Managing Desalination Technology

A Study on Florida's Solution to Diminishing Water Sources

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Table of Contents

How do water municipalities (organizations) that operate water desalination facilities correctly manage and forecast the technology in areas that have little to no fresh water sources?

Abstract

Florida has become the center of desalination technology in North America. This has not come at the hand of desire, but desperation. According to water management experts within the state, Florida quite simply does not have any other options for fresh water but to use desalination technology to solve the problem of diminishing water supplies. This, in turn, has created more problems due to the expense and resources to produce one acre foot (AF) via the desalination method.

Along with the lack of fresh water sources, Florida's population kept on track with growth projections over from 1980 to 2008. In recent years, Florida's population growth rate has increased even farther than past projections have stated. If current growth trends continue Florida will exceed the population growth forecasts and become one of the most populous states in the Union. With this explosion in population comes an even bigger problem of population overcrowding. Current capacity of Florida's desalination plants will cover less than one-third of the expected population growth from new projections.

Technology managers must also consider environmental impacts and the government regulations that minimize those impacts. Environmental impacts also create a unique set of challenges in order to adequately manage the technology effectively. With government regulations dictating the process of handling the impacts safely, mismanagement could have devastating effects and costly consequences for the organization.

The key to these concerns lies in the future of desalination and how organizations correctly manage forecasted population growths and the increasing water demands. This includes the permanent population of coastal area in Florida and the temporary increases stemming from tourism and seasonal activities. With a good knowledge of these areas and an eye for the future within desalination technology, the water management organizations can adequately forecast demands and ensure they are met.

Introduction

Due to its geographical location, the state of Florida has become a leader in desalination technology and has over 120 plants [1]. Unlike many other areas of the country, around 90% of Florida's potable water comes from brackish sources. Florida's biggest problem in terms of water management also stems from its geographical location. With the state surrounded by water, and a seemingly abundant annual rainfall, the problem with the situation is timing, distribution, and quality of available water. More than two-thirds of Florida's annual rainfall occurs in only five months [2], and with limited means for storage, most of this water is lost to the tides. Compounding this problem is Florida's high susceptibility to tropical weather problems and the rapid population growth in the coastal areas. The weather patterns and population growth provide challenges for the water management strategies.

There are three primary types of water found in the Florida water district. They are brackish ground water, brackish surface water, and the most abundant, seawater. The primary difference between these sources of water is in the amount of dissolved salts. Seawater contains higher amounts of dissolved salts (from 15,000 milligrams per liter (mg/l) to over 35,000 mg/l of total dissolved solids). Brackish water has 1,000-15,000 mg/l. The greater the salt content of the water, the higher the pressure or electric power needed to treat water using membranes, resulting in higher energy costs [3]. Due to the significant cost of treating seawater; the first choice is to desalinate brackish water whenever possible.

Some of the key areas of success with desalination have occurred in the Kissimmee Basin, Lower West Coast (LWC), Upper East Coast (UEC), and Lower East Coast (LEC). The LWC is the current leader in brackish water desalination, and generates over 74% of its potable water from this source [4]. In addition, it also has several sea water plants under construction which, when completed, will increase the availability of fresh water. The district wide capacity as of 2008 was 235 million gallons per day, this figure is expected to grow to 540 by 2025 [4]. Some of the challenges and key opportunities to increasing desalination are the high cost of (RO), gaining the required permits, disposal of remaining concentrate, and the high capital cost associated with construction of new facilities.

Engineering Technology Management will play a critical role in the successful development of desalination technologies of the future. Managers must consider how to correctly manage demands due to population increases and the most efficient and cost effective technology available. Some of the considerations will include:

- Providing a high quality, dependable, drought-proof source of water
- Providing an alternative that could allow other stressed water sources to recover.
- Preventing water "wars" and addressing state legislation for source diversification
- Managing the high energy consumption which makes the technology expensive
- Understanding the impacts of concentrate or waste brine from the desalination process as an environmental concern
- Ensuring technological designs (i.e. intakes and discharge points) do not present dangers for ecological systems of surrounding waters

Technology Process

Desalination is the process by which salts or dissolved substances are removed from raw water in order to generate suitable water for intended utility purposes; for example human consumption, industrial, or agriculture. As population growth and water sources reach their limits, desalination will play an important role in meeting water demands. Desalination technology can be grouped in 2 major types [5]:

Membrane Technology	Thermal Technology (Distillation)
Electro-dialysis (ED)	Multi-Stage Flash Distillation (MSF)
Electro-dialysis reversal (EDR)	Multi-Effect Distillation (MED)
Reverse Osmosis (RO)	Mechanical Vapor Compression (MVC)

From the global perspective, the major technologies currently used in the desalination process are RO, MSF, and MED. Thermal technology was dominant in the market for decades particularly in the Middle East. Then the RO process brought about lower energy costs compared to previous applications. This in turn led organizations to convert to RO technology. Therefore, RO has become the dominant technology in the market since 1990. Currently, RO has 53% of total desalination capacity in the world. However, RO technology does have higher non-energy operation costs than thermal technologies [6], hence it has become necessary to develop other technologies and innovations in order to lower the total cost.

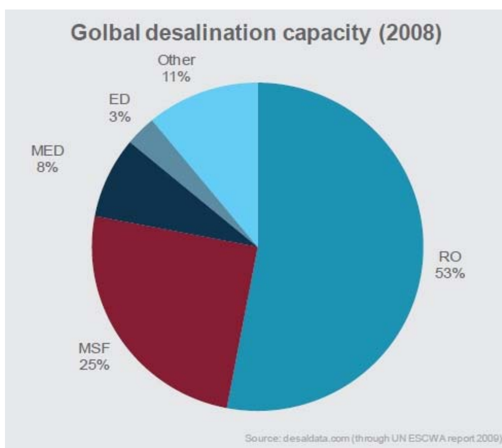


Figure 1: Global desalination capacity – by Technology (United Nations: Economic And Social Commission for Western Asia (ESCWA) 2009)

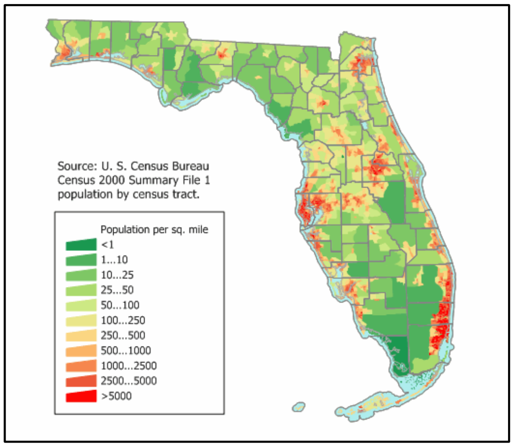
Population & Water Usage Concerns

Population Growth

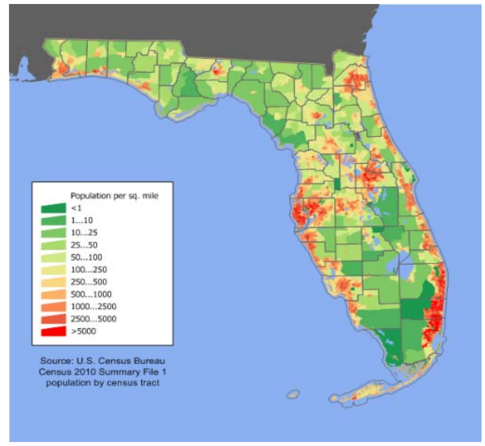
Along with choosing the correct technology, Florida must also contend with a rapidly growing population that is further complicated by the diminishing land area. This population density problem is not based on shrinking land masses, but the expansion of people in an already confined area. Recent studies of the most populous cities in the United States of America have shown that 10 out of the top 15 are classified as coastal communities. This fact also has much to do about commerce as it does the communities need to supply water to the population. While the population growth both in coastal communities and non-coastal communities grow at the same rate, the issues that arise stem from the confined space in which the coastal communities must expand in. Often this leads to a population density much higher than of non-coastal communities. To further complicate the population density issue, seasonal migration patterns add to the population of coastal communities due to such groups as recreational uses and vacationers. Often this increases the strain on natural resources such as water supplies [7].

Much of the population density problem is also based on geography. Coastal counties within the Southeastern United States number 103 but have the lowest land area of other coastal counties around the United States. Between 1995 and 2000 population growth in states such as Florida allowed them to become leading states for population growth due to retirees and job seekers. What was more considered to be areas of retirees started to become prime communities for industries and job seekers alike. Florida showed the greatest population change between 1980 and 2003 (75%). Florida also showed the second largest population growth in coastal areas between 1980 and 2003 (7.1 million persons) [7].

Moving forward through the first part of the 21st century, counties within Southern Florida showed major growth from 2003-2008. Besides slight downward trends of 2007 and 2008, the population growth continued to rise. This growth still had much to do with the same population growth reasons experienced between 1980 and 2002. This equates to an average population density of 300 persons/sq. mile compared to an average population density of 98 persons/sq. mile of non-coastal areas. The highest density and distribution surrounds counties like Miami-Dade, Broward, and Palm Beach; all located in southern Florida [7].

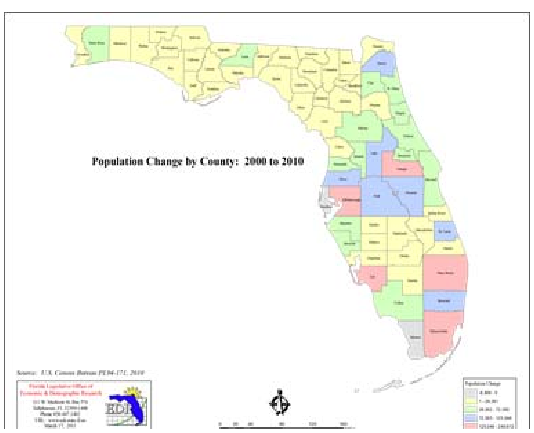


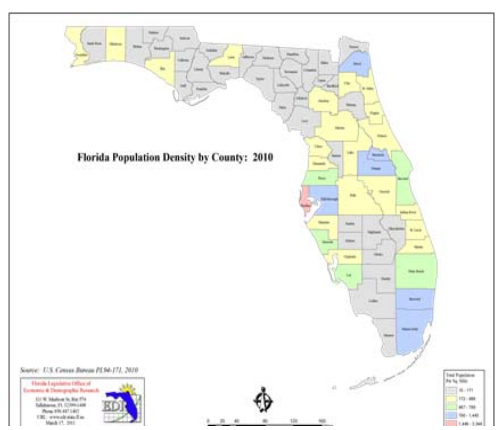
2000 Census



2010 Census

With the rapid population expansion, Florida has become the fourth largest state in the nation, with more than 14 million people in 1995. It is a fast-changing state, with a growth rate over the past 25 years of more than three times that of the entire nation. Since Florida became a state, 150 years ago, its population has grown, on average, 2½ times as fast as the entire United States. Rapid growth has transformed Florida's landscape from rural to urban in a few decades; by 1990, 85 percent of its people lived in urban areas [8].





Natural increase (births minus deaths) constitutes a minor factor in growth as well. The relative shares of recent population growth allocate to natural increase only 13 percent of the state's growth, while migration (domestic and international) was responsible for 87 percent, or five-sixths of Florida's increase. The rate of increase in Florida's foreign-born population is twice that of the state’s very high overall rate of increase, demonstrating that immigration is leading that increase, second only to domestic migration from other states [8].

With these factors in mind, the state’s Bureau of Economic and Business Research projects a population in 2020 of 20,158,000. In 2015, Florida is expected to pass New York to become the third largest state in the nation. It is estimated that four million persons will be added to Florida’s population between 1990 and 2020 through domestic migration. Only California and Texas will outstrip Florida in overall growth. It is possible that the Census Bureau and the state have underestimated Florida’s growth. If Florida simply continued to increase by over 30 percent per decade, as it has since 1920, the population in 2020 would be over 27 million [8], [9].

Water Usage

According to a 2005 study, Florida’s total water withdrawals were approximately 18 billion gallons per day (bgpd). Of these total withdrawals, in 2005, approximately 6.9 bgpd were of freshwater. Of that, 37% was for human consumption. By 2025, the amount of water withdrawals is projected to climb to 8.5 bgpd for human consumption. Even with robust water conservation programs in place, the estimated gross public supply per capita water use approximately 158 gallons per day (gpd). Water usage has dropped by 9% since 2000 proving that the conservation programs work. However, much of the rest of the state’s water demands (commercial, agricultural) continues to strain the water supplies. The demands are also a result of population growth along the central and southern regions of Florida [10].

Government Involvement

Technology

The federal government has been playing a critical role in the development of desalination technology. No one federal agency is responsible for the promotion of desalination technology and a total of over 24 million dollars invested in FY2005-2006 [11]. Instead many different agencies are funding research related to their specific needs. The Bureau of Reclamation was responsible for over half the federal spending on research. Other agencies and national laboratories made up the balance of funding. The level of involvement and type of research the government should be funding is a hotly debated subject. As the need for more potable water increases with population, and the availability of water decreases, the federal government continues to play a critical role in all aspects of desalination [11].

Desalination research and development is in the National Innovation System which has the collaboration of government, industry, and academic research. The ultimate goal is to minimize cost of producing water by desalination process. An example of this exists in California where the Affordable Desalination Collaboration used the US Navy's seawater desalination test facility at Port Hueneme to test various membranes and involved operational components in order to determine optimal process capabilities [12]. The facility has become a platform to test new technologies and evaluate how to reduce the overall cost of seawater RO processes.

Another example is Australian advanced membrane technologies for water treatment. The research cluster is a collaboration of government, industry, and universities between Australia and US in order to improve membrane technology and leverage efficient water recovery systems. This collaboration brought a national database of membrane technology which facilitated the information transferring within researchers and its practical application [12].

Environmental Regulation

One of the biggest challenges facing desalination technology are the constraints placed upon it by federal and state regulations. In addition to the standard construction and zoning permits required for any facility, desalination plants are affected by additional requirements [13]. Every additional permit or regulation to follow generally means more expenditures in facility operations. Unfortunately, many of these regulations were not drafted with desalination in mind and by default is classified incorrectly. According to Efrain Rodriquez, Regional Vice President of American water Enterprises, many of the permits for the placement of new intake and discharge structures have a lengthy process time. Some of these regulations include:

- *Clean Water Act* - A permit is required if the facility plans to get rid of the waste water through surface water discharge. The EPA sets water quality guidelines and pretreatment standards in order to ensure protection of the receiving body of water [14].

- *Safe Drinking Water Act* - If the plant is going to use deep well injection for disposal of waste products, they must follow the underground injection control guidelines and wellhead protection program regulations. Engineering studies will have to be performed to ensure that the protection of underground drinking water sources [15].

- *Resource Conservation and Recovery Act* - In some states, desalination concentrate is still classified as hazardous waste. In Florida though, regulations have been passed to adjust the classification of the concentrate as a potable water byproduct [13]. It is up to the utility to determine if the byproduct meets hazardous waste classification.

- *Toxic Substances Control Act* - The sale of toxic chemical substances is tightly controlled by the government. This regulation must be overcome before concentrate can be sold to other parties for possible alternate uses [16].

- *Hazardous Materials Transportation Act* - If the concentrate or cleaning waste is classified as hazardous materials, transporting it off site is subject to stringent regulations [17].

Environmental Impacts

Over the past several decades, human populations have grown exponentially which has led to the industrial revolution. The interactions between human population dynamics and industrial activities have affected significant demands for water supply. Fresh and clean water is always one of the most valuable natural resources for human beings. Not only does reduction in water quantity and quality increase the demand pressures, but it also has negative impacts on the environment. Finding a new alternative water source is a critical issue for the challenges of achieving sustainable water resource management. A desalination plant is one choice for a new freshwater source, which could provide potable water and fulfill population needs. However, there are some arguments against construction of desalination plants because they cause several environmental concerns in the surrounding area and atmosphere. The negative environmental impacts can be addressed in term of toxicological, physical, and ecological issues.

Toxicological Impacts

Brine discharge is fluid waste produced by the desalination plant which consist of a high percentage of salt and dissolved minerals; these often are returned back to the ocean. The effects of the concentrated brine discharge to the ocean are critical factors, which must be controlled for the favorable environment of marine organisms. Some marine organisms will have the ability to tolerate a huge range of salinity alteration, but not all marine organisms can adapt to a condition of extreme salinity. Not only do the changes in salinity influence marine organisms' activities, but they also affect their development, population, and reproductive traits [18]. However, these impacts would vary between different types of organism. The sudden fluctuation in salinity concentrations is a problem, which disrupts marine organisms directly. According to some studies, the discharged brine in the salinity level up to 50 parts per trillion (PPT) might have a serious impact on marine organisms' survival rate [19]. The vulnerability of the marine environment in the surrounding desalination plant could be measured by characteristics of marine organisms and their habitats. The salinity concentration of brine disposal is often much denser than the seawater's natural salinity. Designing brine plumes to extend further along the ocean floor than the surface is needed for contribution of benthic organisms to brine discharges [20]. The plant's design can reduce the concentrated impacts on the environment by understanding the operation of proper concentrate disposal and construction methods. For example, in the case of reverse osmosis desalination, the salt content of the discharged brine is almost double that of seawater, but the thermal desalination discharge consists of a brine salt content approximately 10% more than seawater [21]. Moreover, the characteristics of the sea such as waves, depth, or currents also influence the concentrate of salinity.

Chemical Contaminant Impact

The processes of desalination plants contribute significantly to multi-component wastes, which affect coastal water quality and marine organisms. Toxic contaminants are one of the largest negative impacts of desalination plants on the environment, which should consider the amount of chemical disposal in the operation process. Desalination plants that use large amounts of chemicals also see large chemical spillover and heavy metal concentrates brine discharges. This, in turn, leads to a large concentration found in algae, mussels and sediments surrounding desalination plant outfall plumes. For example, in a single Florida desalination plant outlet in Key West, copper was detected in seawaters surrounding the plant. The brine discharge from the desalination plant released copper more than 45 Kg per day during the 1960s-1970s. Copper concentrations in water surrounding the desalination plant were five to ten times higher than the background. This excessive level of copper could have affected marine life. However, not only copper was found, but other contaminants also were introduced by brine discharges during the desalination process such as heavy metals, chemicals, and a large concentration of salinity level [22]. Much of the chemical agents are used in many processes such as chlorination, clarification, coagulation, acidification, and degasification. All of these processes should be considered a significant safety issue because these chemicals must be made harmless for the treatment of potable water, and the amount of residual chemicals that remain in the disposed concentrate must be controlled [18], [21].

Large quantities of concentrates such as residues of pre-treatment chemicals and post-treatment chemicals, by-product of their reactions, and heavy metals corrosion are produced by desalination processes [18]. Chemicals used in pre-treatment and post-treatment are requirements for all desalination plants in order to treat seawater. These chemicals include sodium hypochlorite, free chlorine, ferric chloride, sulfuric acid, hydrochloric acid, sodium hexametaphosphate, sodium bisulphate, sodium polyphosphate, crystalline acid, and citric acid. The potential contaminants of chemical used in the desalination plants can be one of environmental concerns because there is danger in the case of chemical leakage to residential areas or the ocean. Therefore, the plants have monitoring devices in order to assess a spill risk [18].

Physical Impacts

Temperature alteration of seawater is another impact of brine disposal which plays a critical role in environmental impact. The sudden alteration of temperature levels could kill marine life, and could cause a lasting change in species composition and abundance in the discharge area. Not only does temperature alteration have an impact on growth rates and reproduction of marine organisms, but it also influences marine habitats [22]. Brine discharge has a potential to cause a raise in seawater temperature. Temperature of the seawater could be increased to 40°C in the area of brine disposal, which it normally fluctuates between 10°C to 25°C. However, thermal impact generally depends on the type of desalination plants [20].

Another physical concern is noise pollution. A reverse osmosis desalination plant is one type of desalination plants, which produces noise pollution by its process of energy restoration. High-pressure pumps, energy recovery turbines, and other machineries cause noise pollution in desalination plants [21], [23]. If a desalination plant was located in a residential area without the appropriate technologies, excessive levels of noise might cause health problems such as hearing loss. Therefore, availability of other energy forms should be considered for use in the desalination process such as selecting of alternative energy, like solar or wind, and use of acoustic canopies, which can mitigate noise generation [18].

Generating electrical energy and steam is required to power desalination plants with fossil fuel, but these energy requirements have a major contribution on air pollution. An external supply of electrical energy is necessary to burn fuel in a thermal plant [24]. Burning more fossil fuels to increase energy production for the desalination plant produces air pollution and greenhouse gas emissions into the atmosphere. Gaseous emissions and airborne particles from electricity production include carbon monoxide, nitric oxide, nitrogen dioxide, sulfur dioxide, dust, and smoke which could stay suspended in the air and spread anywhere with the wind. This air pollution could cause health problems in humans and also could have impacts on the Earth's climate. However, finding ways to reduce this impact is a significant problem, so pushing renewable energies for desalination plants is a great consideration because it might help significantly reduce air pollution [18].

Ecological Impacts

There are many considerations to be taken into account when deciding where to build a desalination plant. To minimize costs, the site should be located as near as possible to the source of the water intake and existing storage or distribution pipelines. Unfortunately this often overlaps with sensitive wildlife habitats. This can include dunes, wetlands and nesting grounds for endangered species. Florida is a very bio-diverse region and contains more varied species of plants and animals than almost every other state [25]. According to a scientific survey of Florida, it was discovered that there were at least 25 species unique to the region [26].

In order reduce the effect that desalination plants have on the local environment, an option referred to as co-siting can be used. By building a desalination plant on the same site as an existing power plant or industrial facility, it can be possible to lower the capital cost of construction and energy. When combined with a coastal power plant, excess heat can be utilized for the desalination process and the combined waste products reduce the effect of drastic salinity effects [27]. It is usually cheaper and easier to build further away from shoreline and sensitive areas than co-siting.

Impingement and Entrainment

Although localized changes to temperature and salinity from concentrate discharge were originally thought to be the biggest threat to the marine environment, recent studies have shown otherwise. According to the California Coastal Commission, marine life is most heavily affected by the impingement and entrainment of organisms by the intake valves [28]. Impingement occurs when fish and shellfish are killed on the screens protecting the intake systems while entrainment occurs when eggs and larvae are taken in and killed by the desalination process. Another study performed 20 years after the construction of Diablo Canyon Nuclear Power Plant studied the adverse effects of the plant on the environment. Researchers estimated that the impingement/entrainment rate of its cooling intakes was between 10 to 30 percent with "potential dramatic effects on the local coastal environment" [29]. Diablo Canyon was built in an area when environmental impacts were not a large concern and was poorly designed as a result. Intakes should have been placed in deeper water where there is much less marine life activity.

An alternate method to lessen the impingement and entrainment would be to use subsurface intakes. By placing the intakes below the surface, the sand and gravel are used to filter the water of marine life. This method is much more costly as it is needed to drill beneath the surface and the resultant flow rate is much lower than that of an open water intake of the same size. It is much more cost efficient to perform more extensive intake location surveys and use advanced filter technology to minimize environmental impacts.

Technology Management Assessment

There are two main factors to be concerned in a desalination technology selection: The salinity of the feed water, the type of energy available at a given location [30]. Sources of raw water has different salinity concentration, types of salts, and chemical components. For example, either RO or ED process are an appropriate technologies to desalinate brackish water which has salinity concentration up to 3000 ppm, however if the water has higher concentration, RO process is the best choice. Both technologies are driven by electrical or mechanical power, thus it will be a critical part of the selection of energy sources. Either solar, photovoltaic, or wind power is an appropriate choice for off-grid sites, depending on the quality of energy source at the location. In a case of seawater desalination, RO and MED are the suitable choice because both technologies are mature and reliable and the renewable energy solution could be applied depending on the location. If the wind energy quality is high, wind-powered RO is the best choice. However, if the site has high geothermal activity, it would be the best selection to provide continuous desalination without requiring the energy storage, therefore the geothermal MED is recommended for technology selection [30].

Much of the future of desalination technology management surrounds the five key components of the process [12]. Through careful research and development, innovations that will allow desalination to become more affordable and practical are possible. Not only are these areas key to future, but also key to the current landscape of technology management within the fields of desalination.

Water from any source is delivered to the treatment plant through intake structures and conveyance. The geological context affects plant type, location feasibility, and intake configuration. The intake structures are different by type of sources. Surface water intake structures should be concerned with changes in physical, biological, and chemical characteristic. On the other hand, estuarine or groundwater has stable chemical and physical characteristics rather than surface water, but the significant changes is salinity is influenced by the tidal cycle [12].

Pretreatment is the most critical elements of all desalination process because it will decrease dissolve matter and suspended solid from raw water, and prevent biological growth. The more efficiency this stage is, the less impact to the desalination process performance. Feed water contains various components depends on its origin, is fed through the membrane in order to reduce particles size, then it is adjusted for hardness and pH. The cost of pretreatment process varies with water source, local site factors, and environmental conditions [12]. The capital and operating cost of the pretreatment stage could be 50% of the overall process, therefore the improvement of pretreatment process significantly affects different costs [31].

RO Treatment, or RO, is the process of separating water from dissolved solids through the use of membranes. The tendency for water to flow through a membrane can be expressed as osmotic pressure. The calculation for osmotic pressure is osmotic pressure= *iMR,* where R is the universal gas constant, T is the absolute temperature in Kelvin, M is the molarity of the dissolved salts in the solution, and *i* is the Van't Hoff Factor [32]. The membranes used for reverse osmosis have a dense barrier layer and are designed to allow only the passage of water while preventing the passage of solutions. This process requires that a high pressure be applied to one side, and a lower pressure to the other. This pressure will vary depending on the type of water used. Usually 2-17 bars for brackish water, and 40-70 bar for seawater which has a higher natural osmotic pressure [33].

The largest operating seawater desalination plant is located in Tampa Florida [34]. This plant was originally scheduled to open in 2006, but disputes over ownership and bankruptcy proceedings delayed the opening until 2008. This plant now provides over 10% of the region's drinking water supply [34]. The initial costs were $110 million, but do to overages and delays, the cost soared to over $158 million. The seawater plant itself is located next to the Big Bend Power Station located at Apollo Beach, 18 miles south of Tampa.

The raw water intakes are located near the power plant's discharge tunnels. The water collected by these intakes first undergoes a chemical filtration process. This chemical process, along with constant back-washing helps reduce the slit density index. The actual (RO) process is made up of trains of membranes, cartridge filters, high-pressure pumps, and an energy recovery turbine. Each battery of (RO) membranes is fed with high-pressure from a 2,250hp pump, which is controlled by a variable frequency drive that allows the pressure to vary between 625psi and 1,050psi. The need to vary the pressure is a result of the varying levels of salinity found in the water. The water leaving the (RO) membrane train is so pure, without addition treatment it would cause damage to the water-system infrastructure. The introduction of chemicals like calcium hydroxide and sodium hydroxide are used to harden the water and adjust the pH level [9]. Understand the process and recognizing the key factors of such then becomes the most critical part of the RO portion of the process [34].

Post-treatment is the process to adjust the hardness and alkalinity in RO water and eliminate metal ions which can degrade water quality after finishing RO process. The cost of post-treatment process is related to associates with the chemistry of outcome water and the complexity of infrastructure [12].

Managerial approaches of remaining salt solution involves discharging to sewers for treatment in wastewater treatment plants, discharging to surface water or deep well injection, reusing as irrigation for corps or landscaping, waste minimization in evaporation ponds, land application, and zero-liquid discharge by thermal process. Each method has different aspects of cost, environmental impacts, benefit, and limitations. The least expensive cost is discharging to surface water, the most expensive is zero-liquid discharge by thermal process. Florida generally manages desalination concentrate by discharging to surface waters or sanitary sewers or deep well injection, and land applied. The largest plant at Tampa Bay draws concentrates back to the power plant for diluting before discharge to surface waters, Hillsborough Bay [12].

Future Technology Management Concerns

Increasing energy prices hold the biggest impact on the future of desalination technology. As energy costs are expected to increase, they directly affect the cost of desalination and how it competes in the market. Desalination technology is an energy-intensive industry, so the fluctuation of energy prices an important driver to the business [6].

The development of membrane efficiency conducted by both government and private sectors, reduces the overall cost of RO desalination. However, several issues must be considered about achieving an operational cost that is low enough compared to other desalination technologies or alternative solution for distributing fresh water such as distribute by tankers transportation.

The environmental issues become more important due to the global warming situation. The crucial environmental issues of desalination plants are the concentrate management and the CO2 emission which have a high impact to the environment. Therefore, future research must be conducted to reduce these environmental effects. The 2008 National Research Council attempted to determine the potential of U.S. desalination technology in the future through the report about "Desalination: A National Perspective" [12]. It stated that the following factors were critical to research in the field:

- Decreasing the cost of membrane production and prolonging membrane utilization lifetime.
- Exploring alternative energy resources such as solar, geothermal, power plant co-location) to facilitate desalination plants.
- Developing more efficiency of pretreatment systems
- Using new development to integrate with existing technologies or improve old technologies

From the above objectives, the two main components can be arranged to focus further development of the RO process: membrane technology development and energy supply innovation.

Membrane Technology

Membrane technology is widely used around the world, almost 80% of desalination uses membrane technology for brackish and seawater and 90% of which implementing RO technology [35]. Much of the focus is on a semipermeable membrane process which implemented in RO Technology [33], particularly at Florida desalination plants. Generally, there are three types of RO membranes [6]: Cellulosic, Aromatic Polyamide, and Thin film composite. The rejection of organics and the cost places lowest to highest respectively. Due to the increasing in usage of membrane technology, many research attempts to develop membrane technology for two main objectives: Increasing water quality outcome, and minimizing cost, energy consumption, and environmental impact.

Recently, The Southwest Florida Water Management District (SWFWMD) partnered with American Membrane Technology Association (AMTA) to develop new membrane technologies. AMTA determined that in the future membrane technology will be the permanent configuration of seawater desalination in many coastal communities within the next decades. Moreover, home treatment units will be increasing available for individuals concerned about quality of water [33].

Energy Supply Innovation

The required energy to desalinate brackish water in RO process ranges from 2-11 kWh/1000 gallons, whereas the required energy for seawater desalination ranges from 11-26 kWh/1000 gallons in the same process [12]. This energy requirement depends on the operational conditions, type of treatment system, and the most important factor, concentration of salt in the raw water. Therefore, using renewable energy is a good solution to minimize the cost and reduce the environmental impacts. The scope of renewable energy can be divided into 2 sets: Indirect integration and direct integration. Indirect Integration dictates that renewable energy will generate electricity to drive desalination processes. Under this category, the integrations can be broken up into two categories: modular and grid/utility scale.

Modular integrations would be used in small scale desalination facility which integrates with small scale renewable power generation such as a wind turbine, solar photovoltaic array. This technology should include energy storage technologies and operate in rural or off-grid area [6]. Grid/Utility-scale integration is attractive among desalination business using the principle co-location which locates plants close to solar or wind energy farms. Desalination plants use grid to decouple from utility-level renewable energies. This co-location not only reduces energy needs but it also reduces capital and operational costs. Many desalination plants co-locate with a power plant in order to share a common seawater intake. For instance, the Tampa Bay Water Desalination plant is co-located with a power plant controlled by Tampa Electric Company (TECO). The Tampa Desalination plant takes advantage of the "waste heat" of TECO to improve the membrane efficiency, sharing seawater intake, and blending the concentrate [12].

The direct Integration method will use the heat or pressure to drive the process. However this method entirely depends on type of desalination technologies used. RO technology is driven by pressure, so it converts the renewable energy such as wind energy or wave/tidal energy source to generate pressure to drive the process. On the other hand, the thermally driven technology, such as MSF or MED, use solar power or thermal waste heat to re-input for the driving process. The advantage of direct integration comes from avoidance of energy losses in the electricity conversion process [6].

Management of Environmental Impacts

Nearly all of the environmental impacts described previously have simple solutions that can be answered by workarounds or technological improvements. Unfortunately there is a direct correlation between capital cost and environmental friendliness. It is therefore the goal of the project manager to balance these costs and minimize both costs and adverse effects. In the end though, it is up to society and the legislature to ultimately determine how when preventative or corrective actions are warranted concerning environmental issues. Additionally the problem of what to do with desalination discharge waste has not been adequately solved. Currently the only choice in the matter is where to dump it which is not a viable long term solution. Nationally, about 72% of all plants discharge into surface water or sewers and 13% use deep well injection [36]. Whether it is returned to the ocean or buried underground, the long term effects this may have are still unknown.

Some alternate uses for the lower salinity concentrates could include using it as a dust suppressant at construction sites, deicing roadways, or application to salt tolerant vegetation. The problem with these, and many other possible uses, is that there is not enough local demand requiring all of the concentrate created by a desalination plant. Transportation costs of shipping the rest elsewhere is too prohibitive, limiting the scope of reuse in these cases.

The ideal solution to this problem would be to find some beneficial use for the desalination concentrate without transportation needs. The Bureau of Reclamation's roadmap calls for increased research in options for dealing with this problem. One possibility is to mitigate the problems associated with the freshening that occurs when storm water is discharged into the ocean, thereby lower salinity, by adding salty concentrate to the runoff [37]. Like all the other solutions though, this cannot handle all of the concentrate and storage during dry spells can add up.

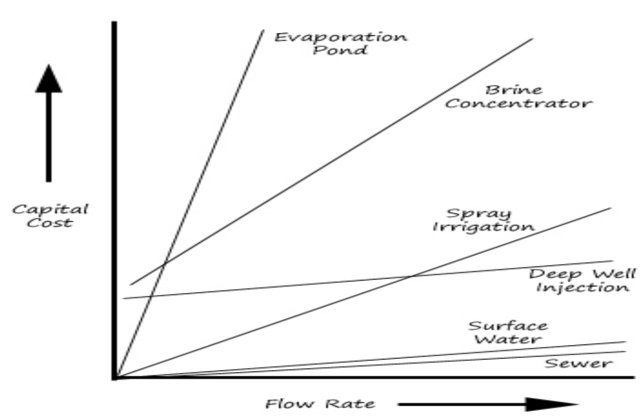
Selective Salt Recovery

One option being considered in recent months is a way to dispose of the byproduct and make money at the same time, or at least offset a large portion of costs. One Australian company, Geo-Processors, claims to be able to do just that. Through several of their patented processes, they are working to precipitate out several salts individually which can then be sold [38]. These salts can include either

Calcium Chloride, Magnesium Hydroxide, Calcium Carbonate, or many more depending on the composition of the source water. Unfortunately, Sodium Chloride is the most predominant salt in seawater and also one of the lowest valued [39].

A report prepared by the U.S. Department of Interior examined market values of common concentrate components and compared them to the cost of landfill disposal. For a hypothetical desalination plant, they estimated landfill costs to be around $365,000 per year or $60 per ton. Determining the profit margins is a lot more complicated matter. Depending on the source water and desalination plant type, the average market value of sellable salts could be anywhere from $20 to $200 per ton [40]. As there is no example of a large scale selective salt recovery plant it is impossible to determine the cost of the salt extraction process. As technologies continue to advance though, it looks very promising that instead of paying to dispose of concentrate, utilities could process the waste and significantly offset their operation costs through salt sales.

Not only could this provide a source of revenue, but the environmental impacts related to many of the alternate disposal methods could be avoided. This is especially true in the case of inland brackish water desalination where the option to return to the ocean is not available. Risk of groundwater contamination and wildlife impacts can be drastically mitigated while at the same time possibly increasing freshwater



Management of renewable desalination technology

The desalination industry highly depends on energy; the higher cost of energy, the higher price of desalinated water to consumers. Therefore, renewable energies are becoming more attractive as good alternatives to reduce cost and environmental effects. The criteria of technology selection need to be concerned with size of plant, type of feed-water, location, technical infrastructure, available of grid electricity, and type of potential energy resources in a location [32]. The World Intellectual Property Organization (WIPO) indicates that there are 4,551 patent families for desalination and 921 patent families relating to desalination and renewable energy integration [6]. Due to its dominance in the desalination process, the focus will be on the alternative energies which are suitable for RO desalination process. There are three main types of renewable energy resources that are attractive to that end: geothermal, solar, and wind [32].

Geothermal energy's main advantage is it does not require energy storage system, and it provides. Geothermal energy can be used in a wide range form room temperature up to over 300F, therefore it is suitable for commercial production of electricity [32].

The most promising solar energy for RO desalination units is solar photovoltaic (PV) system because the rapidly developing technology of PV causes the decreasing of cost dramatically. PV converts solar radiation into electricity, this type of technology requires grid electricity [1]. It can be implemented with both seawater or brackish water but seawater require more energy which means more PV arrays need to be installed. This type of technology is appropriate with remote distance area which has relative low plant capacity [1].

Wind turbine energy is a good option to coastal areas which have high availability of wind power. It is a mature technology and more cost effective than solar energy. Although wind can produce both mechanical and electrical energy, only electrical energy is appropriate for large scale capacity plant. The

SDAWES project (Seawater Desalination with an Autonomous Wind System) tested by implementing wind energy with RO process compared to other desalination technologies such as ED and MVC. The result shows that the RO process is the best result of using wind energy [1].

Feed water quality	Product water	RE resource available	System size			Suitable combination
			Small (1–50 m^3d^{-1})	Medium (1–50 m^3d^{-1})	Large (1–50 m^3d^{-1})	
Brackish water	Distillate	Solar	*			Solar distillation
	Potable	Solar	*			PV–RO
	Potable	Solar	*			PV–ED
	Potable	Wind	*	*		Wind–RO
	Potable	Wind	*	*		Wind–ED
Seawater	Distillate	Solar	*			Solar distillation
	Distillate	Solar		*	*	Solar thermal–MED
	Distillate	Solar			*	Solar thermal–MED
	Potable	Solar	*			PV–RO
	Potable	Solar	*			PV–ED
	Potable	Wind	*	*		Wind–RO
	Potable	Wind	*	*		Wind–ED
	Potable	Wind		*	*	Wind–MVC
	Potable	Geothermal		*	*	Geothermal–MED
	Potable	Geothermal			*	Geothermal–MED

Table 1: Recommended renewable energy–desalination combinations [41].

Conclusion

The future of desalination technology lies within the major areas that current technology managers must consider daily. At the heart of the matter is the growing concerns around population increases and diminishing natural resources such as water. Technology managers within this discipline have and will need to consider these factors when moving to new innovations within the future. Along with the population variable also comes how to manage that through technology. Only through technology will managers be able to continue to supply fresh water to the masses that is inexpensive and safe.

Furthermore, population centers will not be the only concerns for impact. With new technologies comes a need for government regulation that does not step over bounds and yet ensures the ecological impacts are held to a minimum. Along with population centers, environmental and ecological impacts will also be critical areas for technology managers to consider. Such technologies has the ability to destabilize a delicate balance that includes the population centers along with wildlife. Only through proper management of these critical areas will the future technology be able to continue to provide freshwater in areas that have none.

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Appendix A: Interview Questions & Answers

Interview with Efrain Rodriguez, Regional Vice President, American Water Enterprises

What strategies do you employ to help reduce the high energy requirement?

There are multiple topics some of which are project specific, for example, the collocation of a seawater plant with a power plant can drive power savings if you can get closer to an optimum water temperature. Hydraulic profiles for raw water, process and transition are also important when selecting the location of the facility. Particularly for seawater, the type of membranes and membrane arrangement can be used to optimize efficiencies for a given water quality profile. There are some mechanical technology's you can use to help reduce power consumption such as energy recovery turbines and pressure exchangers. Finally, in some states, you can negotiate special rates with energy companies, look at peak vs. non-peak consumption, etc.

Is there any revenue to be made from waste products?

There maybe a few options but none I'm aware has become a mainstream or cost-effective one. You could generate chlorine form the brine or could find a beneficial reuse for sludge, further investigation (and drive) may be needed.

How do you convince the public that the high price of desalination is worth it?

This is simple, what is the price to secure safe and reliable potable water during a drought condition? Desalination is not the first option to consider for potable water needs but it is one of many options to consider as part of a balanced and effective strategy. Where there is abundant surface water or ground water (without negatively impacting streams or aquifers) these would become your first options but *when you do not have anymore, or to protect the ones you have by not abusing of them, you then turn into desalination as a supplementary source.*

Do you invest in new desalination research?

While I cannot disclose specifics we do invest in research on an ongoing basis.

What is the bottleneck of running desalination plant particularly about technology?

The most difficult topics are permits for new intake and discharge structures and power consumption. We have the available technology to do it but it is time consuming (permits) and costly (power).

What is your attitude about the prospect of desalination in the future?

I think desalination will continue to grow, our fresh water sources are limited and new needs will have to come from desalination. The key is for it to be done right and when/where needed.

About the environment issue, we perceive that desalination use a lot of energy and how do you manage with the environment issue?

Desalination uses a lot of energy particularly compared to ground water and even surface water. In my view if the need is there to use desalination to secure safe and reliable water, we need to do so as efficiently as possible but not downsizing the critical importance of having safe and reliable potable water. While the energy use is high, it has decreased significantly due to technological and process improvements, we need to continue in that trend.

How many years for the breakeven point of desalination plant?

It is difficult to compare on apples to apples. If you look at an area that is water starved, they always have fresh water options, it may mean building a 500 mile raw water pipe and buy raw water from a different area that would be more expensive than building a local desalination facility.

How do you balance water distribution vs. distributed desalination plants?

Most systems are unique and you need to make a specific water management plan for each region taking into account your available sources, capacity, demand, etc. and manage items such as seasonal changes and needs.

We saw a drastic growth of desalination plants in Florida in the last 5 years, so what is the critical factor of growth?

Simple, there is no more fresh water available locally and plenty of desalination capacity to address needs and overcome drought conditions, additionally, FL has recognized that if the abuse of fresh water sources, the impact is significant and potentially irreversible.

How critical is desalination to the local economy and business environment?

I think is a key component as a means to secure sustainable source of water, not only provides stability to the potable water in the area, it would allow for additional growth and development where it maybe the bottleneck preventing this in a given area

Is your facility on the cutting edge of desalination?

I would say so, it is the largest sea water desalination facility in North America and to do so efficiently it required a unique design, we spent months in piloting and engineering and even after the plant started operation we have continued to optimize processes.

What type of procedures are in place to protect your source of water, and the water after desalination process?

*Our water source is the Tampa Bay so not much on the protection side but there is a thorough sampling plan to ensure we monitor what we receive so that any potential threat can be quickly contained and addressed. On the product water side there are a set of very specific protection plans that our client has in pla*ce (we only operate the plant, they manage the transmission and distribution). For security reasons, they do not disclose what these plans are.

Interview with Byron Riebow, Area Operations Manager, Florida Keys Aqueduct Authority

What strategies do you employ to help reduce the high energy requirement?

We utilize Energy Recovery Turbines (ERT) to reclaim most of the pressure from the concentrate side of the membrane. The ERT is basically a multi stage high pressure pump with the flow reversed.

Is there any revenue to be made from waste products?

Currently we do not have a program of that type.

How do you convince the public that the high price of desalination is worth it?

In our instance, all the water distributed in the Florida Keys comes from the mainland via the Aqueduct to Key West. Our Desalination plants are maintained to a constant state of readiness for catastrophic events (hurricane, incidental damage at bridges, etc).

Do you invest in new desalination research?

Our plant personnel keep abreast of new technology with mandatory continuing education.

What is the bottleneck of running desalination plant particularly about technology?

We utilize single pass technology, the original method of desalination. Obviously the cost for new technology is probable the largest bottleneck.

What is your attitude about the prospect of desalination in the future?

As conventional sources of water are depleted / rendered unusable, desalination is one of the technologies that can be utilized.

About the environment issue, we perceive that desalination use a lot of energy and how do you manage with the environment issue?

As our plants are only utilized in an emergency, they are fossil fuel dependent (diesel). When running our carbon footprint will be large.

How many years for the breakeven point of desalination plant?

Good question, but until the price of water comes up to let's say the cost of a gallon of diesel, I am not sure you will ever break even.

How do you balance water distribution vs. distributed desalination plants?

Our desalination plants are used only for emergencies or demand shaving. When system demand exceeds our conventional production permit, we will run a RO plant at the mainland facility to provide the excess demand from our RO permit.

We saw a drastic growth of desalination plants in Florida in the last 5 years, so what is the critical factor of growth?

Dwindling fresh water sources.

How critical is desalination to the local economy and business environment?

No water, no growth.

Is your facility on the cutting edge of desalination?

Our mainland facility is cutting edge with new energy recovery technology and latest membranes.

What type of procedures are in place to protect your source of water, and the water after desalination process?

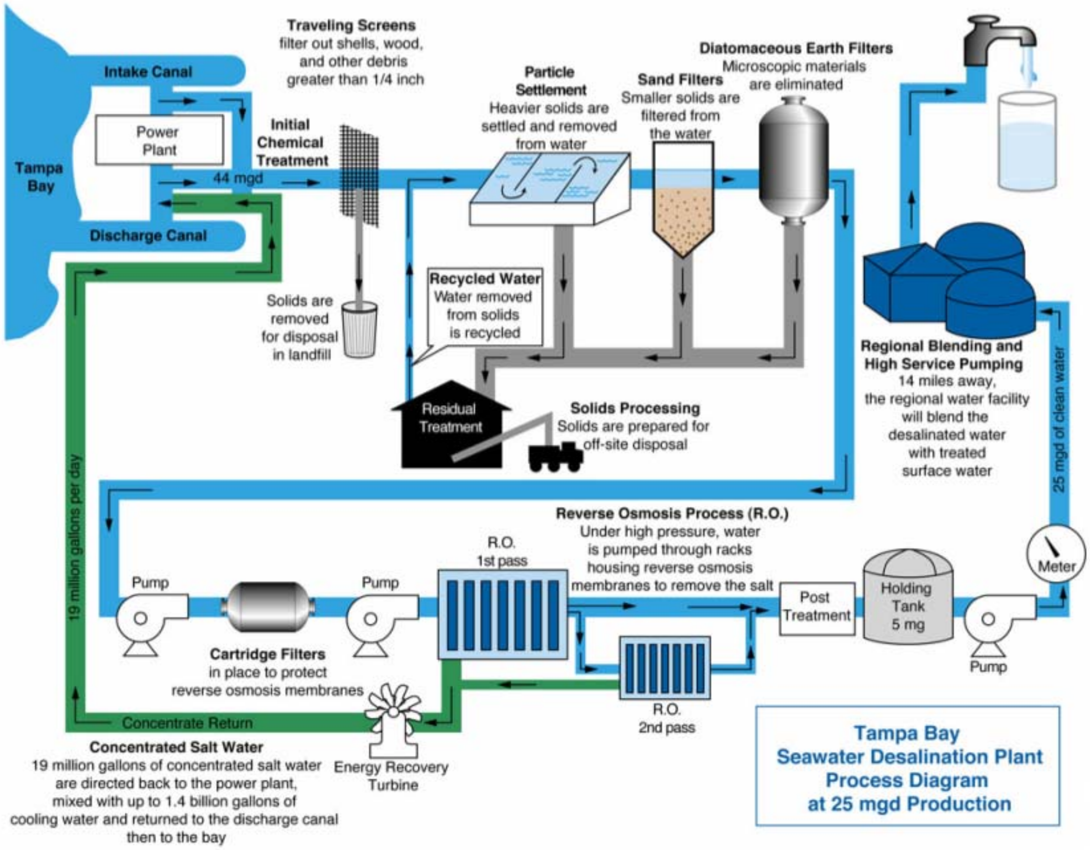
We employ numerous watershed protection program best management practices.

Appendix B: Supplemental Diagrams & Graphs

Table 5-1. Typical Economic Summary Table by Project

Project Name: Kay Bailey Hutchison Desalination Plant Owner: El Paso Water Utilities (EPWU) Location: El Paso, Texas Membrane Process: Reverse Osmosis Concentrate Disposal Method: Deep Well Injection			
	Capital Cost ($)	O&M Costs ($/year)	Amortized Unit Costs ($/Acre-Foot)
Treatment	$ 72 Million	$4,626,000	485
Disposal	$ 19 Million	$200,000	49
Total	$ 91 Million	$4,826,000 (assumes-80% operation)	534 (per acre-foot of potable water)
Source of Construction Funds: Total of $91 Million from a variety of sources: a. EPWU Bonds and Cash b. Congressional Appropriation c. Loan from Texas Water Dev. Board d. U. S. Army Contribution			

Source: Table by Michael Fahy with permission from El Paso Water Utilities, El Paso, TX


Traveling Screens
filter out shells, wood, and other debris greater than 1/4 inch
Diatomaceous Earth Filters
Microscopic materials are eliminated
Intake Canal
Particle Settlement
Heavier solids are settled and removed from water
Sand Filters
Smaller solids are filtered from the water
Power Plant
Initial Chemical Treatment
Tampa Bay
44 mgd
Discharge Canal
Recycled Water
Water removed from solids is recycled
Solids are removed for disposal in landfill
Regional Blending and High Service Pumping
14 miles away, the regional water facility will blend the desalinated water with treated surface water
Residual Treatment
Solids Processing
Solids are prepared for off-site disposal
25 mgd of clean water
19 million gallons per day
Reverse Osmosis Process (R.O.)
Under high pressure, water is pumped through racks housing reverse osmosis membranes to remove the salt
R.O. 1st pass
Pump
Pump
Meter
Post Treatment
Holding Tank 5 mg
Pump
Cartridge Filters
in place to protect reverse osmosis membranes
R.O. 2nd pass
Concentrate Return
Concentrated Salt Water
19 million gallons of concentrated salt water are directed back to the power plant, mixed with up to 1.4 billion gallons of cooling water and returned to the discharge canal then to the bay
Energy Recovery Turbine
Tampa Bay Seawater Desalination Plant Process Diagram at 25 mgd Production