world, but not in Florida) like multi-stage flash distillation, will remove the salt and a number of other substances, but volatile and many other organic compounds may not be removed.

Electrodialysis (one facility in Florida) works to remove ionically-charged substances, but will not remove other 'neutral' or non-charged chemicals like certain organics. Reverse osmosis (RO) is very effective at removing most substances, most importantly salts. At least a portion of some chemicals like the ammonium ion, however, may not be as effectively removed by RO (Koyuncu, et al., 2001). Knowing the treatment technology employed helps the facility owner, their representatives, and DEP understand what will be in the concentrate and guide the selection of the most appropriate management option.

The selection of the option will be discussed in greater detail below, but briefly, the facility owner and their representative should be aware of the volume and composition of the concentrate. If the final salt content is low then land application options may be available without affecting vegetation, also called phytotoxicity. If brackish Upper Floridan aquifer waters were used as the source waters then the plant may be located far from surface waters and underground injection of the concentrate into a deep saline aquifer may be the best environmental and economical option available (Heimlich, et al., 2009).

Entrainment of organisms should be evaluated where the facility uses surface water as its source water. Entrainment is the trapping of organisms in the facility's intake system, by either drawing the organisms into the treatment facility or impinging or holding the organism against the screens at the opening of the intake. Typically, the volume withdrawn from the surface water is a very small part of the source water volume or flow. But occasionally, when the volume of the intake water is a significant portion of the source water, then entrainment of organisms can become an issue. Regardless of the intake flow, steps can be taken to minimize entrainment by locating the intake structures where there is sufficient water to minimize the impact of the planned withdrawals. The intake structures can also be designed to reduce the flow velocity providing an opportunity for organisms to escape being drawn into the intake structure. Screens or booms or both can be used to exclude organisms from the intake. Figure 4-2 below shows a side view of "fish excluder" screen system designed to prevent impingement (larger organisms becoming trapped against the filtering screens) and entrainment in this manner.

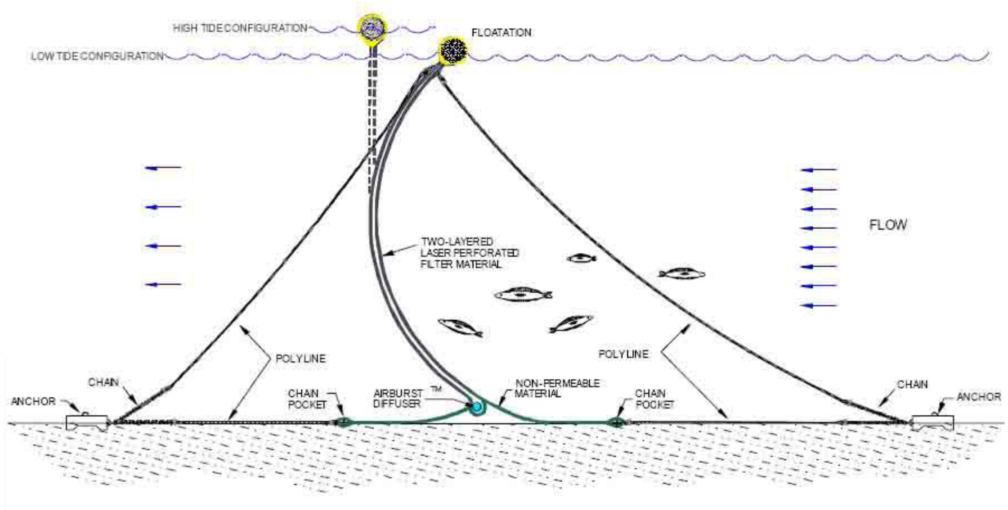


**Figure 4-2. Side View of a Fish Exclusion Screen around a Surface Water Intake Structure (NRC, 2008)**

The issue of impingement and entrainment can be eliminated in circumstances where it is possible to use directional drilling to install piping below the seabed and draw water down through a sandy bottom, rather than pump it from the surface (Meyerhofer, 2008; Reynolds, 2009). This approach also provides some initial filtration as water is drawn down through the sand, and is illustrated in Figure 4-3, below. The seawater desalination facilities in the Florida Keys use this approach. Shallow groundwater wells draw in seawater to be conveyed to the plant's intake.

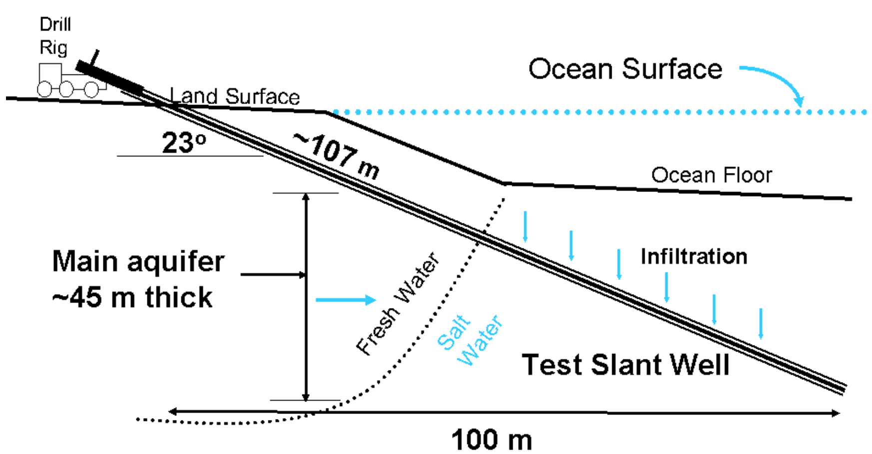


**Figure 4-3. Directional Drilling to Install Intake Piping Below the Seabed (NRC, 2008)**

### 4.3 Desalination Concentrate Discharge and Management Options

There are a variety of management methods for handling the desalination concentrate. Some of the options are:

- discharge to sewers for treatment at wastewater treatment plants,
- discharge to surface water,
- irrigation of crops or landscaping,
- land application for aquifer recharge,
- deep well injection,
- evaporation ponds, and
- zero-liquid discharge thermal processes (Davis and Rayman, 2008).

In general, the costs associated with these options are in increasing order with discharge to sewers being the least expensive (NRC, 2008). A more detailed discussion of the concentrate management challenges is presented in Appendix E. Two useful informational resources on the subject are: Jordahl, 2006; and, Mackey and Seacord, 2008.

In Florida, desalination concentrate is primarily discharged to surface waters, land applied, deep well injected (UIC), or discharged to sanitary sewers. The largest facility in the state, the Tampa Bay Water desalination plant, discharges to surface waters. The facility draws cooling water from a power plant and discharges the concentrate back to the power plant where it is diluted before discharge to Hillsborough Bay (TBW, 2008). Figure 4-4 shows the breakdown of concentrate management methods in use by active desalination facilities in Florida.

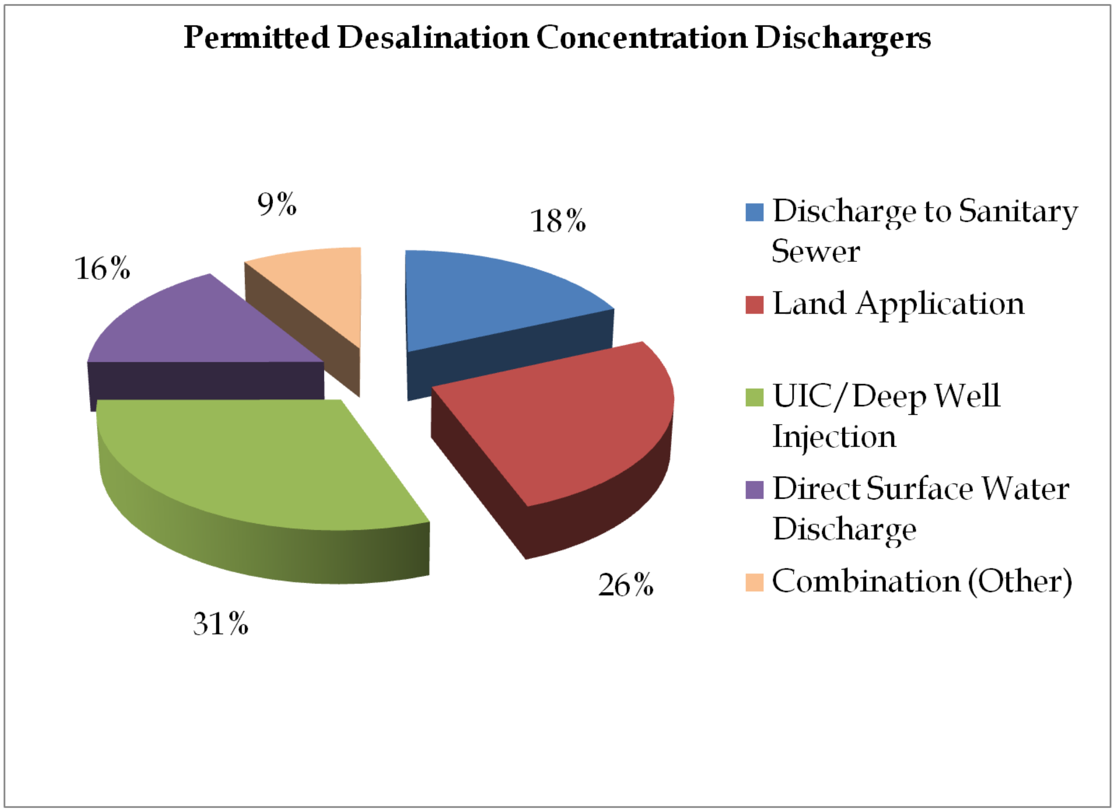


**Figure 4-4. Desalination Concentrate Management Methods in Florida (FDEP, 2008a)**

Figure 3-7 in Section 3 of this report provides a similar pie chart showing the distribution of concentrate management in the United States. There are distinct differences between these two figures that demonstrate the uniqueness of Florida's environmental setting compared to the rest of the country. Nationally, land application, for example, accounts for only 2%, but represents about 34% in Florida. This is a reflection of the low salinity of the source water and the chemical composition being more suitable for blending and land application, as well as the importance of water reuse in the state compared to most other states in the country (Bryck, et al., 2008). The geologic setting of Florida permits a greater use of injection wells (almost twice the national average).

***Discharge to Domestic Wastewater Treatment Collection Systems***

Approximately 20% of desalination facilities discharge their concentrate to permitted domestic (i.e. sanitary) wastewater treatment plants (WWTP). These RO facilities are typically smaller, or their concentrate contains low levels of salt, or both. This option depends on the ability and willingness of the WWTP to accept the saline discharge and continue to meet the requirements of its own discharge permit. Water treatment plants that discharge concentrate to domestic facilities are considered industrial discharges and must meet pretreatment requirements established by the domestic wastewater utility. A receiving wastewater treatment facility is primarily concerned about the concentrate characteristics in order to determine the salt content in the influent to the WWTP. Too high a salt content will affect the plant's treatment efficiency and can possibly damage the biological elements of the treatment process. If the wastewater facility discharges to surface water, these desalination plants are classed as Industrial Users and may be subject to federal industrial pretreatment requirements imposed by the utility under the Clean Water Act (CWA) (33 U.S.C. §1251 et seq., 1972). If the WWTP facility applies reclaimed water to land they must make sure the effluent salt concentration does not cause plant damage.

The concentrate may by-pass the wastewater facility and be post-blended with treated domestic wastewater effluent before the effluent is discharged to surface water, land applied, or injected underground. These options provide dilution of the concentrate, reducing environmental issues related to elevated minerals, whole effluent toxicity, or ionic imbalance toxicity.

The post-blending method would require the domestic facility to revise its National Pollutant Discharge Elimination System (NPDES) permit to account for the changes in its discharge composition associated with the addition of the demineralization concentrate. These permitting options are addressed in Rule 62-620.625(6), F.A.C., (previously referenced). The Department worked with SJRWMD to map out the wastewater permitting process for desalination and demineralization water treatment plants. The NPDES Wastewater permit and other state and federal permit programs are discussed in SJRWMD reports and technical memoranda and can be accessed at http://sjr.state.fl.us/technicalreports/pdfs/SP/SJ2006-SP1.pdf (R. W. Beck, Inc., et al., 2006).

***Direct Surface Water Discharge***

Surface water discharges are regulated under the federal Clean Water Act through the NPDES permitting program. USEPA has authorized the Department to administer the program and issue NPDES permits. Therefore, any proposed surface water discharge would be required to apply to the Department for an individual NPDES permit prior to commencement of any discharge.

Approximately 18% of desalination facilities in Florida discharge concentrate to surface water. The surface water may be the Atlantic Ocean or Gulf of Mexico, coastal estuaries, freshwater lakes or rivers, or to storm water management systems that discharge to surface waters. Each of these potential locations poses it own unique set of technical and environmental issues. Typically, demineralization concentrate has a higher salinity than the receiving water. This may result in exceedences of water quality standards, including aquatic toxicity (Danoun, 2007).

Exceedences of water quality standards caused by the higher salinity of the concentrate discharge can sometimes be mitigated by using special discharge piping systems called diffusers, which allow the effluent to mix more quickly with the receiving water. There are also situations where the source water quality has a different chemical composition than the receiving water. For example, a brackish, groundwater source water may have a different ratio of minerals than a receiving seawater environment. The salt ratio of the concentrate is different than the receiving waters or 'ionically imbalanced'. Where appropriate, mixing zones can be granted in the vicinity of the outfall (Rule 62-4.244(3)(d), F.A.C.; http://www.dep.state.fl.us/water/rulesprog.htm#ww). Diffuser systems are a commonly used technology for a variety of wastewater applications worldwide. The image below shows an example of a section of piping for a wastewater effluent diffuser system.

**Figure 4-5. Example of an Effluent Diffuser System (Not Associated with a Desalination Project) (Dayton & Knight, Ltd., Vancouver, BC, Canada. 2008)**

The St. Johns River Water Management District and the South Florida Water Management District have supported several studies to look at the feasibility of siting desalination facilities in their districts (R.W. Beck, Inc., et al., 2006; Metcalf & Eddy, et al., 2006). Several SJRWMD publications examined the feasibility of ocean outfalls of desalination concentrate (CH2M HILL, 2005a; 2005b), the feasibility and limiting problems associated with locating a desalination discharge on the Indian River Lagoon (R.W. Beck, Inc., et al., 2006), and the feasibility of locating a facility along the St. Johns River, on the southern shore of Lake Monroe (CH2M HILL, 2004). In the last part of this section of the report, a more detailed discussion will be presented of environmental issues of concentrate in the receiving water.

### *Land Application and Blending with Reclaimed Water for Recharge and Irrigation*

Approximately 29% of desalination concentrate is land applied, frequently by blending with reclaimed water for recharge and irrigation. Reclaimed water is the term used for domestic wastewater treated to levels that allow it to be reused in various ways. Reclaimed water is used for irrigation, for example, in lieu of using drinking water, thus preserving groundwater and fresh surface water resources for human consumption. Florida's regulations for reuse of reclaimed water and desalination concentrate management have detailed requirements to ensure public health and safety and to meet water quality standards (Chapter 62-620, F.A.C., Wastewater Facility Permitting and Chapter 62-610, F.A.C., Reuse of Reclaimed Water and Land Application http://www.dep.state.fl.us/water/rulesprog.htm#ww).

The Department rule also establishes mixing formulas to make sure the concentrate blended with the reclaimed water and discharged to land application will have a relatively low salinity. Saline tolerant vegetation may be needed in order to maintain proper ground cover. As mentioned earlier, the relatively large percentage of reuse of desalination concentrate used in the state is a reflection of the low salinity of the source waters used in many of the RO plants in Florida. Lower mineral content in the concentrate provide the utility with more opportunities to directly use the water for irrigation or for blending with reclaimed water for land application. In Florida this is especially true, where more than 600 MGD of reclaimed water is used.

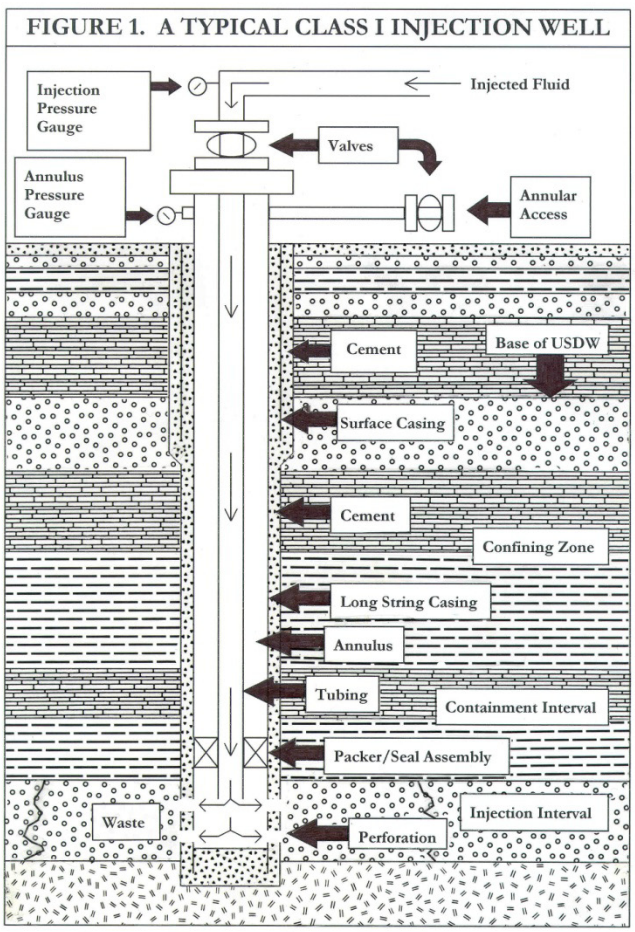


**Figure 4-6. An Idealized Cross-section of an Underground Injection Control Well (FDEP, 2008c)**

### *Deep Well Injection*

Approximately 33% of desalination concentrate in Florida is discharged to specially designed and constructed deep wells permitted through the Underground Injection Control (UIC) program, in Chapter 62-528, F.A.C. (http://www.dep.state.fl.us/water/rulesprog.htm#ww).

Deep well injection or Class I well systems essentially operate by injecting the concentrate stream below at least one confining geologic layer. The salty nature of the concentrate helps it blend with the saline waters of the injection zone (Heimlich, et al., 2009). Concentrate can also be blended with other industrial wastewater or with treated domestic wastewater at wastewater facilities that use Class I wells, but typically that would require the municipality to upgrade the injection well to handle the more corrosive nature of a brine discharge. If the concentrate enters the wastewater facility through the collection system or at the headworks of the wastewater plant, then the effluent is considered domestic wastewater and the well will not need to be upgraded.

The SJRWMD has looked at the potential for using Underground Injection Control (UIC) Class V wells for disposal of RO concentrate along the coasts of Flagler, Brevard, and Indian River Counties (L.S. Sims & Associates, Inc., 2006; CH2M HILL, 2008). Unlike the Class I deep wells, Class V UIC wells do not need to be injected into a confined aquifer, and the well depth can be shallower and less expensive to construct. However, the lack of confinement means the water quality of the injectate must meet drinking water quality standards where the receiving groundwater is an Underground Source of Drinking Water (USDW). Groundwater containing concentrations of TDS greater 10,000 mg/l is not considered potable water or an USDW. Treatment standards for discharge into such waters are reduced, such as in the Florida Keys.

The purpose of the SJRWMD studies was to determine if there were high TDS zones in the coastal counties where the shallower Class V wells would be feasible. Based on the available groundwater data it appears that the ocean side of the coastal barrier islands in Flagler County and the southern coastal portion of Indian River County would offer the greatest potential for Class V wells. The study suggests an exploratory drilling program to better delineate the brackish-saline water interface along the barrier islands to site pilot Class V wells.

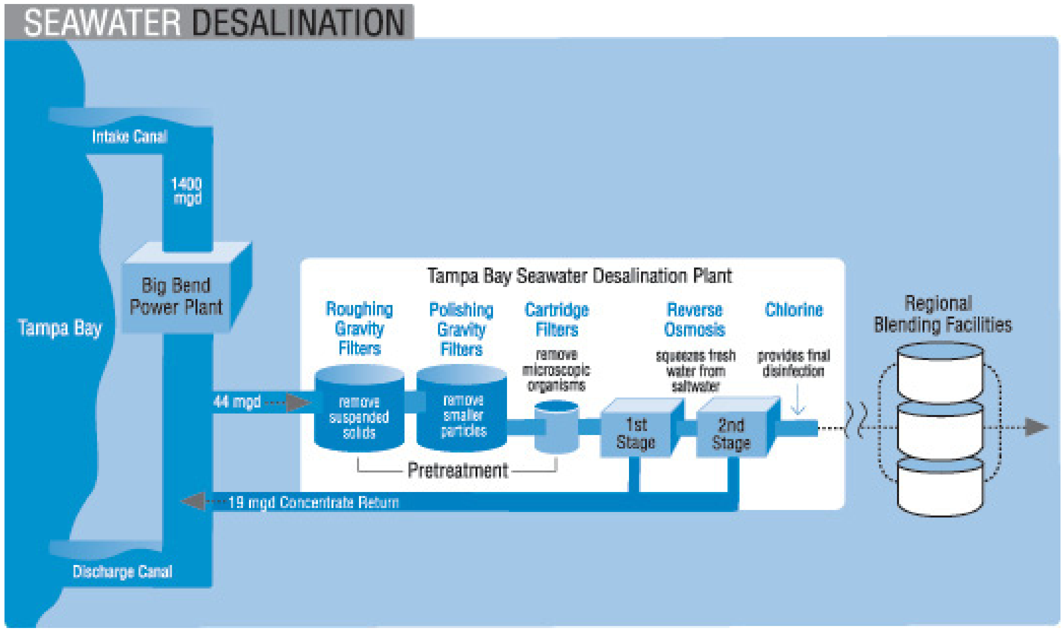


**Figure 4-7. Process Overview for Co-Location of a Desalination Plant and Steam Electric Power Plant (NRC, 2008)**

### *Concentrate Blending at Co-located Coastal Electric Power Plants*

A surface water discharge method used in Florida is the co-location of a desalination facility with an existing power plant. The Tampa Bay Water desalination facility is an example of this approach and became fully operational in December 2007. Co-location is practical for power plants with once-through cooling water systems, described as follows. Once-through cooling water systems are located adjacent to coastal surface waters, rivers and lakes. The power plants pump very large quantities of surface water through their cooling systems and return nearly all the water to the source. In the co-location scenario, a portion of the cooling water, once heated, is used for desalination and the concentrate is returned to the cooling water stream before its discharge back to the surface water. At the Tampa site, approximately 44 MGD of saltwater is drawn from the heated effluent and processed through the RO facility. Up to 25 MGD of potable water is generated and 19 MGD of brine concentrate is returned downstream of the RO source water intake, where it blends with about 1000 MGD of cooling water before entering Hillsborough Bay (TBW, 2008). Just to the north of the Tampa site, the City of Tarpon Springs is planning a 6.4 MGD RO plant that offers a slight variation of this approach (Robert, et al., 2009). Brackish groundwater will be the source water and concentrate disposal will be to a nearby power plant cooling water discharge canal.

**Figure 4-8. Aerial View of a Desalination Plant (foreground) Co-Located with a Steam Electric Power Plant (background) (TBW, 2008)**

Combining a desalination treatment plant with a once-through cooling water system offers the cost-saving advantage of utilizing existing permitted intake and discharge structures (Voutchkov, 2007b; 2008). However, once-through cooling water power plants in Florida are generally located in coastal bays and estuaries where environmental issues must be addressed in order for discharge to be feasible.

The SJRWMD conducted a feasibility study for the co-location of a desalination facility with an existing power plant that utilizes the Indian River Lagoon as a once-through cooling water source and discharge destination. Modeling of the projected discharges showed that the poor circulation patterns in the lagoon, at the chosen locations, would have resulted in the buildup of salts and significant environmental impacts. Therefore it was not a recommended site for locating a large-scale desalination facility, although small-scale facilities could be feasible (R.W. Beck, Inc., et al., 2006).

Similarly, the SFWMD examined potential co-locations in its jurisdictional area (Metcalf & Eddy, 2006; VandeVenter, et al., 2008). Using technical, regulatory, and socioeconomic feasibility as screening tools, candidate sites were reduced to three locations (Ft. Myers, Lauderdale, and Port Everglades) that were recommended for further evaluation, including conceptual design and specifications for a pilot study.

Desalination facilities may also be co-located at coastal or estuarine municipal wastewater facilities, where the blended effluent would mix better in the brackish or marine environment and the two waste stream characteristics would be diluted. For example, the salt of the concentrate would be diluted by the freshwater of the municipal wastewater, and the nutrients of the wastewater would be diluted by the low nutrient concentrate. An example of this type of arrangement is the City of Hollywood, where the city-owned utility's water treatment RO plant treats brackish groundwater and blends the concentrate stream with the utility wastewater prior to entering the utility's ocean outfall (City of Hollywood, 2009).

**HOLLYWOOD WATER TREATMENT PLANT**

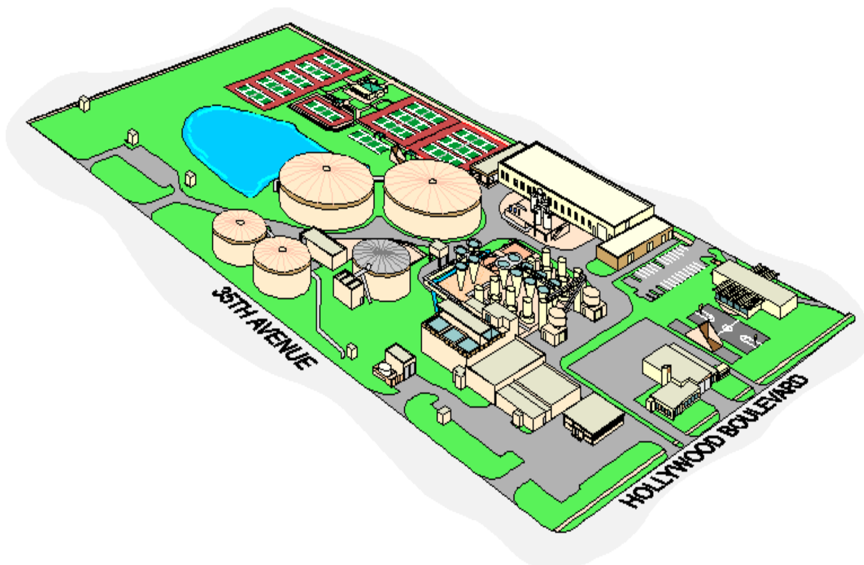


**Figure 4-9. Illustration of the City of Hollywood Water Treatment Plant using a Combination of Reverse Osmosis and Nanofiltration to Treat Source Waters from Two Aquifers (City of Hollywood, 2009)**

Another example is currently under construction in Deerfield Beach where the concentrate from the nanofiltration plant is recovered by blending it with additional Florida aquifer water and fed to a new 3 MGD RO plant for further treatment (SFWMD, 2009).

### 4.4 Potential Environmental Issues for Surface Water Discharges

There are currently 46 NPDES surface water discharge permits for desalination and demineralization water treatment plants in Florida (FDEP, 2008b). Many of these have been in operation for a number of years. From the data collected at these sites we can provide some insight as to the potential environmental problems any one site may experience. Some of the environmental concerns have already been discussed in this section. UIC injectate must meet primary and secondary drinking water standards if the injection zone is in an Underground Source of Drinking Water (USDW) (<10,000 mg/l TDS). The applicant can seek water quality exemptions for the secondary standards, but must meet the primary drinking water quality standards. Land application of concentrate must not be phytotoxic or have a high enough salt content to harm the vegetation receiving the irrigation water. Disposal to collection systems must not affect the biological integrity of the wastewater treatment facility. Where intake waters are drawn from surface waters, attention must be given to minimizing entrainment of the surface water organisms.

The remainder of this discussion will focus further on environmental issues associated with concentrate discharged to surface waters. Concentrate will be presented as two primary components, the major salt groups (for example, sodium, chloride, sulfate, calcium, magnesium) and other parameters (for example, nutrients, metals, and organics). Either group, when discharged into surface waters must not cause toxicity or impact the biological community of the receiving waters.

The environmental impact from the major salts is related to the absolute or total concentration of salt, measured as TDS or total salinity measured in ppt, or the composition or ratio of the salts.

If the source water used is the same as the receiving water, like at the Tampa Bay Water desalination facility, where estuarine water is both the source water and the receiving water, the specific salts will be in the same ratio. In this situation, the concern is the total salt content. If the concentrate's salinity is too high it becomes toxic to plants and animals in the receiving water environment. How high is too high depends on the receiving water's salinity. In estuary or open ocean water, the ambient salinity can range from 15 to 35 ppt. In this setting, desalination concentrate exceeding 40 ppt can cause an unacceptable impact to the ecology of the receiving water. Site specific analysis is needed to determine the amount of dilution needed to bring the final discharge salinity into an acceptable range for the receiving water.

If the source water comes from a different source than the receiving water, for example, a groundwater source water is used and the concentrate is discharged into a brackish surface water like an estuary, the final salt content of the discharge may be lower than the estuary or even the same, but the ratio or type of salts is different than those of the estuary. The estuary salt is dominated by sodium and chloride and the groundwater by calcium and sulfates. The discharge is said to be 'ionically imbalanced' and can cause toxicity. It is toxic because the organisms in the receiving water are accustomed to this ratio of salts. A shift in the ratio can cause an osmotic imbalance and toxicity. A site specific analysis is needed to determine if there is toxicity and, if so, what steps would need to be taken to minimize the impact of the salt imbalance. Fortunately, the major salts in brackish water do not bioaccumulate or biomagnify in the receiving water food chain like some substances such as lead and mercury. In fact, several, like calcium, are building blocks for the plants and animals. Therefore, the focus in dealing with ionically imbalanced concentrates is to provide an initial dilution.

### *Circulation*

Another consideration related to the salt content of the concentrate is salt buildup or accumulation in the receiving waters. Even where the concentrate salinity is not toxic, poor circulation of the receiving water may limit flushing of the system and the salt content will increase over time to a point where it is toxic to the ecological community. If the source water is from the same water body, the change will be accelerated. The more complex the flow patterns in the receiving waters the more difficult and costly it is to demonstrate that no accumulation of salt occurs. In the case of the Tampa Bay Water desalination facility, the complex water movements in Hillsborough Bay required the use of sophisticated near field and far field models to show no impact.

The SJRWMD identified several types of possible adverse effects of desalination on a brackish estuary in its 2006 report titled *Evaluation of Potential Impacts of Demineralization Concentrate Discharge to the Indian River Lagoon (Study)*. The study focused on co-location of a desalination plant with power plants in Brevard County in a portion of the Indian River Lagoon near Titusville, and used long-term water quality modeling to evaluate potential changes to the lagoon based on a co-located desalination plant. Although this study was a preliminary look at possible effects using computer models, it provides some insight into the types of concerns that need to be addressed in a semi-enclosed tidal estuary typical of much of the Florida coastline.

The study showed a long-term increase in salinity and decrease in seagrass, which provides the major habitat for juvenile gamefish, baitfish and crustaceans within the lagoon. Significant decreases in the number of the species were also predicted. According to the study, these effects would not be confined to the vicinity of the concentrate discharge, but would be more widespread throughout large areas of the lagoon.

Discharge in an open ocean environment, however, was shown in other SJRWMD reports to have less adverse impacts, depending on the location and design of the discharge system (CH2M HILL, 2005a; CH2M HILL 2005b; R.W. Beck, Inc., et al., 2006).

***Dissolved Oxygen***

Dissolved oxygen levels in the water can also have an impact on the aquatic environment surrounding the discharge location. Where temperature and/or salinity changes have resulted in the water column becoming stratified, or layered, oxygen may not be able to diffuse from the near-surface to deeper layers. This leads to decreased levels of dissolved oxygen in these deeper layers, which could have negative effects on the respiration of the organisms present there. Less mobile or non-mobile organisms such as juvenile fish and clams are most affected by this drop in dissolved oxygen. This can also impact other animals that depend on them as food source (R.W. Beck, Inc. et. al, 2006).

The stratification resulting from poorly dispersed concentrate into the receiving water can result in damage to the benthic or bottom community, including the seagrasses (Gacia, et al., 2007; Perez Talavera and Quesada Ruiz, 2001; Pilar Ruso, et al., 2007).

***Other Parameters***

The SJRWMD ocean outfall discharge feasibility study used Indian River Lagoon water as the source water and used a pilot RO facility to determine what parameters may be of concern. Looking at more than 160 parameters (nutrients, metals, radiologicals, violatile organics, toxicity and others), researchers found fluoride and copper to be of concern in Class II shellfish waters, and only copper to be of concern in Class III recreational waters (Reiss Environmental, Inc., 2003a; 2003b). A mixing zone could be used to bring these parameters into compliance.

At other locations in Florida, radiologicals like radium and nutrients like ammonia were present at acceptable levels in the source water, but exceeded water quality standards in the concentrate.

Another potential source of contaminants in the concentrate is from chemicals used in the operation and maintenance of the desalination facility (NRC, 2008). These include cleaning and conditioning reagents, anti-scaleant chemicals, and metals generated from corrosion of piping (iron, chromium, and nickel). Table 4-1 summarizes the types of pretreatment chemicals used to condition the source waters and Table 4-2 summarizes the typical cleaning formulations used in the maintenance of nanofiltration and RO membranes. Some chemicals like chlorine can combine with organic materials and form another group of chemicals, disinfection by-products such as total trihalomethane, that must be evaluated (Agus, et al., 2009).

| Chemical Additive | Reported Dosing (mg/l) | References |
|---|---|---|
| Chlorine | 0.5-6 | Abart, 1993; Redondo and Lomax, 1997; Morton, et al., 1997; Woodward Clyde Consultants, 1991 |
| Sodium bisulfate | 3-19 | Morton, et al., 1997; Redondo and Lomax, 1997; Woodward Clyde Consultants, 1991 |
| Ferric chloride | 0.8-25 | Baig and Kubti, 1998; Woodward Clyde Consultants, 1991 |
| Polyelectrolyte | 0.2-4 | Ebrahim, et al., 1995; DuPont, 1994; Hussain and Ahmed, 1998 |
| Sulfuric Acid | 6.6-100 | Al-Shammiri, et al., 2000; Morton, et al., 1996; Al-Amad and Aleem, 1993 |
| Sodium Hexametaphosphate (SHMP) | 2-10 | Al-Ahmad and Aleem, 1993; Al-Shammiri, et al., 2000; FilmTec, 2000 |
| Polyacrylic acid | 2.9 | Woodward Clyde Consultants, 1991 |
| Phosphonate | 1.4 | Al-Shammiri, et al., 2000 |

**Table 4-1. Reported Dosing Concentrations of Pretreatment Chemical Additives in Reverse Osmosis Desalination (NRC, 2008)**

| Foulant Type | Cleaning Solutions |
|---|---|
| Inorganic salts[a] | 0.2% HCl<br>0.5% $H_3PO_4$<br>2% citric acid |
| Metal oxides | 2% citric acid<br>1% $Na_2S_2O_4$ |
| Inorganic colloids (silt) | 0.1% NaOH, 0.05% Na dodecyl benzene sulfonate, pH 12 |
| Silica (and metal silicates) | Ammonium bifluoride<br>0.1% NaOH, 0.05% Na dodecyl benzene sulfonate, pH 12 |
| Biofilms and organics | Hypochlorite, hydrogen peroxide, 0.1% NaOH, 0.05% Na dodecyl benzene sulfonate, pH 12<br>1% sodium triphosphate, 1% trisodium phosphate, 1% sodium EDTA |
| [a]Barium sulfate, calcium carbonate, calcium sulfate | |

**Table 4-2. Typical Nanoflitration and Reverse Osmosis Cleaning Formulations (NRC, 2008)**

Desalination water treatment facilities have been permitted and operated in Florida since the 1970's. The Department has a well-developed regulatory process for ensuring that utilities have the opportunity to expand and develop new desalination facilities in the state, and that the concentrate can be managed to protect Florida's water resources, including natural systems. Desalination utilities have been permitted to implement a broad range concentrate management options. Forty-six facilities, for example, discharge concentrate to surface water under NPDES permits issued by the Department in full compliance with the federal Clean Water Act. Many others, the majority of demineralization facilities, discharge either to land application and deep wells, or discharge to domestic wastewater facilities for treatment. The options often incorporate blending with reclaimed water for recharge and irrigation. This large number of facilities and the diversity of concentrate management scenarios demonstrate the effectiveness of Florida's regulatory approach and adaptability of Florida's public water supply utilities.

## *SECTION FIVE: Conclusions*

- *Florida is the national leader in the application of desalination, in the number of projects and the volume of potable water generated by the technology.*
- *Given the large numbers of desalination plants in Florida, and the anticipated development of new facilities over the next 10 years, desalination has been proven to be a feasible and cost-effective source of supply for many utilities. While technological improvements and cost-sharing could hasten the wider application of desalination technology, it is clear that few barriers now exist for its expanded use in the state.*
- *Thermal Distillation, while a dominant technology in the world, is a minor component of the U.S. desalination and non-existent in Florida. The primary reason is energy needs compared to other technologies. Reverse Osmosis is by far the dominant technology used in the state. This may change as technology provides new options.*
- *Finite water resources in Florida provide the major incentive for aggressive water conservation and the need to develop alternative water resources, including reuse of treated wastewater and storm water, desalination, water conservation, and Underground Injection Control (UIC) Aquifer Storage and Recovery (ASR) systems and above ground reservoirs.*
- *The 2005 Legislature created the Water Protection and Sustainability Program to encourage and partially fund the development of alternative water supplies to meet the future potable water needs of the state. In the first three years of the program (2005-2008), the program provided funding assistance for the construction of 344 projects. Of these, brackish water desalination projects are expected to provide 234*

*million gallons of potable water per day. Continued funding of the program would provide additional incentive for the development of alternative water supplies in Florida, including desalination.*

- *The costs associated with desalination can vary greatly depending on the source water, typically increasing in cost when moving from the use of brackish groundwater to open seawater. However, the costs for environmentally safe disposal at some locations may offset the cost savings of using of lower-salinity source water. Co-location at steam electric power plants or large municipal wastewater treatment plants can reduce the energy, capital and operational costs.*

- *Use of new technology (nanotechnology, energy efficient pumps, alternative energy sources, use of 'waste heat') should continue to reduce the costs to operate and maintain desalination processes like membrane filtration and, equally important, reduce the carbon footprint.*

- *Technology transfer is vital for government agencies and utilities in Florida. Partnering with existing desalination organizations, such as the American Membrane Technology Association (AMTA), Affordable Desalination Collaboration (ADC), WaterReuse Foundation, and International Desalination Association (IDA), is needed to remain abreast of innovative technologies and to exchange 'lessons learned'.*

- *Similar to technology transfer, an exchange of information is needed on environmental issues associated with desalination. This information would help to minimize the potential risks associated with development of new desalination facilities.*

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## *APPENDIX A: Reverse Osmosis (RO) Membrane Technologies*

### *What is osmosis?*

Osmosis is a natural process involving fluid flow across a semi-permeable membrane barrier. Consider a tank of pure water with a semi-permeable membrane dividing it into two sides. Pure water in contact with both sides of the membrane at equal pressure and temperature has no net flow across the membrane because the "chemical potential" is equal on both sides. If salt is added on one side, "osmotic pressure" will cause flow from the pure water side across the membrane to the salt solution side. This will continue until the equilibrium of chemical potential is restored. In scientific terms, the two sides of the tank have a difference in their "chemical potentials," and the solution equalizes its chemical potential by osmosis.

### *What is a semi-permeable membrane?*

Semi-permeable refers to a membrane that selectively allows certain substances to pass through it while retaining others. In actuality, many things will pass through the membrane but at significantly different rates. In reverse osmosis (RO), the solvent (water) passes through the membrane at a much faster rate than the dissolved solids (salts). The net effect is that a solute-solvent separation occurs, with pure water being the product.

### *Reverse Osmosis*

In reverse osmosis, the freshwater water molecule, under high pressure, moves in the opposite direction or 'reverse' direction than would occur normally. The high pressure will raise the chemical potential of the water in the salt solution and cause a solvent or in our case a freshwater flow to the pure water side, because it now has a lower chemical potential. This phenomenon is called reverse osmosis.

The driving force of the reverse osmosis process is applied pressure. The amount of energy required for osmotic separation is directly related to the salinity of the solution. Thus, less energy is required to produce the same amount of water from brackish water than the saltier seawater. This is an important point because as the source increases in salinity, the higher the pressure needed to produce the potable water, the greater the energy needs, and the higher the cost. The pressure needed to be exerted on the high solute side of the membrane, ranges from 30–250 pounds per square inch (psi) when the source water is fresh and brackish water, to 600–1000 psi for seawater (Hydranautics, 2001b).

There are three major groups of polymeric materials which can be used to produce satisfactory reverse osmosis membranes: cellulose acetate (CAB), composite polyamide (CPA), and thin-film composite. Depending upon the polymeric material composition of the membrane, the manufacturing process, operating conditions and performance of the membrane will differ significantly. Research on reverse osmosis began in the 1950's when the first membranes were made of cellulose acetate. The costs to make, operate and maintain these membranes restricted their application, until the early 1980's, when research in U.S. resulted in the first composite polyamide membrane. This membrane had significantly higher permeate flow and salt rejection than cellulosic membranes. Since then, improvements in materials and their configuration have further reduced costs and improved the strength and resiliency to changing temperatures and pH.

*Cellulose Acetate Membranes*

The original cellulose acetate membrane, developed in the late 1950's by Loeb and Sourirajan, was made from the cellulose diacetate polymer. Currently, cellulose acetate membranes are usually made from a blend of cellulose diacetate and triacetate. The membrane is formed by casting a thin film of acetone-based solution, comprised of the cellulose acetate polymer with swelling additives, onto a non-woven polyester fabric. After the initial casting, two additional steps, including a cold bath followed by high temperature annealing, complete the membrane formation process.

Cellulose acetate membranes are inexpensive and easy to manufacture but suffer from several limitations. One such limitation is that their asymmetric structure makes them susceptible to compaction under high operating pressures, especially at elevated temperatures. Compaction occurs when the thin dense layer of the membrane thickens by merging with the thicker porous substructure, leading to a reduction in product flux.

Other common limitations of cellulose acetate membranes include:

- Are susceptible to hydrolysis;
- Can only be used over a limited pH range (low pH 3 to 5 and high pH 6 to 8, depending on the manufacturers);
- Undergo degradation at temperatures above 35°C;
- Are vulnerable to attack by bacteria; and
- Have high water permeability but reject low molecular weight contaminants poorly.

In comparison, cellulose triacetate membranes have advantages such as improved salt rejection characteristics and reduced susceptibility to pH, high temperature and microbial attack. However, cellulose triacetate membranes have a lower water permeability than cellulose acetate membranes. Blends of cellulose triacetate and cellulose acetate have been developed to take advantage of the desirable characteristics of both membranes.

*Composite Polyamide Membranes*

Composite polyamide membranes are manufactured in two distinct steps. First, a polysulfone support layer is cast onto a non-woven polyester fabric. The polysulfone layer is very porous and is not semi-permeable; that is, it does not have the ability to separate water from dissolved ions. In a second, separate manufacturing step, a semi-permeable membrane skin is formed on the polysulfone substrate by interfacial polymerization of monomers containing amine, and carboxylic acid, and chloride functional groups. This manufacturing procedure enables independent optimization of the distinct properties of the membrane support and salt rejecting skin. The resulting composite membrane is characterized by higher specific water flux and lower salt passage than cellulose acetate membranes.

One advantage to use of polyamide composite membranes is that they are stable over a wider pH range than cellulose acetate membranes. However, polyamide membranes are susceptible to oxidative degradation by free chlorine, while cellulose acetate membranes can tolerate limited levels of exposure to free chlorine. Also, compared to a polyamide membrane, the surface of a cellulose acetate membrane is smooth and has little surface charge. Because of the neutral surface and tolerance to free chlorine, cellulose acetate membranes will usually have a more stable performance than polyamide membranes in applications where the feed water has a high fouling potential, such as with municipal effluent and surface water supplies.

Another advantage to use of polyamide membranes is that they have better resistance to hydrolysis and biological attack than cellulosic membranes. They can also be operated over a pH range of 4 to 11, but extended use at the extremes of this range can cause irreversible membrane degradation. They can withstand higher temperatures than cellulosic membranes; however, like cellulosic membranes, they are subject to compaction at high pressures and temperatures. Polyamide membranes also have better salt rejection characteristics than cellulosic membranes, as well as better rejection of water soluble organics.

*Thin-Film Composites*

As the name indicates, thin-film composite (TFC) membranes are made by forming a thin, dense, solute rejecting surface film on top of a porous substructure. Because the water flux and solute rejection characteristics of the membrane are predominantly determined by the thin surface layer, whose thickness can range from 0.01 to 0.1 µm, the construction materials and manufacturing processes for the layer can be varied and optimized in order to achieve the desired combination of properties. For example, several types of materials have been developed for the surface layer of the thin-film composite membranes, including aromatic polyamide, alkyl-aryl poly urea/polyamide and polyfurane cyanurate. While the thin surface layer composition often varies, the supporting porous sub layer is typically made of polysulfone.

One disadvantage to polyamide thin-film composites is that, like polyamide asymmetric membranes, they are highly susceptible to degradation by oxidants, such as free chlorine. Consumers must be consistent in their maintenance of the TFC systems, particularly the carbon pre-filtration element which is present to remove free chlorine (and other oxidative organics) and prevent damage and premature destruction of the TFC membrane. Although the stability of these membranes in the presence of free chlorine has been improved by modifications of the polymer formulation and the processing technique, exposure to oxidants still must be minimized.

A comparison of characteristics of these three membrane types is given in Table A-1 below:

| Comparison of Reverse Osmosis Membranes | | | |
|---|---|---|---|
| **Feature** | **Cellulosic** | **Aromatic Polyamide** | **Thin Film Composite*** |
| **Rejection of Organics** | L | M | H |
| **Rejection of Low Molecular Weight Organics** | M | H | H |
| **Water Flux** | M | L | H |
| **pH Tolerance** | 4-8 | 4-11 | 2-11 |
| **Temperature Stability** | Max 35 deg C. | Max 35 deg C. | Max 45 deg C. |
| **Oxidant Tolerance(e.g. free Chlorine** | H | L | L |
| **Compaction Tendency** | H | H | L |
| **Biodegradability** | H | L | L |
| **Cost** | L | M | H |
| L = Low; M = Medium; H = High | | | |
| *Thin film composite type having polyamide surface layer | | | |

**Table A-1. (Source: Aquatechnology**, http://www.aquatechnology.net/reverse_osmosis.html)

*Membrane Module Configurations*

The two major membrane module configurations used for reverse osmosis applications are hollow fiber and spiral wound. Two other configurations, tubular and plate and frame, have found good acceptance in the food and dairy industry and in some special applications, but modules of this configuration have been less frequently used in reverse osmosis applications.

## *APPENDIX B: Thermal Distillation Processes*

Thermal distillation was the earliest method used to desalinate seawater on a commercial basis, and thermal processes have been, and continue to be, a logical regional choice for desalination in the Middle East for several reasons. First, the seas in the region are very saline, hot, and periodically have high concentrations of organics, which are challenging conditions for reverse osmosis (RO) desalination technology. Second, RO plants are only now approaching the large production capacities required in these regions. Third, dual-purpose cogeneration facilities were constructed that integrated the thermal desalination process with available steam from power generation, improving the overall thermodynamic efficiency by 10-15 percent (Hamed, et al., 2002; Hanafi, 2002). For these reasons, combined with the locally low imputed cost of energy, thermal processes continue to dominate the Middle East. In other parts of the world, where integration of power and water generation is limited and where oil or other fossil fuels must be purchased at market prices, thermal processes are relatively expensive (GWI, 2006a).

In the United States, thermal processes are primarily used as a reliable means to produce high-quality product water (≤ 25 mg/l total dissolved solids [TDS]) for industrial applications, because distillation processes are very successful at separating their target—dissolved salts—from the bulk feedwater. Distillers almost completely reject dissolved species, such as boron, which can be problematic for RO. Distillers, however, are sensitive to volatile contaminants that may evaporate from the feedwater and carry over into the distilled water, where they may or may not condense.

Three major thermal processes have been commercialized: multistage flash (MSF) distillation, multiple effect distillation (MED), and mechanical vapor compression (MVC), and each one is a mature and robust technology (see Box B-1). MSF and MED processes demand both thermal energy (typically steam) and electrical energy. Thermal processes are configured to use and reuse the energy required to evaporate water, known as the latent heat of evaporation (about 2,326 kJ/kg of water or 2,438 kWh/kgal at normal atmospheric conditions). How efficiently the latent energy is reused is a function of project-specific economics, considering capital and operating costs.

The combined energy requirements of thermal technologies are greater than that of membrane processes, but it is not simple to compare the total energy use of these diverse processes, because MSF and MED are capable of using low-grade and/or waste heat, which can significantly improve the economics of thermal desalination (see Box B-2). Utilities in the United States have generally overlooked opportunities to couple thermal processes with sources of waste heat to produce desalinated water more economically.

In the Middle East, the largest of the MSF and MED plants are built along with power plants and use the low-temperature steam exhausted from the power plant steam turbines. This "cogeneration" approach combines water production with the generation of electric power using the same fuel and offers a method to improve the energy efficiency of desalination plants while sharing intake and outfall structures. Large MSF distillers are commonplace in the Middle East largely because of cogeneration.

In another example, many of the largest modern cruise ships select the thermal MED desalination process because MED requires 20 to 33 percent of the electrical energy of RO and because the heat energy it requires can be obtained from the ships' propulsion engines. MSF and, increasingly, MED units are also used in industry to make water for liquid natural gas and methanol plants. These industrial processes have a relatively small demand for freshwater, relative to the massive quantities of waste heat generated by the petrochemical process, and can be designed to be quite inefficient. When the residual heat energy has little or no value, there is no economic justification to invest in more efficient designs. Scale deposition in thermal desalination units is a concern but is generally mitigated by control of the operating temperatures and concentrations and use of polymer-scale inhibitors. The potential for mineral-scale deposition in a thermal desalination plant is considered an economic optimization issue, not a limitation of the process.

Thermal technologies, including variations of MSF's forced circulation configuration, can work with supersaturated salt solutions and are used in brine concentrators for minimizing the volume of desalination concentrate. However, operating at extremely high recoveries is not usually economical for desalination applications due to the boiling point elevation caused by the salt. In fact, economic considerations affected by boiling point elevation normally limit water recovery of thermal seawater desalination plant designs to about 35 to 50 percent, not considering cooling water. Although thermal desalination technologies are mature technologies, opportunities remain for additional cost savings. Thermal technologies are not optimized to the highest efficiencies, due to current practical constraints in materials and design and considerations of the source, condition, and value of the thermal energy being utilized. All thermal processes are affected by the cost of heat transfer surfaces (which are primarily copper or titanium alloys) and the development of new material options could reduce these costs. Also, the methods of distributing feedwater over the heat transfer surface of thin-film processes (e.g., MED, MED-TVC, VC) are proprietary and could benefit from further research. There may be additional opportunities for improved efficiencies in new designs of thermo compressors for MED-TVC systems. There are also needs for additional research and development into improved configurations and applications to utilize low-grade and/or waste heat and into entirely new processes that optimize the use of low-grade heat (see Box B-2). For example, there has been a recent review of an industrial application that would utilize low-grade energy at sulfuric acid plants (Shih and Shih, 2007). Heat is produced when sulfur is burned and when concentrated acid is diluted. Thermal desalination plants incorporated into this process could therefore produce the water used to dilute the acid which in turn produces the heat required for the thermal desalination process. The location of low-grade and/or waste heat resources near saline water sources and large consumers of water, including industry, has not been investigated, and research on opportunities to utilize low-grade and/or waste heat could yield economical applications of existing thermal desalination technology in the United States.

**BOX B-1** ***(Excerpted from NRC, 2008)***

**Overview of Thermal Desalination Processes**

Three primary thermal desalination processes have been commercially developed:

• **Multistage flash** (MSF) distillation, a forced circulation process, is by far the most robust of all desalination technologies and is capable of very large production capacities per unit. Globally, MSF is among the most commonly employed desalination technologies. MSF uses a series of chambers, or stages, each with successively lower temperature and pressure, to rapidly vaporize (or "flash") water from the bulk liquid. The vapor is then condensed by tubes of the inflowing feedwater, thereby recovering energy from the heat of condensation (Figure 4-12). The number of stages used in the MSF process is directly related to how efficiently the system will use and reuse the heat with which it is provided.

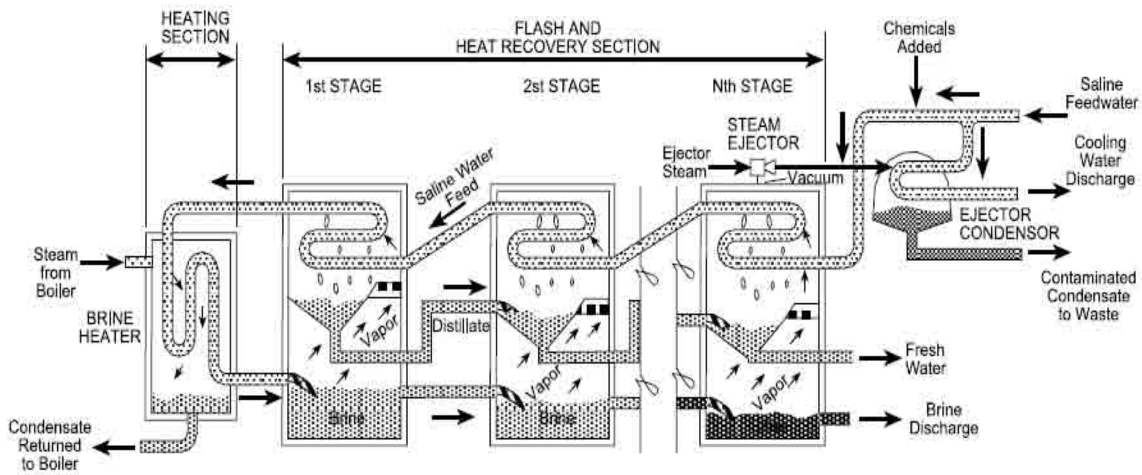


**Figure 4-12. Multistage flash evaporation. SOURCE: Buros, et al. (1980); Buros (2000). Reprinted courtesy of U.S. Agency for International Development.**

• **Multiple effect distillation** (MED) is a thin-film evaporation approach, where the vapor produced by one chamber (or "effect") subsequently condenses in the next chamber, which exists at a lower temperature and pressure, providing additional heat for vaporization (Figure 4-13). MED technology is being used with increasing frequency when thermal evaporation is preferred or required, due to its reduced pumping requirements and thus its lower power use compared to MSF. MED plants were initially limited in size but MED technology is planned for an 800,000 $m^3$/day desalination plant in Jubail, Saudi Arabia. Since the early 1990s, MED has been the process of choice for industrial low-grade, heat-driven desalination. The largest MED plants incorporate thermal vapor compression (TVC), where the pressure of the steam is used (in addition to the heat) to improve the efficiency of the process.

***Continued***

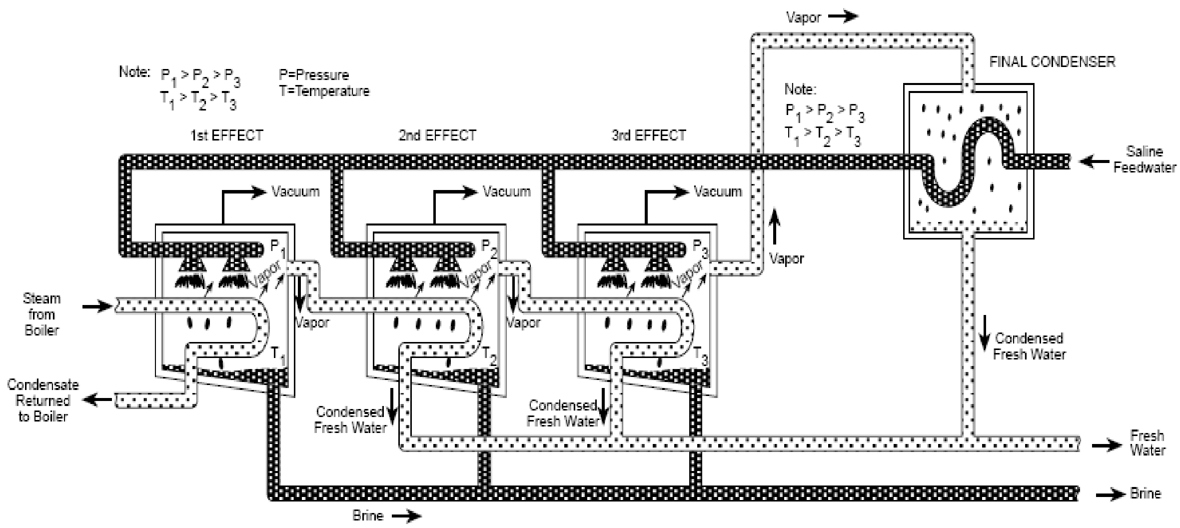


**Figure 4-13. Multiple effect distillation process. SOURCE: Buros et al. (1980); Buros (2000). Reprinted courtesy of U.S. Agency for International Development.**

- **Vapor compression** (VC) is an evaporative process where vapor from the evaporator is mechanically compressed and its heat used for subsequent evaporation of feedwater (Figure 4-14). VC units tend to be small plants of less than 2,839 m3/day that are used where cooling water and low cost steam are not readily available. VC systems can operate at very high salt concentrations and the VC process is at the heart of many industrial zero liquid discharge systems (Pankratz and Tonner, 2003).

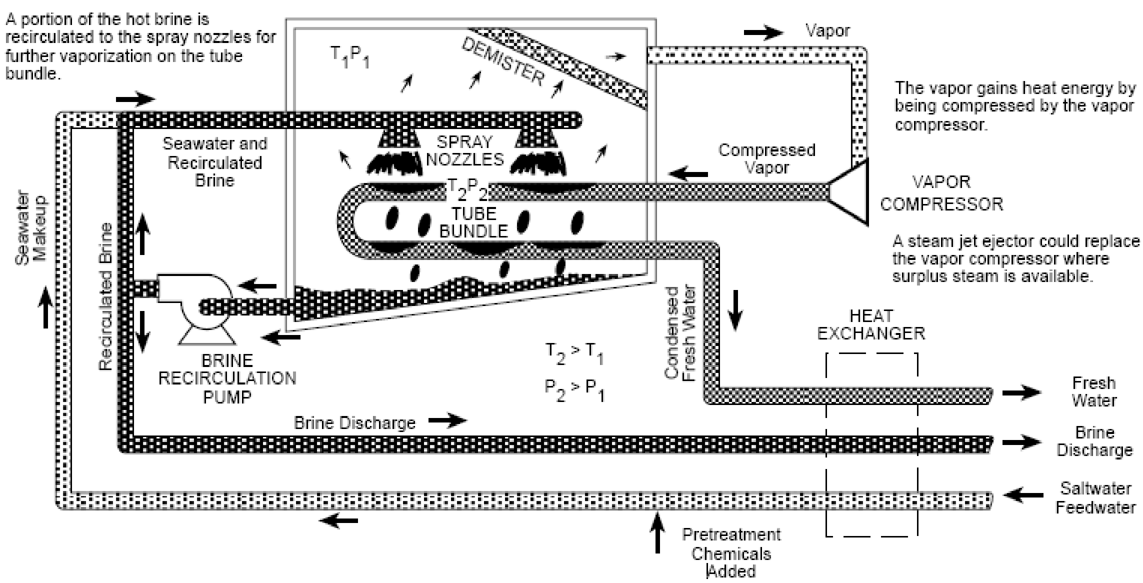


**Figure 4-14. Vapor compression process. SOURCE: Buros et al. (1980); Buros (2000). Reprinted courtesy of U.S. Agency for International Development.**

Other non-hybrid thermal desalination approaches, including solar stills and freezing, have been developed for desalination, although they have not been commercialized to date (Buros, 2000). In brief, a solar still uses the sun's energy to evaporate water from a shallow basin, which then condenses along a sloping glass roof.

**BOX B-2 (*Excerpted from NRC, 2008)***

**Low-Grade and Waste Heat for Desalination**

Low-grade heat and waste heat are two terms that are often used synonymously but, depending upon the application, they may have completely different meanings. The term *low-grade heat* is often used to describe heat energy that is available at relatively low (near-ambient) temperatures, which is of minimal value for industrial or commercial processes. In contrast, waste heat, which may or may not be low-grade heat, contains energy that is released to the environment without being used. Both have potential value for desalination.

Most of the largest desalination facilities in the world are dual-purpose facilities that produce both freshwater and electricity. In all of these facilities at least some of the electricity is generated by high pressure steam when it is expanded through turbines. In the case of backpressure turbines, when the steam leaves the turbine, it can no longer produce electricity even though it is still slightly above atmospheric pressure. The waste energy from this exhaust steam is ideal for use by thermal desalination processes. In contrast, condensing turbines have a cool exhaust steam under vacuum conditions. Therefore, when condensing turbines are used in combination with thermal desalination, some low pressure steam is extracted for use in the desalination process. Extracted low-grade steam could, in theory, be used to generate more electricity, but practical circumstances (e.g., electricity demand, limited operating flexibility) influence whether this low-grade energy would, in fact, be used this way. Thus, low-grade heat might also be wasted under specific circumstances. Large slow-speed diesel generators, such as those used to power large ships, also represent a source of low-grade heat that is often wasted. The cooling water can easily be used to heat both MED and MSF processes without affecting the efficiency of the power generation. Exhaust-gas boilers can also be added to capture otherwise wasted energy for use for desalination or to generate additional electricity.

There are other potential sources for waste heat that are simpler to identify as waste, such as industrial stack emissions or cooling circuit heat that is rejected to rivers, lakes, or the air via heat exchangers or cooling towers. Contrary to common belief, these heat plumes may contain useful energy, even though this energy may not be economical for use in the existing industrial processes.

There are economic costs associated with the use of waste or low-grade heat, such as the cost of installing and operating the heat recovery system. The act of recovering the heat may also affect the efficiency of the main process. When a previously wasted energy stream is used, it may then be valued as a potential revenue stream by its owner. When these costs are considered, the energy is not free, but in many cases energy costs can be reduced to a small fraction of the total process cost of desalination.

# *APPENDIX C: Recent Desalination Technology Innovations*

## *Membrane Distillation*

Membrane distillation is an example of a hybrid technology combining the concept of membrane filtration with low temperature distillation. The concept relies on a temperature gradient between a heated liquid source water, running along a hydrophobic membrane, and cooler gas or liquid on the other side of the membrane flowing in the opposite direction. Water vapor moves from the heated solution through the membrane into the cooler environment where the purified water condenses and is removed. Contrary to the high temperature requirements of thermal distillations, this process takes advantage of the high salt content of the concentrate to drive the process at much lower temperatures and at a lower pressure than normally required for reverse osmosis (Dow, et al., 2008; Gunderson, 2008).

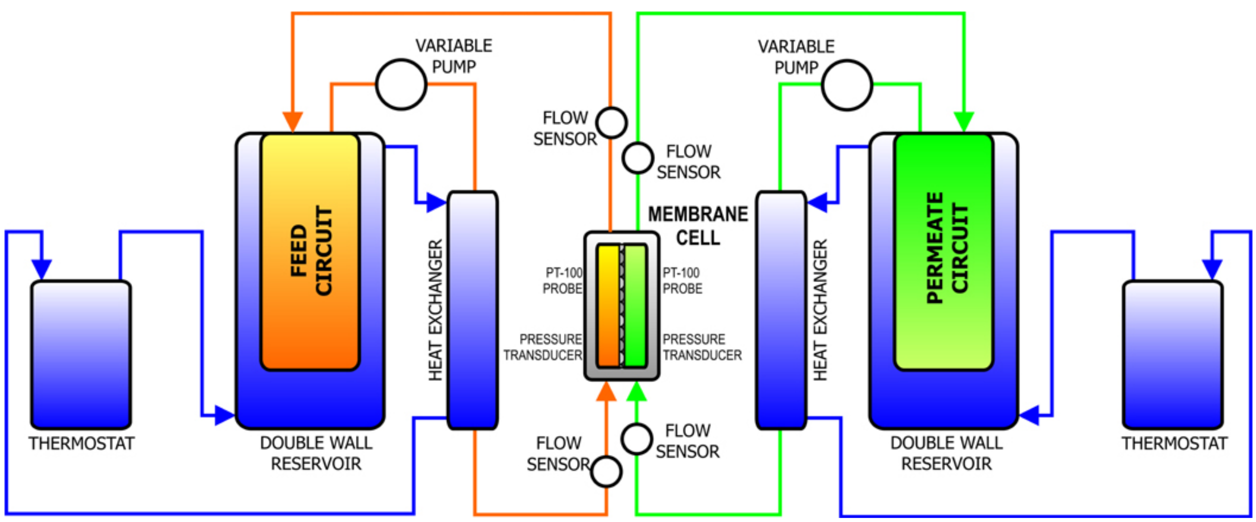


**Figure C-2. Membrane Distillation Process Flow (Lorenz, 2007)**

## *Forward Osmosis*

As mentioned earlier, osmosis is the natural movement of salts from a higher concentration to an area lower concentration. Forward osmosis (FO) builds on this concept by using a high concentration of a chemical that "draws" the water molecules through the membrane, leaving the salts behind (See Figure C-2). The chemical is then separated from the water, by heating for example, and reused in the process (McGinnis & Elimelech, 2007; Cath, et al., 2006; Teoh, et al., 2008). This is a fairly old technology that is being re-examined in light of new membrane technology and the development of new chemical compounds that require less energy to separate from the desalted water. Another innovation is the co-location of the desalination facility at a power plant where waste heat can be used to drive the separation of the chemical from the water. In some cases, to reduce energy costs, FO is used only to pre-treat the source water before treating with RO.

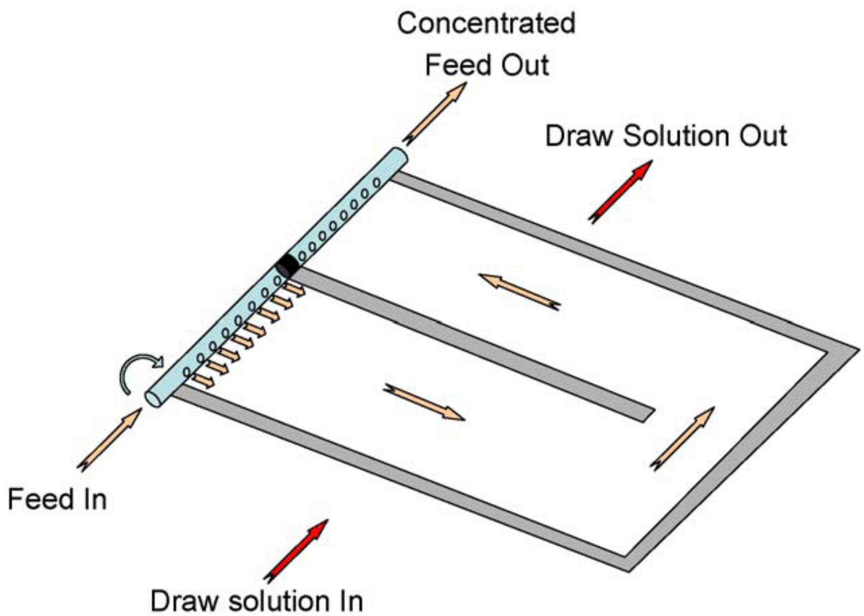


**Figure C-2. Flow Patterns in a Spiral-Wound Module Modified for Forward Osmosis. The feed solution flows through the central tube into the inner side of the membrane envelope and the draw solution flows in the space between the rolled envelopes. (Cath, et al., 2006)**

### *Solvent Flow in Forward Osmosis (FO), Pressurized Forward Osmosis (PRO), and Reverse Osmosis (RO)*

For FO, the applied pressure ($\Delta P$) is approximately zero and water diffuses to the more saline side of the membrane. For PRO, water diffuses to the more saline liquid that is under positive pressure ($\Delta\pi > \Delta P$). For RO, water diffuses to the less saline side due to hydraulic pressure ($\Delta P > \Delta\pi$). Osmotic pressure ($\pi$) is the pressure which, if applied to the more concentrated solution, would prevent transport of water across the membrane.

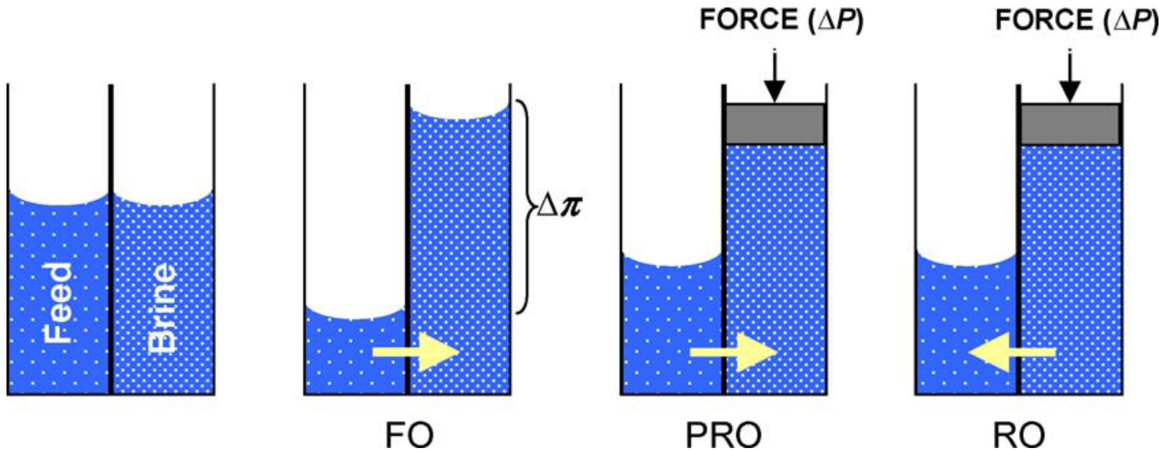


**Figure C-3. Illustration of Three Osmotic Processes: Forward Osmosis (FO), Pressurized Forward Osmosis (PFO), and Reverse Osmosis (RO)**
**(Cath, et al., 2006)**

### *Clathrate Desalination*

In Clathrate desalination, freshwater is separated from seawater by trapping water molecules in carbon dioxide molecules at an elevated temperature and pressure into a Clathrate crystal which is separated from the brine and then broken down to release the water molecule. The concept of using Clathrate has been around for decades, but recent advances have increased the size of the crystal and reduced the energy demands to improve the feasibility (Gunderson, 2008).

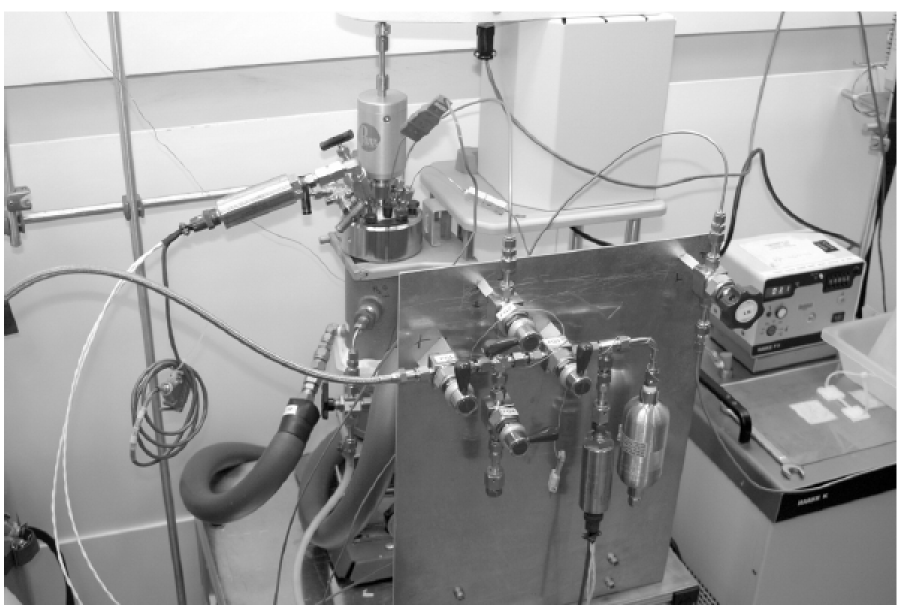

**Figure C-4. Detail view of Hydrate Cell apparatus showing pressure cell and stirrer head, gas distribution manifold, pressure transducers and temperature instrumentation. (Bradshaw, et al., 2006)**

### *Nanocomposite Membranes*

The concept of nanocomposite membranes is to take the existing polymer membrane chemistry and make it perform better, using thin-film composite membranes with nanostructured material. Replacing existing facility membranes, it promises to have a greater efficiency of water extraction at the same pressure, reducing the energy costs. Fouling resistance is improved as well (Graham-Rowe, 2008; Gunderson, 2008; CSIRO, 2009; Jeong, et al., 2007).

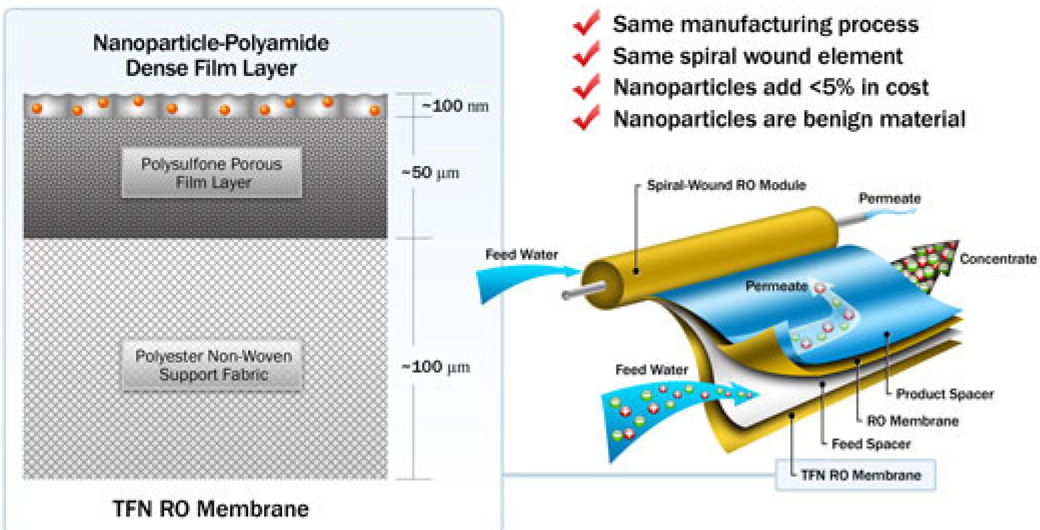


**Figure C-5. Conceptual Drawing of Thin-Film Nanocomposite (TFN) Reverse Osmosis Membranes (Gunderson, 2008; Dais Analytic, 2009).**

Clay-polymer nanocomposites show particular promise due to their ease of manufacture (large sheets), their rigidity (self supporting), and their excellent mechanical properties. However, the process of transport through the clay-polymer nanocomposite and mechanisms of pore size selection are poorly understood at the ionic and molecular level. In addition, manufacturing of clay polymer nanocomposite membranes with desirable properties has proved challenging (Moon, et al., 2006).

A team of Australian and US scientists has made a breakthrough in the development of membranes that, paradoxically, allow large molecules through far more readily than smaller ones. The new nanocomposite membranes are more selective and faster acting than previous versions used for molecular separation, which could have implications for many applications of the technology. These membranes are also more foul resistant, allowing for lower maintenance costs (CSIRO, 2009).

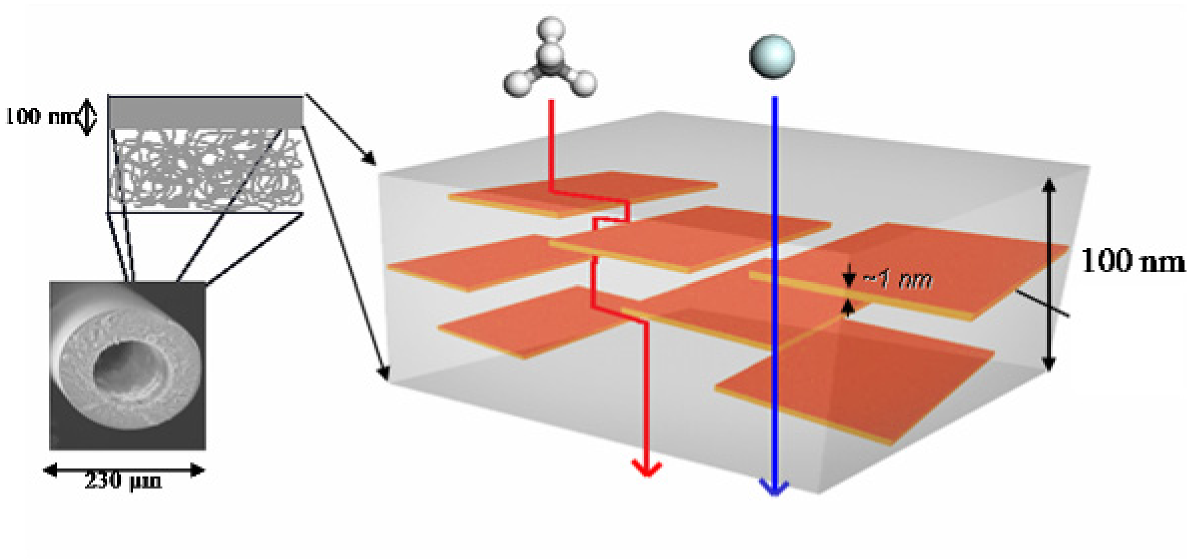


**Figure C-6. The Nanocomposite Membrane**
**(Source: "Research on Nanocomposite Polymeric Membranes", http://www.cems.umn.edu/research/tsapatsis/NIRT/index.htm)**

### *Energy Efficient Pumps*

It is important to maintain consistent pressure to the membranes in order to maximize the efficiency of the RO membranes in separating the water from the salt. It is also important to utilize the energy from spent concentrate to reduce the energy costs. One of the winners of the 2008 Global Water Innovative Technology awards was Ocean Pacific Technologies for their Axial Piston Pressure Exchanger Pump (Gunderson, 2008; Ocean Pacific Technologies, 2008b). Illustrated in Figure C-7, the unit is both a high pressure pump and an energy recovery device.

An axial piston pump is a positive displacement pump that has a number of pistons (usually an odd number) arranged in a circular array within a housing, which is commonly referred to as a cylinder block, rotor or barrel. This cylinder block is driven to rotate about its axis of symmetry by an integral shaft that is, more or less, aligned with the pumping pistons (usually parallel but not necessarily).

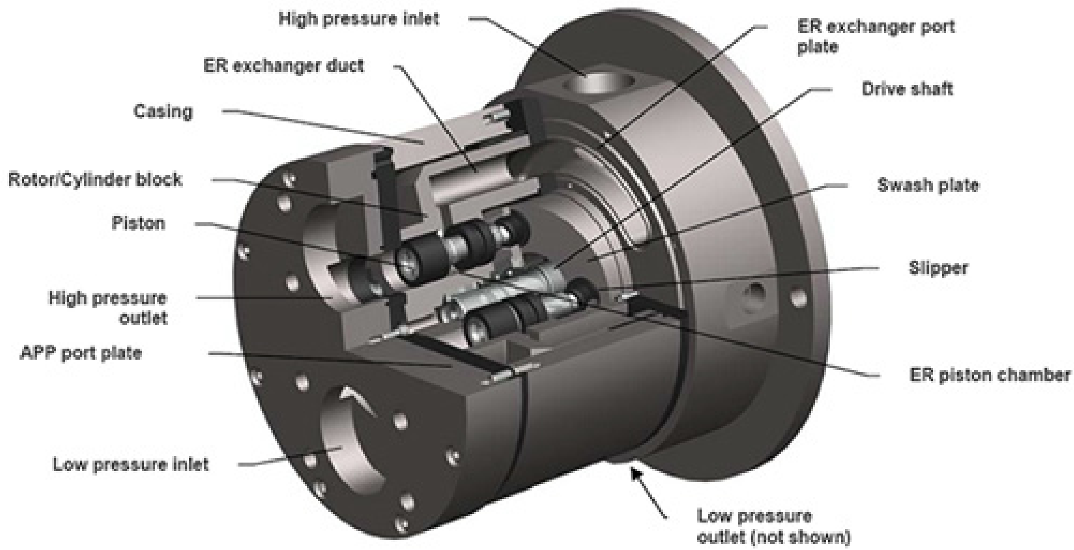


**Figure C-7. A Cross-Section of the OPT X-Pump (Ocean Pacific Technologies, 2008a)**

### *Dewvaporation*

In the dewvaporation technology, a stream of heated air (warmed by heat generated by combustion or solar methods or waste heat from another process) is humidified by running a stream of saline water on a heated surface. The saturated air is moved along condensing heat transfer films, where the condensate is collected as product water (Hamieh, et al., 2001).

The technology uses dewvaporation towers to carry out water purification. These towers are fairly simple in construction, mainly consisting of corrugated plastic. The process utilizes two independent water streams: one of which is the process hot water loop, and the other contains the water to be treated. The hot water loop can contain any type of water. Heating the process water is the major energy requirement for the dewvaporation process, and can be accomplished using solar energy. A water heater may be used in combination with the solar panels for times when solar energy alone is inadequate.

**Figure C-8. Picture of a Dewvaporation Tower Looking Down from Top (Vikram and Deng, 2005)**

### *Freeze Desalination*

The freeze desalination process uses the phase shift of water from liquid to solid to exclude the salt from the ice crystals. The ice is washed to remove the salty film, and then melted to produce water. The desalination processes described thus far fall into two categories: those that remove the freshwater, leaving concentrated saltwater behind and those that remove the salts and leave behind the freshwater. The freezing method falls within the first category. Salt waters have a certain critical temperature, which is a function of their salinity. When the saltwater is reduced to this temperature, ice crystals composed of freshwater are formed. It is then possible to mechanically separate the ice crystals from the solution and then melt the crystals to produce freshwater. This is the basic principle on which freezing desalination methods are based as illustrated in Figure C-9, below.

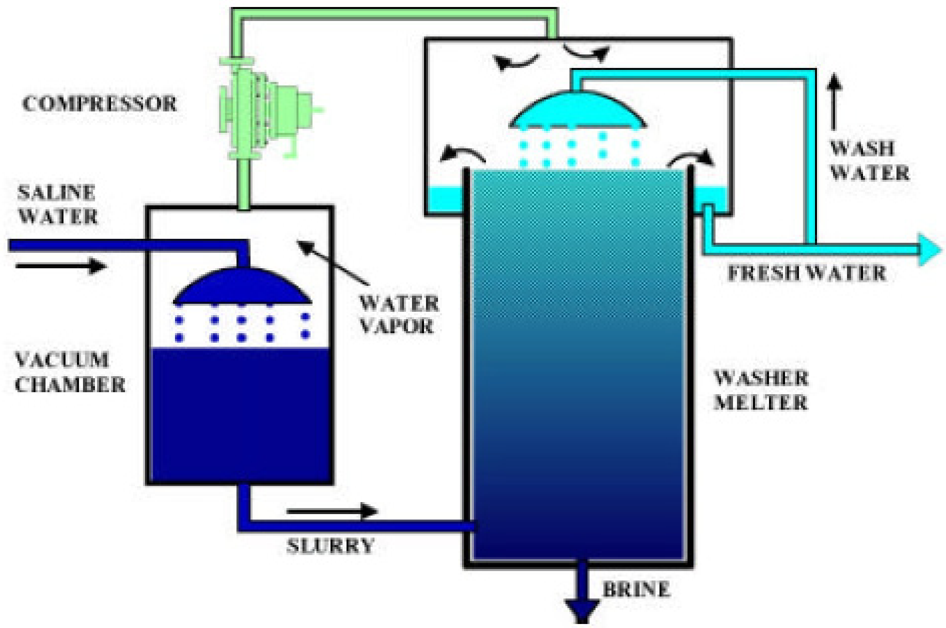


**Figure C-9. Schematic of Vacuum Freeze Desalination (Clayton, 2006)**

### *Membrane Vapor Compression*

Similar to membrane distillation, membrane vapor compression uses lower temperatures and moderate pressures to pump vapor through hydrophobic membranes (Ruiz, 2005). Vapor compression refers to a distillation process where the evaporation of sea or saline water is obtained by the application of heat delivered by compressed vapor. Since compression of the vapor increases both the pressure and temperature of the vapor, it is possible to use the latent heat rejected during condensation to generate additional vapor. The effect of compressing water vapor can be done by two methods.

The first method utilizes an ejector system motivated by steam at manometric pressure from an external source in order to recycle vapor from the desalination process. The form is designated ejecto or thermo compression.

Using the second method, water vapor is compressed by means of a mechanical device, electrically driven in most cases. This form is designated mechanical vapor compression (MVC). The MVC process comprises two different versions: vapor compression (VC) and vacuum vapor compression (VVC). VC designates those systems in which the evaporation effect takes place at manometric pressure, and VVC the systems in which evaporation takes place at sub-atmospheric pressures (under vacuum). The compression is mechanically powered by something such as a compression turbine. As vapor is generated, it is passed over to a heat exchanging condenser which returns the vapor to water. The resulting freshwater is moved to storage while the heat removed during condensation is transmitted to the remaining feedstock.

The VVC process is the more efficient distillation process available in the market today in terms of energy consumption and water recovery ratio. As the system is electrically driven, it is considered a "clean" process, it is highly reliable and simple to operate and maintain. Use of nanotechnology in the development of the membranes can further improve the efficiencies and reduce costs (Gunderson, 2008; Dais Analytic, 2009).

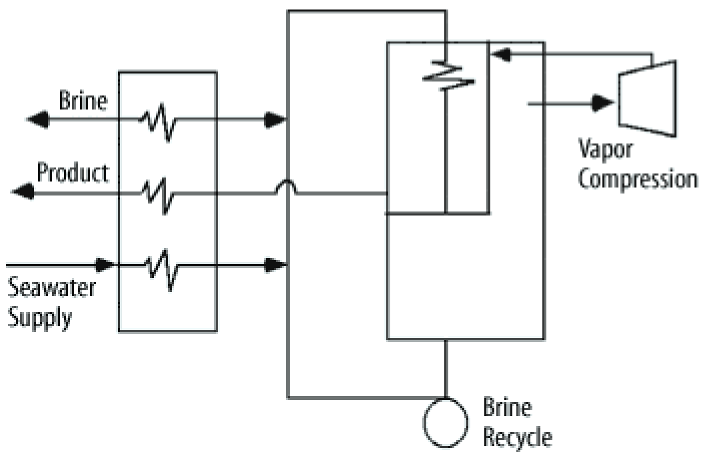


**Figure C-10. The VC process involves evaporating the feedwater, compressing the vapor, and then using the heated compressed vapor as a heat source to evaporate additional feedwater. (Source: http://www.usewaterwisely.com/totm0706.cfm, 2006)**

## *APPENDIX D: Desalination Pretreatment Considerations*

The initial removal of large particles from the feed water is accomplished using mesh strainers or traveling screens. Mesh strainers are used in well water supply systems to stop and remove sand particles which may be pumped from the well. Traveling screens are used mainly for surface water sources, which typically have large concentrations of biological debris. It is common practice to disinfect surface feed water in order to control biological activity. Biological activity in well water is usually very low, and in majority of cases, well water does not require chlorination. In some cases, chlorination is used to oxidize iron and manganese in the well water before filtration. Well water containing hydrogen sulfide should not be chlorinated or exposed to air. In presence of an oxidant, the sulfide ion can oxidize to elemental sulfur which eventually may plug membrane elements.

Settling of solids contained in surface source water in a detention tank results in some reduction of suspended particles. Addition of flocculants, such as iron or aluminum salts (See Figure D-2), results in formation of corresponding hydroxides; these hydroxides neutralize surface charges of colloidal particles, aggregate, and adsorb to floating particles before settling at the lower part of the clarifier.

Well water usually contains low concentrations of suspended particles, due to the filtration effect of the aquifer. The pretreatment of well water is usually limited to screening of sand, addition of scale inhibitor to the feed water, and cartridge filtration.

Surface water may contain various concentrations of suspended particles, which are either of inorganic or biological origin. Surface water usually requires disinfection to control biological activity and removal of suspended particles by media filtration. The efficiency of filtration processes can be increased by adding filtration aids, such as flocculants and organic polymers. Some surface water may contain high concentrations of dissolved organics. Those can be removed by passing feed water through an activated carbon filter. Depending on the composition of the water, acidification and the addition of scale inhibitor may be required.

Cartridge filters, almost universally used in all reverse osmosis (RO) systems prior to the high pressure pump, serve as the final barrier to water born particles. The nominal rating (or maximum size of particles) commonly used in RO applications is in the range of 5 - 15 microns. Some systems use cartridges that can remove particle as small as 1 micron. There seems to be little benefit from lower micron rated filters as such filters require a high replacement rate with relatively small improvement in the final feed water quality. Recently, new pretreatment equipment has been introduced to the RO market. It consists of back-washable capillary microfiltration and ultrafiltration membrane modules. This new equipment can operate reliably at a very high recovery rates and low feed pressure. The new capillary systems can provide better feed water quality than a number of conventional filtration steps operating in series. The cost of this new equipment is still very high compared to the cost of an RO unit (Hydranautics, 2001a).

Cost of pretreatment will vary with source water quality, local site factors and environmental constraints. For example, exotic mussels, shown in Figure D-1, invaded the intake structure of the Tampa Bay Water desalination facility. These tiny Asian green mussels, originally native to the Indian and Pacific oceans, were found to be clogging filters at the plant. It is thought that they were accidentally introduced into Tampa Bay in ballast water from a bulk cargo ship.

**Figure D-1. Asian Green Mussels in the intake system of the Tampa Desalination Facility (TBW, 2008)**

**Figure D-2. Flocculation with Ferric (Iron) Chloride at the Tampa Desalination Facility (TBW, 2008)**

**Figure D-3. Following Chemical Pretreatment the floc and sediment are separated from the water with plate settlers. (TBW, 2008)**

**Figure D-4. Diatomaceous Earth Precoat Filter Vessels provide one of the final stages of filtration prior to reverse osmosis membranes at the Tampa Desalination Facility. (TWB, 2008)**

# APPENDIX E: Concentrate Management Challenges and Limits (NRC, 2008)

| Method | Capital Costs a | O&M Costs a | Land Area Required | Permitting Complexity | Applicable for Large Conc. Flows | Potential Environmental Impact | Possible Pre-treatment Needs | Labor Needs and Skill Level (for operation) | Energy Use | Public Perception Concerns | Climate Limitation | Special Geological Requirements |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface water discharge | L[a] | L[a] | -- | H | Yes | M | M | L | L[b] | H | Maybe[f] | N |
| Sewer discharge | L[a] | L[a] | -- | M | No | M | L | L | L[b] | L | N | N |
| Subsurface discharge (deep well injection) | M-H | M | L | M | Maybe | L | L | L | M | L-M[e] | N | Y |
| Evaporation Pond | H | L[c] | H | M | No | M | L | L | L | H | Y | Y |
| Land Application | M | L | H | M | No | M-H | L | L | L[b] | H | Y | Y |
| Thermal evaporation | H | H | L | L[d] | No | L[d] | L | H | H | L | N | N |

L = low; M = medium; H = high; Y= yes; N = no; dashes indicate not applicable. [a] Costs are highly site specific; general trends in relative costs are indicated; cost for surface water or sewer discharge can be higher if the distance from desalination facility to the discharge water body or sewer is large, necessitating long pipelines and/or pumping facilities. [b] Energy use for surface water or sewer discharge or land application can possibly be higher if the distance from desalination facility to the discharge water body, sewer, or land application site is large, possibly necessitating pumping facilities. [c] O&M costs for evaporation ponds can possibly be higher if a significant amount of monitoring wells and associated water quality analysis are required. [d] Permitting complexity and environmental impacts of thermal evaporation can possibly be higher if the feedwater-to-desalination process contains contaminants of concern that could be concentrated to toxic levels in the concentrated slurry or solids that are produced from this concentrate treatment process. [e] Low (L) pertains to Florida (where deep-well injection is commonly practiced) and moderate (M) pertains to other states in the United States. [f] Climate can indirectly influence surface water discharge by affecting the quantity of surface water available for dilution.

# APPENDIX F: FDEP Regulated RO Facilities as of December 2008

| FDEP District | Facility | Plant Name | Design Capacity (MGD) |
|---|---|---|---|
| NWD | AFRL AREA (TYNDALL AFB) | PLANT #1 | 0.432 |
| NWD | EASTERN SHIPBUILDING | PLANT 1 | 0.069 |
| | | | |
| NED | HORSESHOE BEACH WTP | HORSESHOE BEACH WTP | 0.215 |
| NED | SUWANNEE WATER & SEWER DISTRICT | SUWANNEE WATER | 0.375 |
| NED | PALM COAST UTILITY | MEMBRANE SOFTENING PLANT (NF) | 6.384 |
| NED | PALM COAST UTILITY | WTP # 3 | 3.000 |
| NED | BULL CREEK FISH CAMP | BULL CREEK | 0.003 |
| NED | DUNES COMMUNITY DEVELOPMENT DISTRICT | DUNES CDD RO WTP | 0.720 |
| NED | ST. JOHN'S HARBOR | PLANT #2 | 0.200 |
| NED | ST. AUGUSTINE WTP | WTP # 2 (RO) | 2.000 |
| NED | HASTINGS WTP | HASTINGS WTP | 0.219 |
| NED | NORTH BEACH UTILITIES | NORTH BEACH UTILITIES | 0.778 |
| NED | CAMACHEE COVE YACHT HARBOR | CAMACHEE COVE WTP | 0.071 |
| NED | CR-214 MAINLAND | REVERSE OSMOSIS WTP | 8.000 |
| NED | SOUTH WOODS ELEMENTARY SCHOOL | SOUTH WOODS ELEMENTARY SCHOOL | 0.039 |
| NED | INGLIS WATER DEPT. | INGLIS WTP | 0.500 |
| NED | YANKEETOWN WATER DEPT. | YANKEETOWN | 0.432 |
| | | | |
| CD | CAMELOT RV PARK INC | REPLACEMENT PLANT | 0.024 |
| CD | PALM BAY CITY OF | R.O. PLANT | 1.500 |
| CD | PALM BAY CITY OF | SOUTH REGIONAL R.O. WTP | 4.000 |
| CD | SOUTH BREVARD WATER CO-OP | SOUTH BREVARD WATER CO-OP | 0.120 |
| CD | MELBOURNE CITY OF | R.O. TREATMENT PLANT | 6.500 |
| CD | LIGHTHOUSE COVE | LIGHTHOUSE COVE | 0.022 |
| CD | HARRIS CORPORATION-MALABAR WTP | HARRIS CORPORATION-MALABAR WTP | 0.128 |
| CD | SERVICE MANAGEMENT SYSTEMS INC | AQUARINA R.O. WTP | 0.086 |
| CD | SOUTH SHORES UTILITY ASSOCIATION | SOUTH SHORES UTILITY ASSOC | 0.122 |
| CD | WINGATE RESERVE SUBDIVISION | WINGATE RESERVE SUBDIVISION | 0.042 |
| CD | VERO BEACH CITY OF | VERO BEACH 3.3MGD R.O. WTP | 3.300 |
| CD | INDIAN RIVER COUNTY UTILITIES (2 WTPS) | SOUTH COUNTY R.O. (8.57 MGD) | 8.570 |
| CD | INDIAN RIVER COUNTY UTILITIES (2 WTPS) | NORTH HOBART RO (3.53 MGD) | 3.530 |
| CD | COUNTRYSIDE NORTH MHP | COUNTRYSIDE NORTH MHP | 0.133 |
| CD | CLERMONT JEHOVAH'S WITNESSES | KINGDOM HALL OF JEH.WIT-CLERMN | 0.054 |
| CD | LAKE VILLA ESTATES | LAKE VILLA ESTATES PLANT | 0.010 |
| CD | SPRUCE CREEK FLY IN | SPRUCE CREEK FLY-IN | 0.550 |

| | | | |
|---|---|---|---|
| CD | KINGSTON SHORES | KINGSTON SHORES | 0.058 |
| CD | ORMOND BEACH | ORMOND BEACH CITY OF | 12.000 |
| CD | RIVERWOOD PARK CAMPGROUND | RIVERWOOD CAMP | 0.010 |
| CD | HALIFAX PLANTATION | HALIFAX PLANTATION | 0.750 |
| | | | |
| SED | HOLLYWOOD CITY OF | HOLLYWOOD PLANT-LIME SOFTENING | 37.500 |
| SED | HOLLYWOOD CITY OF | REVERSE OSMOSIS | 4.000 |
| SED | NORTH MIAMI BEACH | NORWOOD R.O. PLANT | 12.000 |
| SED | BISC NATL PK-ELLIOTT KEY | ELLIOTT KEY RECREATION | 0.012 |
| SED | FKAA J. ROBERT DEAN W.T.P. | FKAA REVERSE OSMOSIS PLANT | 6.000 |
| SED | UTILITIES INC OF HUTCHINSON ISLAND | INDIAN RIVER PLANTATION WTP | 0.400 |
| SED | FPL - MARTIN PLANT | FLORIDA POWER & LI. INDIANTOWN | 0.061 |
| SED | MARTIN CO UTIL UTILITIES | MARTIN CO UTIL N RO/5.5 MGD | 5.500 |
| SED | MARTIN CO UTIL UTILITIES | MARTIN CO UTIL TF RO | 10.000 |
| SED | SAILFISH POINT | SAILFISH POINT UTILITY CORP. | 0.350 |
| SED | WELLINGTON WTP | WELLINGTON RO | 6.300 |
| SED | NEW HOPE SOUTH INC ( SUGAR FARMS ) | FORMER SHELLTON LAND&CATTLE | 0.014 |
| SED | BOCA RATON WTP | GLADES ROAD | 70.000 |
| SED | OKEELANTA SUGAR MILL | REVERSE OSMOSIS PLANT(10/20/94 | 0.600 |
| SED | HIGHLAND BEACH WATER PLANT | HIGHLAND BEACH WATER PLANT | 2.250 |
| SED | MANALAPAN WTP (LEROY C.PASLAY) | MANALAPAN WATER DEPARTMENT | 1.935 |
| SED | TEQUESTA WTP | TEQUESTA WTP R.O. | 2.400 |
| SED | JUPITER WATER SYSTEM TOWN OF | JUPITER REVERSE OSMOSIS PLANT | 12.000 |
| SED | US SUGAR CORP-BRYANT MILL | US SUGAR WTP | 0.003 |
| SED | US SUGAR CORP-BRYANT MILL | BRYANT RAIL ROAD RO PLANT | 0.001 |
| SED | GOLF VILLAGE OF | VILLAGE OF GOLF WTP | 0.864 |
| SED | ATLANTIC SUGAR ASSOCIATION INC. | R/O PLANT(04/04/97) | 0.060 |
| SED | OSCEOLA/VERMILLON SUGAR MILL | OSCEOLA SUGAR MILLS | 0.072 |
| SED | PALM BEACH COUNTY WATER UTILITIES | SYSTEM 3 | 30.000 |
| SED | PALM BEACH COUNTY WATER UTILITIES | SYSTEM 9 MEMBRANE | 26.880 |
| SED | PALM BEACH COUNTY WATER UTILITIES | SYSTEM 10 R.O. PLANT | 3.000 |
| SED | FIRST PARK SOUTH FLORIDA | PB PARK OF COMMERCE WTP | 0.180 |
| SED | ABC MONTESSORI OF JUPITER FARMS | KIDWORKS-NEW R/O PLANT | 0.002 |
| SED | JUPITER FARMS COMMUNITY ELEMENTARY SCHOO | SAME | 0.040 |
| SED | JUPITER FARMS COMMUNITY SHOPPING CENTER | SAME AS ABOVE | 0.091 |
| SED | US SUGAR PREWITT TRACTOR SHED | PREWITT TRACTOR SHED | 0.003 |
| SED | PELICAN WATER CORPORATION | PELICAN LAKE VILLAGE | 0.053 |
| SED | GLADES UTILITIES AUTHORITY | GLADES REGIONAL WTP | 10.000 |
| SED | FT. PIERCE UTILITIES AUTHORITY | FPUA REVERSE OSMOSIS WTP | 3.000 |
| SED | PORT ST LUCIE UTILITIES | PRINEVILLE RO 11.15 MGD | 11.150 |
| SED | PORT ST LUCIE UTILITIES | JAMES E. ANDERSON RO WTP | 22.500 |
| SED | OCEAN TOWERS / ISLAND VILLAGE | OCEAN TOWERS (@ ISLAND DUNES) | 0.120 |
| SED | MIRAMAR APTS./AKA BELLA VISTA | MIRAMAR APTS./AKA BELLA VISTA | 0.075 |

| | | | |
|---|---|---|---|
| SED | GROVE OF FT. PIERCE INC. THE | FT. PIERCE | 0.100 |
| SED | SPANISH LAKES FAIRWAYS | SPANISH LAKES FAIRWAYS | 0.570 |
| SED | ST. LUCIE COUNTY FAIRGROUNDS | ST. LUCIE COUNTY FAIRGROUNDS | 0.025 |
| SED | FLAMINGO | FLAMINGO WTP | 0.160 |
| | | | |
| SD | FLORIDA GOVERNMENTAL UTILITY AUTHORITY | GOLDEN GATE WTP | 2.099 |
| SD | CITY OF MARCO ISLAND | MARCO ISLAND R.O. PLANT | 6.000 |
| SD | COLLIER COUNTY REGIONAL WTP | COLLIER CO NORTH RO PLANT | 20.000 |
| SD | S.W. FLORIDA RESEARCH ED. CTR. | S.W.FL. RESEARCH ED. CTR. | 0.010 |
| SD | SABAL PALM ELEMEN / CYPRESS PALM MIDDLE | SABAL PALM ELEMENTARY SCHOOL | 0.015 |
| SD | CITRUS BELLE CONCENTRATE PLT | CITRUS BELLE CONCENTRATE WTP | 0.036 |
| SD | CLEWISTON CITY OF | CLEWISTON RO PLANT | 3.000 |
| SD | TURKEY RUN SUBDIVISION | TURKEY RUN SUBDIVISION WTP | 0.025 |
| SD | ALICO CAMP SITE | ALICO CAMP SITE WTP | 0.005 |
| SD | SOUTHERN GARDENS CITRUS | SOUTHERN GARDENS CITRUS WTP | 0.850 |
| SD | ALVA MIDDLE & ELEMENT. SCHOOL | ALVA MIDDLE & ELEM. SCHOOL WTP | 0.020 |
| SD | BONITA SPRINGS UTILITIES | BONITA SPRINGS REVERSE OSMOSIS | 6.600 |
| SD | ISLAND WATER ASSOCIATION | ISLAND WATER ASSOC. (R.O) WTP | 5.990 |
| SD | USEPPA ISLAND CLUB | USEPPA ISLAND CLUB WTP | 0.056 |
| SD | GREATER PINE ISLAND WATER ASSOCIATION | GREATER PINE ISLAND WTP | 3.290 |
| SD | CAPE CORAL CITY OF | CAPE CORAL RO PLANT | 18.100 |
| SD | LEE COUNTY UTILITIES | L.C.U. N. FT MYERS R.O. PLANT | 6.000 |
| SD | LEE COUNTY UTILITIES | L.C.U. PINEWOODS R.O. PLANT | 5.300 |
| SD | LEE COUNTY MOSQUITO CONTROL | LEE COUNTY MOSQUITO CONTL. WTP | 0.005 |
| SD | CHARLESTON PARK | CHARLESTON PARK | 0.035 |
| SD | SYNGENTA FLOWERS-ALVA FARM | SYNGENTA FLOWERS INC ALVA FARM | 0.005 |
| SD | BURNT STORE CENTRE | BURNT STORE CENTRE | 0.003 |
| SD | ALLIGATOR PARK | ALLIGATOR PARK WTP | 0.060 |
| SD | CHARLOTTE HARBOR WATER ASSN. | HARBOUR HEIGHTS | 0.750 |
| SD | GASPARILLA ISLAND WATER ASSOC | GASPARILLA ISLAND R.O. PLANT | 1.270 |
| SD | LITTLE GASPARILLA UTILITY INC | LITTLE GASPARILLA PLANT | 0.072 |
| SD | CHARLOTTE COUNTY UTILITIES / BURNT STORE | CCU/ BURNT STORE PLANT | 1.127 |
| SD | TROPICAL PALMS MHP | TROPICAL PALM MHP | 0.080 |
| SD | SUN RIVER UTILITIES INC | RIVERS EDGE WTP | 0.040 |
| SD | KNIGHT ISLAND UTILITIES INC. | KNIGHT ISLAND UTILITIES INC. | 0.090 |
| SD | BOCILLA UTILITIES INC. | BOCILLA UTILITIES INC. | 0.120 |
| | | | |
| SWD | DESOTO CORRECTIONAL INST | DESOTO CORRECTIONAL | 0.800 |
| SWD | WAUCHULA CITY WATER DEPARTMENT | WAUCHULA CITY | 4.780 |
| SWD | EASTBAY RACEWAY PARK | EASTBAY RACEWAY PLANT # 1 | 0.001 |
| SWD | TAMPA BAY SEAWATER DESALINATION FACILITY | DESALINATION PLANT | 25.000 |
| SWD | CLEARWATER WATER SYSTEM | RESERVOIR #1 1657 PALMETTO ST | 3.000 |

| | | | |
|---|---|---|---|
| SWD | DUNEDIN WATER SYSTEM | DUNEDIN CR 1 PLANT | 9.590 |
| SWD | MOSAIC FERTILIZER LLC - NEW WALES | IMCF NEW WALES OP. WATER PLANT | 1.008 |
| SWD | SARASOTA-CITY OF | 1750 12TH STREET | 12.000 |
| SWD | ENGLEWOOD WATER DIST | RO PLANT | 3.000 |
| SWD | KINGS GATE RV PARK | RO PLANT | 0.060 |
| SWD | PETERSON MANUFACTURING CO | PETERSON MFG | 0.017 |
| SWD | SARASOTA CO SPECIAL UTIL DIST | VENICE GARDENS RO PLANT | 2.750 |
| SWD | SUN N FUN RESORT INC | SUN N FUN RESORT INC | 0.195 |
| SWD | VENICE RANCH MOBILE HOME ESTAT | VENICE RANCH MHP | 0.035 |
| SWD | VENICE WATER DEPT CITY OF | VENICE WATER PLANT | 4.490 |
| SWD | WINDWARD ISLE MHP WATER SYSTEM | SAME | 0.050 |
| SWD | LAKE TIPPECANOE | LAKE TIPPECANOE | 0.075 |
| SWD | THE ARBORS | R.O. WATER TREATMENT PLANT | 0.039 |
| SWD | KINGS GATE CLUB | WATER PLANT | 0.083 |
| SWD | CAMELOT LAKES | CAMELOT LAKES | 0.200 |
| SWD | AAA AUTO CLUB SOUTH | AAA AUTO CLUB SOUTH | 0.003 |
| SWD | NOKOMIS GROVES | NOKOMIS GROVES | 0.014 |
| SWD | SNOOK HAVEN | WELL 1 | 0.003 |
| SWD | AMERICAN LEGION POST 254 NP. | NORTH PORT AMERICAN LEGION | 0.002 |
| SWD | FOX LEA FARMS | FOX LEA FARMS | 0.010 |
| SWD | HAZELTINE NURSERIES | HAZELTINE NURSERIES | 0.002 |
| SWD | EUROPEAN ACADEMY | EUROPEAN ACADEMY | 0.003 |
| SWD | NEW GATE SCHOOL-CLARK | NEW GATE CLARK | 0.034 |
| SWD | SARASOTA CO SPECIAL UTIL DIST | T. MABRY CARLTON RESERVE | 17.300 |

***MGD= Million Gallons per Day*** ***Cumulative Design Capacity 514.80 MGD***

# *APPENDIX G: Desalination Links Compiled by Texas Water Development Board (TWDB), 2009*

- **United States Bureau of Reclamation: Water Treatment Engineering and Research**
  **The USBOR's WaTER Group provides expert water and wastewater treatment engineering and research technical services.**

- **Brownsville Public Utilities Board**
  **The Rio Grande Regional Seawater Desalination Project is Texas' first seawater desalination pilot study in support of efforts to construct a full-scale plant on the state's Gulf Coast.**

- **California Coastal Commission**
  **The California Coastal Commission document contains technical and policy information on desalination.**

- **California Department of Water Resources: Recycling and Desalination**
  **DWR's Water Recycling and Desalination program aims to increase the safe and beneficial use of recycled and desalinated water in California.**

- **El Paso Water Utilities**
  **EPWU's state-of-the-art desalination plant at Ft. Bliss, Texas, is the largest inland desalination plant in the world and went online August 8, 2007.**

- **Metropolitan Water District of Southern California**
  **Seawater desalination is an integral part of MWD which provides drinking water to nearly 18 million people in Southern California.**

- **San Diego County Water Authority: Seawater Desalination**
  **When built, the 50-MGD seawater desalination plant at the Encina Power Station will provide water to 100,000 people in San Diego County, California.**

- **South Florida Water Management District**
  **SFWMD plans to have seawater desalination plants operating in the future.**

- **St. Johns River Water Management District – Coquina Coast Seawater Desalination Project**
  **SJRWMD is currently working with county and local governments to determine the feasibility and implementation strategy for a desalination plant in Flagler County, in a region known as Coquina Coast.**

- **Tampa Bay Water: Seawater Desalination**
  **The 25-MGD Tampa Bay, Florida, seawater desalination plant is expected to be completed by the end of 2006.**

- **West Basin Municipal Water District: Desalination Pilot Project**
  **The seawater desalination pilot project located on the California coast marks the first use of microfiltration as a pre-treatment to reverse osmosis.**

- **American Institute of Chemical Engineers**
  **AIChE is the world's leading organization for chemical engineering professionals.**

- **American Membrane Technology Association**
  **AMTA promotes, advocates and advances the understanding and application of membrane technology to create safe, affordable and reliable water supplies for beneficial use.**

- **American Water Works Association**
  **AWWA is an international non-profit scientific and educational society dedicated to improving water quality and supply.**

- **European Desalination Society**
  **EDS is a Europe-wide organization for individuals and corporations who are interested in desalination and membrane technology.**

- **European Membrane Society**
  **EMS promotes knowledge and the use of membranes and membrane processes at universities and in industry.**

- **Indian Desalination Association**
  **InDA aims to develop and promote desalination technology for water supply, reuse, pollution control and other applications in India.**

- **Institution of Chemical Engineers**
  **IChemE is the hub for chemical, biochemical, and process engineering professionals worldwide.**

- **International Atomic Energy Agency: Nuclear Desalination Project**
  **The objective of this IAEA program is to increase the exchange of information on nuclear desalination and other applications of nuclear energy.**

- **International Desalination Association**
  **IDA develops and promotes the appropriate use of desalination and desalination technology worldwide.**

- **International Energy Foundation**
  **The IEF is a non-profit group of scientists and engineers facilitating the transfer of research and technology in all areas of energy with special emphasis on developing countries.**

- **International Solar Energy Society**
  **ISES is a non-profit global NGO dedicated to serving the needs of the renewable energy community.**

- **International Water Association**
  **The IWA is a global network of water professionals spanning the continuum between research and practice and covering all facets of the water cycle.**

- **Japan Water Works Association**
  **Japan Water Works Association is a non-profit foundation which performs various activities for the purpose of ensuring the sound development of water supplies.**

- **Middle East Desalination Research Center**
  **The MEDRC's mission is to conduct, facilitate, promote, coordinate, and support basic and applied research in the field of desalination.**

- **North American Membrane Society**
  **NAM's mission is to serve the synthetic membrane community by fostering the development and dissemination of knowledge in membrane science and technology.**

- **South Central Membrane Association**
  **SCMA is a regional affiliate of AMTA supporting development of membrane technology in water and wastewater treatment operations in Arkansas, Louisiana, New Mexico, Oklahoma, and Texas.**

- **Southeast Desalting Association**
  **SEDA is a regional affiliate of AMTA dedicated to the improvement of the quality of water supplies through membrane desalting and filtration, water reuse, and other water sciences.**

- **The Filtration Society**
  **The Filtration Society is a non-profit organization established to advance and disseminate knowledge in the design and use of filtration and separation techniques in industry, commerce and other aspects of life.**

- **WateReuse Association**
  **WateReuse is a non-profit organization whose mission is to advance the beneficial and efficient use of water using reclamation, recycling, reuse, and desalination.**

- **Water Science and Technology Association**
  **WSTA deals with all aspects of water use and management in the Arabian Gulf region.**

- **World Water Council**
  **The WWC's mission is to promote awareness, build political committment, and trigger action on critical water issues worldwide.**

- **Brackish Groundwater National Desalination Research Facility (New Mexico)**
  **The research facility is a focal point for developing technologies for the desalination of brackish and impaired groundwater found in the inland states. It is located in Alamogordo, New Mexico and was opened on August 16, 2007.**

- **California NanoSystems Institute (California)**
  **A collaborative effort between UCLA and UCSB, this group works in five major areas of nanosystems-related research including renewable energy; environmental nanotechnology and nanotoxicology; nanobiotechnology and biomaterials; nanomechanical and nanofluidic systems; and nanoelectronics, photonics and architectonics. Research is applicable to water treatment and desalination.**

- **Center for Inland Desalination Systems at UT-El Paso (Texas)**
  **In partnership with El Paso's desalination plant, the center was established in 2008 to develop and implement technologies to create alternative water sources in Texas and across the globe. The El Paso desalination plant uses reverse osmosis to treat brackish groundwater from the Hueco Bolson Aquifer.**

- **Center for Membrane Technologies, New Jersey Institute of Technology**
  **The center is an academic-industrial interface consisting of faculty from NJIT, Rowan University, Rutgers University (New Brunswick) and the Stevens Institute of Technology. Seed funding for the center is provided by the New Jersey Commission on Science and Technology through its R&D Excellence Initiative.**

- **Environmental Nanotechnology Research Group at Michigan State University**
  **The group's research program primarily focuses on membrane processes and colloidal and interfacial phenomena in environmental systems.**

- **Institute of Technical Chemistry, University of Essen (Germany)**
  **The main research activities are devoted to functional polymer materials with a focus on molecularly imprinted polymers (MIPs) and synthetic membranes, especially composite membranes. Membrane technologies and processes are evaluated with respect to life science and industrial applications.**

- **Membrane Research, University of Texas at Austin (Texas)**
  **The group's research program is primarily experimental in nature, focusing on developing fundamental structure/property/processing guidelines for preparation of novel, high performance polymers or polymer-based materials for gas and liquid separations as well as barrier packaging applications.**

- **Membrane Technology Group, University of Twente (The Netherlands)**
  **The mission of the Membrane Technology Group is to educate and perform fundamental research, and product and process development in the area of polymeric and hybrid material structures to control mass transport.**

- **National Research Center for Desalination of Brackish Groundwater (New Mexico)**
  **The Tularosa National Research Center for Desalination at Alamogordo, New Mexico, is a federal partnership between the Sandia National Laboratories and the US Bureau of Reclamation that was established to lead the development of a new test and evaluation facility for novel desalination technologies.**

- **Rabin Desalination Laboratory (Israel)**
  **The RDL - part of the Grand Water Research Institute (GWRI) at Technion University - is an inter-disciplinary research institute established to advance the theory and practice of desalination technologies.**

- **Sandia National Laboratories: Desalination and Water Purification (New Mexico)**
  **The Desalination Roadmap and R&D at Sandia National Laboratories is part of the Water Initiative that is operated with funding from the US Government.**

- **Shankar Chellam's Research Group at University of Houston (Texas)**
  **The group's research focuses on: quantifying temperature effects on nanofiltration membrane morphology; fabricating a new class of near-ideal microfiltration membranes; elucidating mechanisms of microbial transport and bacterial fouling; and, modeling performance during municipal drinking water treatment.**

- **The Elimelech Lab, Yale University (Connecticut)**
  **The group's work centers on problems involving physicochemical and biophysical processes in engineered and natural environmental systems. Research is at the interface of several disciplines, including colloid/surface science, molecular biology, nanotechnology, and separation science.**

- **The Center for Biofilm Engineering (Montana)**
  **The Center for Biofilm Engineering (CBE) at Montana State University is a National Science Foundation research center dedicated to finding solutions and applications for industrially relevant problems and potentials of microbial biofilm formation.**

- **The Center for Membrane Applied Science and Technology (Colorado and Ohio)**
  **The MAST Center is a National Science Foundation Multi-site Industry/University Cooperative Research Center at the University of Colorado and the University of Cincinnati to conduct research, transfer technology and promote education in membrane technology.**

- **The Membrane Research Group, McMaster University (Canada)**
  **The membrane research group at McMaster University is involved in the preparation, characterization, evaluation and modelling of a wide range of membranes and membrane separation processes.**

- **The Separations Research Program, University of Texas at Austin (Texas)**
  **Founded in 1984, the Separations Research Program at the University of Texas at Austin is supported by the Chemical Engineering and Chemistry departments at the university. The cooperative industry/university program performs fundamental research of interest to chemical, biotechnological, petroleum refining, gas processing, pharmaceutical, and food companies.**

- **UCLA Water Technology Research Center (California)**
  **The specific objectives of the center are the develop the scientific framework for the desalination plant of the future, capable of economically and effectively producing potable water from brackish water sources, and to train the next generation of desalination and water treatment professionals.**

- **UNESCO Centre for Membrane Science and Technology (Australia)**
  **The activities of the Centre for Membrane Science and Technology at the University of New South Wales, Australia, span a very broad spectrum of research and development in the field of membrane science and technology.**

- **University of Nevada Environmental Engineering Membrane Research Group**
  **The group's research interest include forward osmosis for concentration of anaerobic digester concentrate, removal of natural steroid hormones from wastewater using membrane contactor processes, osmotic MBR, and pressure-retarded osmotic MBR for wastewater treatment.**

- **US Bureau of Reclamation: Water Treatment Engineering and Research (Colorado)**
  **The Water Treatment Engineering and Research (WaTER) Group is part of the Bureau of Reclamation's Technical Services Center in Denver, Colorado. The WaTER Group provides expert water and wastewater treatment engineering and research technical services.**

- **Wiesner Research Group at Duke University (North Carolina)**
  **The group addresses challenges at the interface between water, energy and materials. Specifically, the group's research is oriented along three main axes: environmental nanotechnology; membrane science; and surface chemistry and particle transport.**

- **Desalting Handbook for Planners, 3rd Edition, U.S. Bureau of Reclamation, 2003**
  **The Handbook contains descriptions of both thermal and membrane technologies in common use today, together with chapters on the history of desalination in the U.S. Chapters on pretreatment and post-treatment, environmental issues, and a chapter on case histories precede the final chapter on costs and cost estimating. The Handbook is designed for use by appointed and elected officials, planners, and consultants with a limited knowledge of the technologies involved, but who have enough familiarity with the general principles to recognize that desalting may have value as a viable alternate source of drinking water for their communities (Note: Summary from the Abstract in the Handbook).**

- **Water Desalination Technical Manual, US Army, 1986.**
  **This manual (PDF format) describes the guidelines to be followed in selecting a process capable of producing potable water supplies from brackish water and seawater sources.**