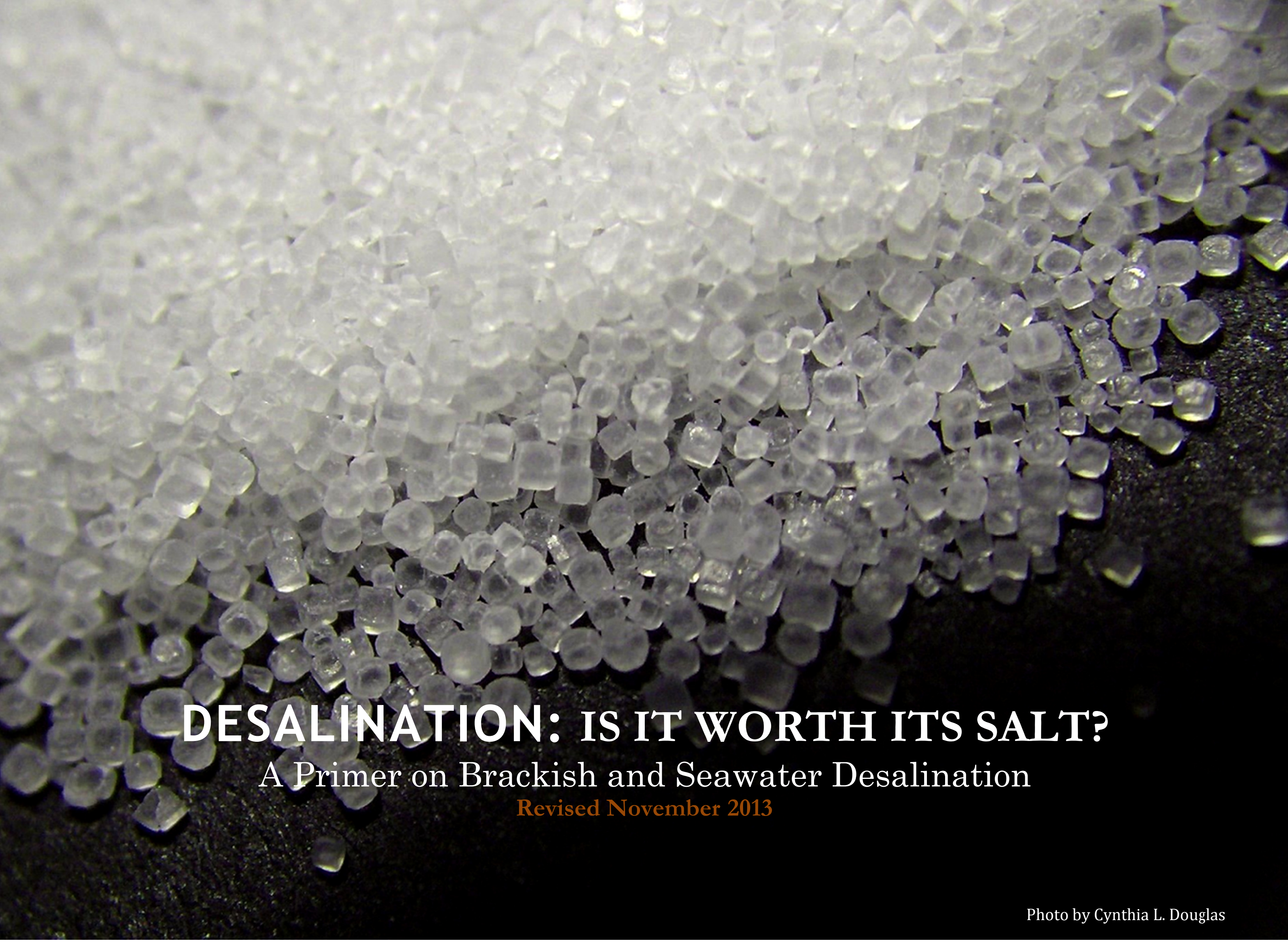

DESALINATION: IS IT WORTH ITS SALT?

A Primer on Brackish and Seawater Desalination

Revised November 2013

Photo by Cynthia L. Douglas

Sierra Club
Founded 1892

Lone Star Chapter

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A Primer on Brackish and Seawater Desalination

by
Lone Star Chapter of the Sierra Club

December 2008

Revised November 2013

SIERRA CLUB
FOUNDED 1892

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Table of Contents:

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Context

1. What is the purpose and organization of this publication?

Desalination is often viewed as a solution to many water supply problems and is often hailed as a 'drought resistant' supply. Certainly, the supply of ocean water does seem to be limitless, and there are vast quantities of brackish groundwater that could be treated to meet drinking water standards. The decreased cost of desalination technologies has made the desalination process more economically attractive. But to fully assess the actual cost and benefits of desalination, there are certain concerns that must be addressed related to environmental impacts and economic factors.

This publication begins with a brief introduction of the desalination process and terminology. The next two sections discuss the environmental concerns and economic issues related to desalination. The final section discusses desalination activities in Texas.

2. Does the publication just pertain to Texas?

Although the last chapter and certain examples in the publication focus on Texas, the environmental and economic issues discussed can be applied to desalination projects everywhere.

3. Does this publication pertain to all uses of desalination?

Desalination is used for many industrial purposes. The focus of this publication, however, is on desalinated water produced for drinking water supplies. Many of the issues discussed in this publication pertain to both uses.

4. Why are some of the words in boldface?

These words are defined in *Glossary and Abbreviations* towards the end of the publication.

5. Why are some sections in different color text?

The original report was prepared in December 2008. Since that time, technological advancements and additional research in desalination has been developed. These highlighted sections provide the reader an easy means of tracking these updates.

6. Will I know everything about desalination once I read this publication?

This publication is meant to be a basic overview of the technology and the environmental and economic issues surrounding desalination. Hopefully, the publication will serve as a starting point to better understand the process and know what issues need to be addressed in the debate over desalination. The *Sources and Links* section at the end of this publication provides references and links to desalination websites.

THE DESALINATION PROCESS

1. What is desalination?

Desalination is a process that removes salts and other **dissolved solids** from **brackish water** or seawater. Sometimes, the term for the process is spelled desalinization; other times, it is referred to as desalting or is shortened to desal. This publication will use desalination (Buros, 2000).

2. What is the difference between brackish water and seawater?

Brackish water is saltier than fresh water, but not as salty as seawater. Brackish water usually has a salt concentration between five and 20 parts per thousand (ppt) and seawater generally has a concentration of salt greater than 20 ppt. Brackish waters are found in bays and estuaries where fresh water mixes with salt water. Brackish waters may also be found in aquifers (California Coastal Commission, 2004; LBG Guyton, 2003; Kalaswad et al., 2004; Sandia National Laboratories and Bureau of Reclamation, 2003).

3. Does a desalination plant have to be located on the coast?

No. A desalination plant can be located on the coast or inland, depending on the water source. Other factors influential in siting are waste disposal options, the proximity to energy sources and water distribution systems, and security considerations (Arroyo, 2004).

4. Is brackish water better to desalinate than seawater?

Because brackish water is less salty, it is less expensive to desalinate, all things being equal. However, other factors such as availability, demand, economics, energy resources and environmental impacts have to be considered for any desalination project. These considerations will be addressed in more detail.

5. How does desalination work?

There are several methods of treatment in use today. The major methods are categorized into two types: thermal and membrane. In thermal methods, either heat or high pressure is applied to the **feedwater** to bring it to a boil and produce steam. The steam then condenses into freshwater.

There are two membrane methods of desalination. One method uses an electrical current to attract the salt molecules through a membrane. The other method employs high pressure to force the water through the membrane (Buros, 2000; Gleick, 2000).

6. Can you give me more detail?

A more detailed description of desalination methods and their advantages and disadvantages is provided in Appendix A.

7. Are there any places that receive all their water from desalination plants?

Several countries in the Middle East and the Caribbean rely heavily on desalination. For example, Saudi Arabia receives more than 70 percent of its drinking water from desalination plants; the British Virgin Islands of Tortola and Virgin Gorda receive almost all of their drinking water supplies from desalination (Mena, 2003; New Water Supply Coalition, 2004; Shea, 2004).

8. What is the most popular method of desalination?

Generally speaking, thermal methods are the most widely used worldwide. The Middle East, Persian Gulf, and North Africa account for about one half of the world's desalination capacity and primarily use the more energy intensive thermal methods because of readily available energy supplies.

The United States, which has 17 percent of the global desalination capacity, primarily uses **Reverse Osmosis (RO)**, a membrane method. Of the 230 large-scale plants in the U.S., 187 use Reverse Osmosis. This method is less energy intensive and more appropriate for desalinating brackish water. About one-half of the plants in the U.S. desalinate brackish water; less than 10% desalinate seawater[1] (American Water Works Association, 2004; Buros, 2000; Cooley et al., 2006; Gleick, 2000).

As of 2006, the United States accounted for about 15 percent of the global desalination capacity, and nearly 96 percent of the plants in the U.S. utilize Reverse Osmosis. Approximately two-thirds of the desalinated water is used for municipal purposes, with 18% used for industrial uses and 9% used for power. Most of this production is from brackish groundwater facilities (National Academy of Sciences, 2008).

Because RO is the most widely used process in the U.S. and Texas, it will be the focus for most of the discussion in this publication. However, many of the same environmental and economic issues apply to all desalination processes.

9. What is the most efficient method of desalination?

Each situation is highly site-specific. Energy costs and the salinity of the source water are both factors in determining the most efficient process. These factors are discussed in more detail in Appendix A and in *The Dollar Costs of Desalination*.

9a. Is desalination really a drought-proof supply of water?

Probably not. Desalination is an energy intensive process. Therefore, unless the source of power for the desalination facility is from an electrical generating facility that does not require fresh water, desalination should not be considered a drought-proof water supply.

10. Why is it called "Reverse" Osmosis?

Under natural conditions (**osmotic pressure**), if a semi-permeable membrane separates solutions with different concentrations of dissolved solids, the solution with the lower concentration of dissolved solids will move through the membrane toward the solution with the higher concentration. If enough pressure is applied to the solution with the higher concentration of dissolved solids (such as saline water), the natural osmotic pressure can be overcome (reversed), forcing the solution through the membrane towards the solution with less dissolved solids and removing the dissolved solids in the solution of higher concentration (Lenntech, undated-c).

11. Is all of the water treated by a plant desalinated?

The desalination process produces two streams of water. One stream, called **product water**, is the desalinated water that is nearly devoid of salts and minerals. The second stream, called **brine** or **concentrate**, contains high concentrations of salts and minerals (such as iron, chlorides, and sulfates) that remain after the desalination process. Desalination methods vary, and 100 gallons of

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[1] River water (26%), wastewater (9%), and pure water (7%) are the remaining sources. Pure water is used in ultra-clean processes such as semi-conductor manufacturing.

feedwater can generally yield between 40 and 90 gallons of product water, and conversely, between 10 and 60 gallons of brine (Buros, 2000; Gleick, 2000; Pantell, 1993).

12. Does desalination only remove salt?

Desalination removes much more than salt alone. A reverse osmosis plant can remove virtually all minerals, suspended solids, viruses and organic compounds, such as algae and bacteria (California Ocean Resources Management Program, 1997; Pantell, 1993).

13. Can any molecules other than water molecules penetrate the membrane and contaminate the water?

No membrane is perfect, and small amounts of contaminants can pass through to the product water. Occasionally, relatively small molecules such as carbon dioxide, silica, boron, boric acid, hydrogen sulfide and small organic compounds can penetrate the membrane. However, aerating the product water using an **ion exchanger** or mixing the product water with other water to dilute the concentration of the unwanted molecules can help alleviate these problems (Cooley et al., 2006; Semiat, 2000).

14. What is the quality of desalinated water?

The quality of the product water depends on the initial quality and salinity of the feedwater and the pressure applied during reverse osmosis. A second pass across the membrane increases the quality. Normally, the quality of the product water exceeds the drinking water standards set by the government (Pantell, 1993).

15. Does desalinated water need to be treated before it is pumped to my house?

Before desalinated water is distributed, it goes through several treatment steps, including pH adjustment, degasification, and hardness adjustment. Because most desalinated water is purer than drinking water standards, it is often mixed with less pure water before it is used for domestic, agricultural or industrial purposes (International Environmental Technology Centre, 1997; Pantell, 1993).

16. Does desalinated water taste or smell different from the water I have now?

The U.S. Desalination Coalition reports on its website that blind taste tests indicate that there is no difference in taste between freshwater and desalinated water (New Water Supply Coalition, 2004).

17. Does a desalination plant run continuously?

RO plants must be shut down or run at partial capacity intermittently in order for the membranes to be cleaned or replaced. Some plants run only at peak water need times, and are not used continuously to provide a community with water (Pantell, 1993; Shea, 2004).

18. What is fouling and how can it be prevented?

Fouling results when salts, biological growth or mineral deposits build up on the membranes and reduce the performance of a desalination plant. Fouling increases costs and decreases the overall quality of the product water.

Pretreatment and **cleaning chemicals** are used to prevent or reduce fouling. Pretreatment methods involve sand or membrane filtration or **coagulation**. Coagulation is a process in which a substance such as ferric chloride is added to the feedwater to cause small particles in the water to form a large mass for easier removal. Cleaning chemicals are used to flush or clean the membranes.

These include chlorine bleach, hydrochloric acid and hydrogen peroxide (Avlontis et al., 2003; Lenntech, undated; Sandia National Laboratories and Bureau of Reclamation, 2003).

19. What is scale and how can it be prevented?

Scale is an accumulation of partially **insoluble** salts on a membrane or on the walls of pipes. Common salts that contribute to scaling are calcium carbonate, calcium sulfate and silica. To combat calcium carbonate, acid can be added. Anti-scalant chemicals may also be used, but they can contribute to fouling. Reducing the temperature of the feedwater can reduce scaling as well (Gleick, 2000; Sandia National Laboratories and Bureau of Reclamation, 2003).

20. What do desalination plants do with brine?

Brine, along with the chemicals used to prevent fouling and scaling, must be disposed of by desalination facilities. The disposal of these wastes is just one of the major environmental concerns about desalination. These concerns, and others, are discussed in the next section, *Environmental Concerns*.

Brine outfall pipe at desalination plant. Photo by Tafasir Khichi.

ENVIRONMENTAL CONCERNS

1. What are the biggest environmental concerns about desalination?

The biggest concerns are: 1) the ecological effects resulting from the disposal of brine from the desalination process; 2) the entrainment of aquatic species in and around the desalination facility intake; and 3) the increased energy required by the desalination process. There are also some potential health concerns resulting from the desalination process.

BRINE DISPOSAL

2. Are there products other than brine that must be disposed of?

Chemicals used during pretreatment, cleaning, and for the preservation of the membranes in a reverse osmosis plant may be discharged in solution with the brine or may be discharged to a treatment plant. Although the volume of the chemical solution is a small percentage of the total discharge from a desalination facility, the chemicals used include chlorine, ferric chloride, biocides, sulfur dioxide, coagulants, carbon dioxide, polyelectrolytes, anti-scalants, sodium bisulfate, antifoam agents, polymers, sodium compounds, hydrochloric acid, citric acid, alkalines, polyphosphate, copper sulfate, acrolein, propylene glycol and glycerin. It's difficult to evaluate the potential toxicity of these chemicals without knowing how concentrated they will be. For example, biocides, polyphosphates, copper sulfate, acrolein and propylene glycol have the potential to be harmful at certain concentrations (American Water Works Association, 2004; California Coastal Commission, 2004; Carman, 2004; Pantell, 1993; Shea, 2004).

3. What are the different methods for disposing of brine?

There are several brine disposal options for desalination plants. Plants located on the coast often discharge directly into the coastal waters. This may involve discharging into a bay or estuary or into the ocean; usually, there is no treatment of the brine before it is disposed. Some plants choose to mix their brine with the discharge of a nearby power plant in order to dilute the high salinity of the brine before it reaches the receiving waters. Some small- and medium-sized plants discharge their brine to the local sewage treatment plant.

Subsurface injection may also be used to dispose of brine. The brine is pumped through wells into water bearing formations of greater salinity than the brine, or into deep wells that reach formations below **potable** aquifers.

Given sufficient land space and an arid climate, developers of desalination plants may build evaporation ponds for the brine. The liquid constituent of the brine will evaporate, leaving only the solids behind, which can then be disposed of in the local landfill. A somewhat experimental method is the creation of salt gradient solar ponds, which can act as an energy source for the desalination plant.

The most common method for brine disposal in the U.S. (45%) is surface water discharge. Disposal through sewer treatment facilities is used 27% of the time and subsurface injection is used 13% of the time. Disposal to land or by using evaporation ponds is used 12% of the time with recycling or reuse of the water used less than 2% (California Coastal Commission, 2004; Mickley, 2004; Pantell, 1993).

4. What are the potential ecological effects of brine disposal to the oceans or bays?

The most obvious effect is the resulting change in salinity around the disposal site. Most saline bodies of water have naturally fluctuating salt concentrations. Marine organisms found in saline waters are accustomed to this gradual shift in salinity concentrations, but they may not be able to adjust to quicker increases in salinity that may be caused by the discharge of brine. Brine discharges can increase the receiving water's salinity by as much as 100 percent in a localized region. This drastic increase may stress or even kill local marine populations by changing fish migration patterns, feeding grounds, or critical habitat. Significant increases in salinity have pronounced detrimental impacts on non-migratory species such as oysters.

Brine disposal also has the potential to impact the levels of dissolved oxygen in the water. Increases in salinity decrease dissolved oxygen, resulting in **hypoxia**, a condition in which low levels of dissolved oxygen result in stress or death to aquatic organisms. Increases in water temperature that result from desalination brine being combined with thermal plant discharges also decreases dissolved oxygen, as do increases in biomass resulting from the disposal of entrained organisms. Thermal plant co-location and entrainment of organisms will be discussed in more detail in later sections (California Coastal Commission, 2004; Murphy, 2005; Pantell, 1993; Shea, 2004).

5. What sort of aquatic organisms are we talking about, and why are they important?

Seawater and brackish water is rich in organisms. Some of these organisms, such as plankton and phytoplankton, are the basis of the marine food chain. A disruption in their population has far reaching impacts on all marine life in the area.

These waters also contain the larvae and eggs of many species. In Texas, for example, 95% of the recreational and commercial fisheries rely on the estuaries of the Texas Gulf Coast where freshwater and nutrients from rivers mix with saltwater from the Gulf. Shrimp and crab lay their eggs offshore in open waters, but their larval stages are transported by spring tides back into estuaries where moderate salinity conditions and adequate nutrients are found (National Wildlife Federation, 2004).

6. But brine disposal isn't the only factor affecting the salinity in bays, right?

This is correct. The amount of freshwater flowing into the bays and estuaries from rivers is a significant factor. As the amount of freshwater is diminished, the salinity increases and impacts marine species and habitat. Thus the location of a brine disposal facility, coupled with decreased inflows, could have a significant impact on bay habitat, especially since desalination facilities are likely to be used during periods of drought.

When considering the impacts that a brine discharge may have on a bay or estuary, it is imperative to consider both the existing and future conditions of the bay. Five out of the seven bays in Texas are considered to be "in peril" because the increased permitted water rights upstream is predicted to decrease freshwater inflow into the bays below levels necessary to maintain appropriate salinity levels or habitats. (National Wildlife Federation, 2004)

7. Is it better to dispose of the brine into the open ocean than a bay or estuary?

Brine disposal into an open ocean takes advantage of both the high salinity of the receiving water and the ocean currents. The brine will be mixed with the ocean water by the currents and, depending on the efficiency of the desalination method used, may not differ drastically in salinity from the ocean water. However, in the localized region where the brine is discharged, circulation may not be sufficient to keep the salinity from increasing. Brine discharges may be denser than the receiving water and may, as a result, sink to the bottom of the water column, potentially affecting the organisms living at the sea floor (California Coastal Commission, 2004; Cooley et al., 2006; Mickley, 2001; Pantell, 1993; Shea, 2004).

8. What about disposing the brine to streams?

This method of disposal is used for small and medium size facilities. Disposal of brine into surface water is regulated by the Clean Water Act and requires a discharge permit. Care must be exercised to ensure that salinity levels in the receiving stream are not increased so as to harm existing biota. In general, brine may not be discharged into surface water if it will increase the salinity of the receiving stream by more than 10 percent. Concerns also exist that contaminants present in the feedwater will be introduced into the receiving streams, especially when the feedwater is from a groundwater source. Desalinated groundwater may also contain levels of hydrogen sulfide and low levels of dissolved oxygen (Mickley, 2004).

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9. What about disposing the brine to a sewer treatment plant?

This type of disposal method is generally used for small facilities. Residual chemicals used to prevent fouling and scaling, along with contaminants found in the feedwater must be treated at the treatment plants; these contaminants are in a concentrated form four to ten times the original concentration. Water from brackish groundwater may contain arsenic, radionuclides, and possibly very low levels of dissolved oxygen (American Water Works Association, 2004).

10. What about injecting the brine into wells?

Disposal of brine by injection into wells is a technique usually associated with brackish groundwater facilities and not ocean desalination. Brine injection has potential where the formation receiving the brine has high **transmissivity** and is adequately isolated below aquifers used for water supply. It is important to have monitoring wells near the injection wells to assure there is no leakage from the injection well or the receiving aquifer. The cost for subsurface injection is greater than surface water or sewer treatment disposal methods and requires a backup method or additional well to be used during periods of maintenance or testing (American Water Works Association, 2004).

Groundwater contamination problems have occurred in several areas of Texas where oil production brines have been injected into wells. Leaks or mechanical breakdowns in the injection process, over-pressurization resulting from high injection rates, and a lack of adequate regulation and enforcement have been cited as the cause of contamination (Middleton, 2006).

11. Are there concerns about evaporation pond and land application disposal methods?

Both methods are relatively expensive and are generally used for small desalination facilities. Although the evaporation ponds usually require an impervious lining, monitoring wells should be used to ensure that the ponds do not leak and contaminate surrounding soils or aquifers. Land application methods such as irrigation require vegetation with high sodium adsorption ratios and adequate trace metal uptakes. Any contaminates in the brine such as arsenic or nitrates would be cause for concern as well. If the facility is to be used full-time, it is important that land application methods are available year round (American Water Works Association, 2004).

12. Are there other methods for disposing of brine?

A few other disposal methods include subsurface outfalls, similar to subsurface intakes that are described in the discussion on Impingement and Entrainment. Some desalination facilities co-locate with other types of facilities that already discharge saline water so that the higher salinity water from the desalination process can be mixed with the existing lower salinity wastewater (California Coastal Commission, 2004).

IMPINGEMENT AND ENTRAINMENT

13. How do the intakes for desalination facilities harm marine life?

The intake pipes can be harmful in two ways: **impingement** and **entrainment**. Impingement occurs when organisms are pulled into an intake pipe and trapped against a fish screen covering the intake, causing injury or death. Entrainment occurs when small organisms pass through the fish screen and are actually taken into the intake pipes; entrainment is considered to be 100 percent lethal because of the high temperatures or the high pressures found within the plants. Thermal power plants, desalination facilities, or any open water intake may cause impingement or entrainment. Because it is less expensive to desalinate water with lower salinities, desalination facilities may be located on estuaries near river mouths where salinities are lower. Such areas are critical habitat for many marine organisms that cannot tolerate high salinity levels (California Coastal Commission, 2004; Pantell, 1993).

14. How can impingement and entrainment be minimized?

Several steps can be taken to minimize both impingement and entrainment. The most effective method is to install beach wells or infiltration galleries which pull in seawater through the overlying substrate, instead of an intake pipe that draws directly from the water column. The overlying substrate functions as a natural filter to keep out small organisms and larvae. The substrate may also provide filtration that improves the quality of the feedwater and reduces or eliminates the need and cost of pre-treatment. However, the impact that these infiltration galleries have on freshwater aquifers and the surrounding beach environment (dunes) should be considered.

Impingement, which is usually a function of the velocity of the intake water, can also be minimized by limiting the intake velocity to approximately half a foot of water per second. A velocity cap, a device that can be attached to the intake, affects the intake direction, changing the intake from a vertical direction to a horizontal direction. Fish can better detect horizontal flows and avoid an intake pipe.

Entrainment can be harder to minimize since the affected organisms are smaller. Locating an intake facility in the least damaging habitat area is the most effective method. Structural methods using small-diameter round screens can also reduce entrainment as do fish return systems which allow fish to return to the source water when they enter the intake pipe (California Coastal Commission, 2004; California Water Desalination Task Force, 2003; Shea, 2004).

15. Can co-locating a desalination facility with an older thermoelectric plant cause problems?

There will be more discussion about the reasons for co-locating desalination plants with existing thermoelectric plants in the section, *Dollar Costs of Desalination.* The decision to co-locate a desalination plant with a power plant, however, raises some significant environmental concerns.

Most power plants were built before the impacts of impingement and entrainment were understood. These older plants utilize a once-through cooling system that pumps seawater through heat exchangers before discharging the water back to the environment. While inexpensive, the cooling systems have significant impingement and entrainment impacts.

Co-locating a desalination plant with a power plant using once-through cooling encourages the continued use of this environmentally damaging technology and significantly increases the amount of water withdrawn by the power plant. Between 15,000 and 40,000 gallons of cooling water are required to produce a megawatt, and between 9.7 and 16.5 megawatts are required to produce a million gallons of desalted water. Thus, a 25 million gallon per day (**Mgd**) desalination facility requires a power plant to withdraw an additional 4-17 Mgd to provide the electricity necessary to process 50 Mgd of feedwater for the desalination plant. Approximately 1 percent of the amount withdrawn is consumed. Such increased withdrawals, coupled with the effects of impingement and entrainment, can have significant impacts on biological organisms, their function, and their habitat (California Coastal Commission, 2004; Callahan, 2004; Cooley et al., 2006, Stillwell et al., 2010).

HEALTH CONCERNS

16. You previously mentioned that some contaminants such as boron might get through a membrane and into the product water. What are some of the other health concerns?

The treatment processes used in desalination may produce byproducts that are of concern to health such as brominated organic byproducts and chlorinated byproducts; both of these have carcinogenic risks. Water that has been through the reverse osmosis process is more acidic and can corrode the distribution system, leaching iron and other toxic metals from the pipes. Post-treatment of the desalinated water, before it goes into the distribution system, can reduce the risk of corrosion (Cooley et al., 2006).

17. Can desalinated water be too pure?

Magnesium and calcium usually get removed in the desalination process. These are essential minerals for our bodies and if we ingest water with low mineral content, the water can leach these minerals from our bodies. However, post-treatment processes can replace some of these minerals (Cooley et al., 2006).

INCREASED ENERGY USE

18. Why are there increased energy requirements associated with desalination?

Desalination facilities require more energy than any other water supply option. Obviously, thermal treatment processes require the most energy, but reverse osmosis facilities also require additional energy to pressurize the source water and force it through the membrane.

19. So this means more electricity will have to be generated to produce desalinated water?

Exactly. In the absence of a significant increase in the use of renewable energy sources (such as solar or wind energy), this increase in energy production would increase the use of fossil fuels, which in turn would increase pollution and greenhouse gas emissions. Thus, from an environmental point of view, renewable energy would be preferred power sources for desalination plants.

20. How much more energy is needed for desalination?

A comparison of the energy usage of various water sources shows that desalination is 44 to 75 times more energy intensive than surface water, 16 to 27 times more energy intensive than groundwater use, and up to four times as energy intensive as brackish groundwater use, (Stillwell et al., 2010).

Examined another way, it has been calculated that it takes 12.9 kilowatt hours (**Kwh**) of electricity to produce 1,000 gallons of desalinated water[2]. On average, per capita water use in Texas

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[2] The U.S. Navy Seawater Desalination Test Facility has achieved energy demands of 6.0 kilowatt hours per thousand gallons at their small demonstration plant using low-pressure RO membranes, high-efficiency pumping, and energy recovery equipment (Affordable Desalination Collaboration, 2006; Texas Water Development Board, 2006).

is 170 gallons per person per day, or about 62,000 gallons per year. Thus, it takes about 800 Kwh to produce enough desalinated water for a person on an annual basis. For comparison, this amount is about six percent of the average electricity a Texan uses on an annual basis[3] (Cooley et al., 2006; Texas Water Development Board, 2012).

21. Can desalination plants be powered by renewable energy sources?

The Perth, Australia Desalination Plant produces up to 38 million gallons per day using power from the Emu Downs Wind Farm. The 48 turbines at the wind farm produce 80 megawatts per day, more than three times the needs of the plant (Mydans, 2007). Since 2008, Australia has constructed five additional large-scale desalination plants. These facilities have a production capacity ranging from 36 to 120 million gallons per day and all use renewable energy sources including wind, solar, and wave energy (Furukawa, 2013).

22. The reference to greenhouse gas emissions, which contribute to global warming, made me think about rising sea levels. Would rising sea levels have an impact on a seawater desalination plant?

There is certainly potential that desalination facilities could be vulnerable to rises in sea levels or increased storm surges resulting from global warming. These potential impacts should be considered in the design and costs consideration of desalination facilities (Cooley et al., 2006).

OTHER IMPACTS

23. Are there other potential impacts to the environment from desalination?

Pumping of brackish groundwater may impact the source aquifer. There are also potential impacts to air and noise pollution.

24. What are the potential groundwater effects of pumping brackish water for desalination?

Depending on the hydrogeology of the aquifer, pumping brackish groundwater may cause freshwater to flow into an area of brackish groundwater, contaminating the fresh groundwater. Pumping groundwater could also lower the water levels in an aquifer. As there are seldom other users of the brackish water, this is generally not an issue. However, this could change as demands on brackish groundwater increase (Arroyo, 2004).

25. Of course there are the problems of air pollution resulting from the increased energy requirements. What other sources of air pollution result from desalination plants?

Desalination plants discharge nitrogen or oxygen gasses during the de-aeration process to control corrosion. RO plants may discharge dissolved gases such as hydrogen sulfide from the product water in a process known as degasification (Pantell, 1993; R.W. Beck, 2004; Semiat, 2000; Shea, 2004).

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[3] In 2008, average annual electrical use per household in Texas was 39.1 kWh per person per day (Stillwell, et al., 2010).

26. How much noise pollution can be expected from a desalination plant?

Noise pollution is a potential risk of a desalination plant. However, housing machinery within sound-dampening materials can mitigate the situation (California Coastal Commission, 2004; Shea, 2004).

27. Does desalination have positive environmental impacts?

Relatively speaking, yes. Having a desalination facility available as a water supply source reduces the development pressure on other potential water sources. This is particularly valuable when the development of an alternative water source could have significant impacts on critical habitats such as bays and estuaries, endangered species habitat, or springs. In some cases, the use of desalinated water may provide the opportunity for other water sources to be made available for environmental needs such as instream flows.

Using desalinated water can also result in behavioral changes. The perception of the ocean as a source of water supply may result in increased public awareness and protection of oceans. Also, the higher costs of desalinated water may make less expensive water conservation alternatives much more attractive (California Coastal Commission, 2004).

Racks of high pressure filter tubes at Lower RioGrande plant. Photo by Texas Water Resources Institute

THE DOLLAR COSTS OF DESALINATION

1. What is the main reason desalination is so expensive?

The number one direct cost is energy. Depending on the process, energy can comprise from a one third to one half of the total desalination cost. It is very important, therefore, to consider electric volatility when planning desalination facilities for they have greater variable costs than other water supply options. The California Coastal Commission estimates that a $0.01 increase in price per kilowatt-hour results in a $50 increase in the cost of producing one acre-foot of desalinated water. Pacific Institute estimates cost increases in a different manner; a 25% increase in energy cost increases the cost of produced water for reverse osmosis by 11%, and for thermal, 15% (California Coastal Commission, 2004; Cooley et al., 2006).

2. What other factors contribute to the high costs of desalination?

The next largest costs can be attributed to the physical plant and the capital costs. Other factors include transportation, brine disposal, maintenance and cleaning (California Coastal Commission, 2004; Mickley, 2001; Semiat, 2000.)

3. How much does desalination really cost?

This is a difficult question to answer. Pacific Institute notes that the production costs alone of desalinated water in California are about $3.00-$3.50 per thousand gallons, but can be as high as $8.35 per thousand. This does not include the cost of delivery to users. Currently, urban water users pay between $1.00 and $3.00 dollars per thousand gallons (Cooley et al., 2006).

4. How much will desalination cost in Texas?

In *Water for Texas 2012*, seawater desalination projects in Texas are estimated to provide over 125,000 acre-feet per year by 2060; brackish groundwater desalination is projected to provide over 180,000 acre-feet annually by 2060. The South Central Texas Regional Water Planning Group (Region L) estimates unit cost for the two largest brackish groundwater desalination facilities to be between $1,200 to 1,300 per acre-foot, or slightly less than $4.00 per thousand gallons. Region L unit cost estimates for a seawater desalination are $2,284 per acre-foot or just over $7 per thousand gallons.

Comparing the unit cost estimates prepared by the Region L between 2007 and 2012 for seawater desalination highlights the volatility associated with cost of desalination. The estimates for desalination in *South Central Texas Regional Water Plan* include the cost of transporting the water several hundred miles to the end user. The largest proposed desalination facility, which would bring water to San Antonio from the Gulf Coast by the year 2060, estimates the cost for a 75 Mgd plant to be about $4.26 per thousand gallons, with 56% of the cost associated with treatment ($2.39) and the remainder ($1.88) with transporting the water to San Antonio. By 2012, this cost had risen nearly two-thirds to $7.01 per thousand gallons, with treatment costs accounting for 52% ($3.71) and the remainder ($3.29) with transport costs. (South Central Texas Regional Water Planning Group, 2006; South Central Texas Regional Water Planning Group, 2011.

5. How much does electricity cost now?

As of 2010, the average price per Kwh for industrial users in Texas was 6.44 cents per kWh, having fallen from 8.79 cents in 2008. Average retail electrical prices for residential Texas customers were 11.6 cents, having fallen from 13.04 cents in 2008. Between 2000 and 2008, retail prices in

Texas for all sectors rose from 6.49 to 10.99 cents, and fell to 9.34 cents by 2010. (Energy Information Administration, 2012).

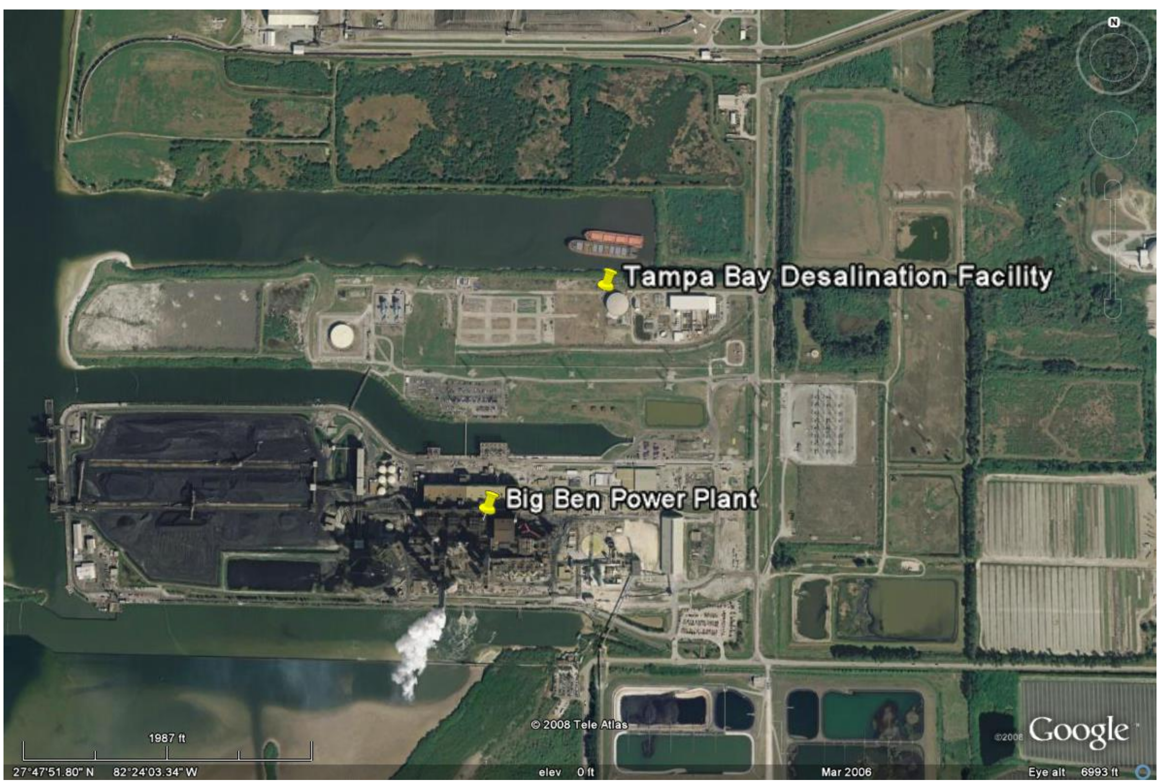
6. Are there other cost considerations?

The rise in cost of raw materials, especially steel, along with an increase in interest rates can make the cost of desalination more expensive. Also, consideration should be given to the probability that desalination plants are more likely to operate during periods of drought. Electrical costs can increase with lower surface water availability, especially in areas that use less expensive hydroelectric power. Nevertheless, electric usage generally increases during drought and desalination may have to compete against increased usage and increased prices (Cooley et al., 2006).

7. Didn't cost estimates have something to do with the problems at Tampa Bay?

In 1999, officials in the Tampa Bay area approved plans to build a reverse osmosis plant with a capacity of 25 Mgd at an average cost of $2.08 per thousand gallons. Despite having several unique conditions that contributed to such an estimated low cost (including electric rates of 4 cents per kilowatt hour), the costs were underestimated. Cost overruns and resulting cost-cutting measures produced fouled membranes and corrosion problems that further increased operations costs. The plant also violated its permitted discharge level, as additional chemicals were needed to clean the membranes.

The plant became fully operational in 2008, 6 years behind schedule. The most recent cost estimate was revised at $2.54 per thousand gallons, but this is expected to increase, as the plant will not operate at full capacity (Cooley et al., 2006). The Tampa Bay facility is still the only large-scale seawater desalination facility in the continental United States.



Aerial view of Tampa Bay Desalination Plant and Big Ben Power Plant. Photo copyright 2007 Google.

8. How will desalination affect water bills?

Most desalination projects in the United States are subsidized to some degree. For example, 90% of the capital cost for construction of the Tampa Bay project was funded with tax monies from the State. Desalination projects in California have been subsidized at a rate of about $0.75 per thousand gallons. These subsidies essentially move some of the additional cost of desalinated water from the ratepayer to the taxpayer (Cooley et al., 2006).

The high cost of desalination coupled with slow economic growth, declining federal support for water projects, and declining municipal water demands can potentially make the investment in desalination a risky proposition for water utilities. Water utilities generate the greatest proportion of their revenue through water sales. If water demands drop due to increased conservation, increased water rates, or a slow economy, water utilities that have invested in costly infrastrucutre run the risk of being unable to pay off their bond indebtedness (Leurig, 2012). Currently, four of the large-scale desalination facilities in Australia are operating in stand-by mode due to cheaper sources of water becoming available (existing reservoirs) following the end of a drought (Murray, 2013).

9. Who assumes the control and risk of a desalination project?

Because of the expense of desalination projects, many governments look to private corporations to develop the resource. In doing so, however, these governments may relinquish control of the resource; water resources have traditionally been viewed and managed as a public resource.

The privatization of water resources presents a variety of issues, especially transparency and accountability issues. With private corporations, the analyses used to make decisions about the water resource may not be readily available to the public. Who is accountable for failures or setbacks associated with a project can also be of concern. Tampa Bay Water, for example, had to assume full responsibility and risk of the Tampa Bay Desalination plant when its project partners were not able to secure financing (Cooley et al., 2006).

10. Is there any chance desalination prices will go down in the future?

According to Pacific Institute, it seems unlikely that prices will decline. Through the 1990s and up to about 2003, improvements in membrane performance helped decrease the cost of desalination. However, since that time, energy costs, the price of raw materials (especially steel), and interest rates have all increased. The result has been a notable increase (up to 35 percent) in the cost estimates for proposed desalination plants. (Cooley et al., 2006).

11. Are there other ways to reduce desalination costs?

Economies of scale, **nanofiltration**, concentrate reduction, energy conservation, and co-location offer potentials for reducing desalination costs.

12. What is meant by economies of scale?

Generally, the cost per unit of water decreases as the volume of water produced increases. For desalination, economies of scale are more significant for small and medium sized facilities than for large facilities. Doubling the size of a desalination plant from 2.5 Mgd to 5.0 Mgd is estimated to reduce cost by 30%, but doubling a plant from 25 Mgd to 50 Mgd only reduces costs by 10% (Cooley et al., 2006).

13. What is nanofiltration?

Nanofiltration, like RO, is a membrane filtration process of desalination. Because the membrane pore size used in nanofiltration is slightly larger than the pore size used in RO, less pressure (and energy) is required to pass the feedwater through the membrane. The City of Long Beach, California has developed a two-step nanofiltration process of desalination that uses 20-30% less energy. The Long Beach project also utilizes intakes and discharges below the ocean floor (Lenntech, undated-b; Long Beach Water, undated).

13a. What is concentrate reduction?

Finding ways to dispose of the concentrate from the desalination process is an expensive and environmentally significant challenge. Finding ways to reduce the amount of concentrate reduces some of the costs associated with the process. Several universities in Australia are examining methods to distill the concentrate; the University of Texas at El Paso is experimenting with zero discharge desalination (Furukawa, 2013; Price, 2013).

14. What type of energy-conserving steps can be taken?

There are two main ways to conserve energy: **co-generation** and **energy recovery**. Co-generation involves using the exhaust steam from an electricity generating power plant. In a thermal desalination plant, the steam can be used to evaporate feedwater and in a membrane plant it can be used to warm the feedwater, which increases efficiency.

In thermal desalination plants, energy can be recovered using heat from the discharged brine and product water to evaporate the incoming feedwater. In a membrane plant, the hydraulic pressure of the brine can be harnessed and converted into energy to power the high-pressure pump (Avlontis et al., 2003; Pantell, 1993; Shea, 2004).

Current research suggests that integrating renewable energy with brackish desalination could resolve some of the problems associated with wind and solar energy, namely the diurnal and season variability of the wind, battery storage and the infrastructure cost associated with electrical transmission. In portions of Texas it may be more economical to utilize wind and solar energy to desalinate and distribute water rather than to distribute the energy itself (Clayton, et al, 2013).

15. Why do some desalination plants co-locate with a power plant?

Co-locating with a power plant can reduce the costs of desalination. Construction costs for the desalination plant are reduced because the desalination plant can share intake and outfall pipes with the power plant.

Power costs are also reduced. Many power plants have a once-through cooling system: intake seawater passes through the system once to cool down the plant before it is discharged (at a higher temperature) back to the ocean. With co-location, the desalination plant utilizes the warmer water discharged from the power plant. Warmer water increases the efficiency of the membranes.

Co-locating also allows a desalination plant to mix its discharge with discharge from the power plant, reducing the salinity and potentially harmful environmental effects of the discharge. Co-located desalination plants also have the potential to buy power at a reduced price due to lower transmission costs and off-peak usage (Arroyo, 2004; California Coastal Commission, 2004; Callahan, 2004).

Photo by Texas Water Resources Institute

DESALINATION IN TEXAS

1. What types of desalination plants are in Texas?

Currently, there are only brackish desalination facilities in the State. However, there is considerable on-going effort to develop seawater desalination.

BRACKISH DESALINATION

2. How many desalination plants are in operation in Texas?

At the beginning of 2010, there were 44 public water supply systems in Texas with desalination facilities capable of producing more than 25,000 gallons per day. The estimated desalination capacity of these plants is 120 Mgd, with 70 Mgd from groundwater and 50 Mgd from surface water. The largest facilities, in terms of production, are in Abilene, Sherman, Southmost (near Brownsville), and Fort Stockton. Another 47 systems with desalination facilities have production capacities less than 25,000 gallons per day. All of these facilities treat brackish surface or groundwater. There are currently no seawater desalination facilities in the state.

About one half of these plants blend product water from desalination with other feedwater. The primary reason for this blending is to reduce high total dissolved solids (TDS) or to eliminate contaminates such as nitrate, arsenic, or radionuclides. All but four of the 38 facilities utilize RO; the others use **EDR** (Nicot et al., 2006).

3. Didn't El Paso recently complete a large facility?

Yes, in August of 2007, the City of El Paso and Fort Bliss Army Base opened what is reported to be the world's largest inland desalination plant. This $87 million reverse osmosis plant blends 15.5 Mgd of desalinated brackish ground water with 12 Mgd of moderately fresh groundwater. The annual operating cost, assuming 7 cents per Kwh, is $4.8 million or $534 per acre-foot (Hutchison, 2007; Seifert and Rogers, 2006).

4. How do desalination facilities in Texas dispose of their brine?

Of the 38 public supply desalination facilities on-line in 2006, fourteen disposed of the brine to surface water, nine disposed of the brine to a sewer treatment facility, and eight disposed to an evaporation pond. Land application was used for five of the plants; it could not be determined what method was used for two facilities (Nicot et al., 2005).

Desalination plants that dispose of their brine to surface water sources use a variety of methods regulated by the Texas Commission for Environmental Quality (TCEQ). Desalination plants located near the Texas Coast, such as the Southmost Regional Water Authority, discharge brine to the nearby Laguna Madre, a hyper-saline lagoon (Sturdevant et al., 2007). Inland desalination facilities generally mix the brine with other water before discharging to surface waters. The City of Kenedy discharges the brine from it brackish groundwater facility next to the discharge point for the wastewater treatment plant (Weynand, 2007). Several municipalities along the Brazos River use desalination to remove the salts from the River. These facilities discharge the brine back to the River.

5. Do any facilities use injection wells?

The new El Paso desalination facility utilizes injection wells to dispose of brine. Three wells more than 3,700 feet deep inject approximately 3.0 Mgd of brine into a formation containing brackish water. An on-going issue regarding these injection wells will be the potential for minerals to precipitate out of the brine as it is supersaturated with calcite, barite, and silica (Hutchison, 2007).

6. How are injection wells regulated?

The Underground Injection Control Program of the Safe Drinking Water Act regulates brine disposal by subsurface injection. As part of this program, various classifications of injection wells and their waste have been developed. Wells that inject hazardous and non-hazardous materials into formations below the lowermost underground source of drinking water are referred to as Class I wells. Texas has 78 of the 163 Class I hazardous, and 110 of the 366 Class I non-hazardous wells in the country. In Texas, the **TCEQ** administers this program (U.S. Environmental Protection Agency, undated).

In an effort to expedite the permitting process, the State Legislature has authorized the injection of non-hazardous brine from desalination operations, along with non-hazardous drinking water treatment residuals (from pretreatment for example), into Class I injection wells under a General Permit.[4] They also allowed the brine and residuals to be used as injection fluid in enhanced oil and gas recovery operations. The State has also studied the possibility of using depleted oil and gas fields to dispose of the brine (Mace et al., 2006).

7. Are any brackish groundwater withdrawals regulated?

The Evergreen Underground Water Conservation District south of San Antonio exempts brackish wells (defined in the District Rules as 3,000 mg/l or greater) from the spacing and production requirements that apply to freshwater wells. However, District Rules require that water levels from nearby freshwater monitoring wells be available on a continuous basis and that dye tracer test be performed to determine any possible hydrologic communication between the freshwater aquifer and the underlying brackish aquifer (Evergreen Underground Water Conservation District, undated).

Legislation introduced during the 83rd Session of the Texas Legislature[5] proposed to exempt brackish groundwater wells (defined here as 1,000 mg/l or greater) from all permitting requirements of groundwater districts. The legislation did not pass.

SEAWATER DESALINATION

7. What is being done to promote seawater desalination in Texas?

In 2003, the Texas Water Development Board (TWDB), at the direction of the Texas Legislature, funded feasibility studies to assess the technical viability of seawater desalination. Three locations, Brownsville, Corpus Christi, and Freeport, were selected for possible pilot plant studies, with Brownsville being selected in the hope that a 25 Mgd full-scale desalination demonstration plant would ultimately be constructed.

The primary finding of the Brownsville pilot project, completed in 2008, is that seawater desalination at the Brownsville Ship Channel is feasible. The preliminary pilot study recommended that before a full-scale plant is constructed, a demonstration scale facility of 2.5 Mgd be constructed on the Brownsville Ship Channel. The demonstration project would be a full production facility, contributing 2.5 Mgd of potable water to the Brownsville Public Utilities Board (BPUB) water

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[4] HB2654, 80th Texas Legislature
[5] HB2334, 83rd Texas Legislature

system. Construction of a smaller demonstration facility, with full-sized intakes and discharge systems constructed to accommodate the ultimate 25 Mgd facility, would provide an opportunity to further address technical issues pertaining to desalination on a smaller scale and at a lower cost, while initiating less technical components of the project at current construction costs (Irlbeck, 2008).

TWDB also provided financial assistance to study a 1 Mgd desalination facility on South Padre Island using horizontal beach wells. The most recent results from this study have found a beach well intake system at this location to be cost prohibitive; the revised plan is to utilize an open seawater intake to provide water to the treatment facility (Irlbeck, 2008; Texas Water Development Board, 2006).

The cost of building the desalination plant on South Padre Island is approximately $13 million. In May of 2011, voters approved a bond proposition for Laguna Madre Water District to construct the project. Construction on this project is to begin in 2014.

8. What is the projected cost of water from the Brownsville facility?

The estimated cost of the Brownsville project is $22.5 million. The Texas Water Development Board requested $9.5 million in Legislative Appropriates to assist BPUB with construction of the project. (Texas Water Development Board, 2012). To date, no appropriations have been provided and the project has not been initiated.

9. What are the environmental concerns regarding the Brownsville and South Padre Island facility?

The proposed intake for the Brownsville facility is the Brownsville Ship Channel and the South Padre Island facility is the Gulf of Mexico. The intake systems for both facilities are being designed to minimize or avoid impingement or entrainment of aquatic species. Withdrawing water from the Brownsville Ship Canal, however, raises potential concerns about the initial quality of the feedwater from the Canal. One of the objectives of the Brownsville pilot study was to characterize feedwater and concentrate water quality (Irlbeck, 2008).

The current brine disposal plans for these two facilities envision disposing of concentrate by diffusion into the Gulf of Mexico. The location of the discharge pipeline for the Brownsville facility through estuarine and dune areas could impact these sensitive habitats during construction and maintenance. Outfall locations for both facilities will have to be in areas where the Gulf can assimilate a large concentration of brine on an on-going basis. Large discharges of brine can result in hypoxia. The ability to model and predict the behavior and impact of these discharges will be an important yet potentially difficult task (Hodges et al., 2006).

An alternative brine disposal plan for the Brownsville facility suggests mixing the brine with surface water from the Rio Grande and applying the concentrate on the salt flats southeast of the city in order to decrease blowing dust. An alternative disposal plan for the South Padre Island facility evaluates the potential for injecting the brine into saline aquifers (Irlbeck, 2013).

10. What types of permits are required to build an ocean desalination plant?

In Texas, various permit applications must be submitted to the Texas Commission on Environmental Quality (TCEQ) as well as other agencies that may have regulatory power based on the specific site: General Land Office, Texas Railroad Commission, Texas Historical Commission, Texas Department of Transportation. A permit from the local groundwater district may also be necessary for brackish groundwater withdrawals. Federal permits from the U.S. Army Corps of Engineers pertaining to the Clean Water Act (dredge and fill in navigable waters) will likely be required. If endangered or threatened species become an issue, permits would be necessary from the National Marine Fisheries and/or the U.S. Fish and Wildlife Service (R.W. Beck, 2004).

ONE FINAL QUESTION

How would the Sierra Club sum up desalination?

Desalination offers the potential for taking pressure off freshwater resources that are of vital importance to the environment. It also provides an opportunity to diversify sources of water supply and to make use of resources that otherwise would not be usable.

Desalination creates its own set of environmental problems, however, resulting from brine disposal, impingement and entrainment, and increased electrical demands. The high costs associated with desalination makes projects vulnerable to changes in electrical rates. These high costs also emphasize the need to implement much less expensive water conservation strategies prior to subsidizing desalination. Because desalination is a relatively new water management strategy, it is imperative that proposed disposal methods, especially deep-well injection and surface water disposal, be carefully monitored and evaluated.

Desalination is one tool in the toolbox for meeting water supply needs. One must take care that desalination is the most appropriate, environmentally sound and cost-effective tool in a specific situation. With proper planning, siting, attention to all energy and environmental factors, and thorough evaluation of the full costs of operation, desalination plants could be a significant part of a comprehensive water supply program that also includes advanced water conservation and effective drought management measures.

Glossary and Abbreviations:

Brackish water: Water that is saltier than potable water but not as salty as seawater. Brackish water usually has a salt concentration between five and 20 parts per thousand and can be found as surface water or as ground water.
Brine: Waste water from desalination containing high concentrations of salts and minerals.
Cleaning chemicals: Chemicals used to remove scale and fouling from membranes.
Coagulation: Process in which a substance is added to the feedwater to cause small particles in the water to form a large mass for easy removal.
Co-generation: Using the exhaust steam from an electricity-generating power plant. In a distillation plant, the steam can be used to evaporate feedwater and in a reverse osmosis plant it can be used to warm the feedwater (which increases efficiency) or for a turbine to power the high pressure pump.
Concentrate: See Brine.
Dissolved solids: The amount of organic or inorganic chemicals dissolved in the water. Filtering the water to remove the suspended solids and evaporating the water can isolate these chemicals. The remaining solids are the dissolved solids.
ED: Electrodialysis
EDR: Electrodialysis Reversal
Energy recovery: Capturing and reusing energy. In a distillation plant, energy can be recovered by using the heat from the discharged brine and product water to evaporate the incoming feedwater. In a reverse osmosis plant, the hydraulic pressure of the brine is harnessed and converted into energy to run the high-pressure pump.
Entrainment: Marine organisms are drawn into the intake pipes along with the feedwater. Entrainment is lethal.
Feedwater: The stream of water entering the desalination plant to be treated.
Flushing: Membrane cleaning method.
Fouling: The buildup of salts, biological growth or mineral deposits on the membranes.
Hypoxia: A condition in which low levels of dissolved oxygen result in stress or death to aquatic organisms.
Impingement: Marine organisms hit the screen over the intake pipe and are injured or killed as a result.
Insoluble: Incapable of being dissolved.
Ion exchanger: A method of purifying water in which elements or compounds in the water are "exchanged" for a harmless ion, such as sodium.
Kwh: Kilowatt-hour
MED: Multiple Effect Distillation
Mgd: million gallons per day
Minerals: Inorganic compounds that are the building blocks of most rocks and are found naturally in most water. They are also needed in trace amounts in the human body.
MSF: Multi-Stage Flash Distillation
Nanofiltration: A pretreatment process that uses membranes to remove suspended solids from the feedwater. Membrane desalination processes that do not require water use nanofiltration.
Non-ionic substances: Compounds that do not have a charge and cannot be attracted by a charge are pulled across a membrane in ED or EDR plants.
Osmotic Pressure: Pressure produced by solutions of different concentrations divided by a semi-permeable membrane.

Oxidant: An element or compound that can remove an electron from another element or compound, changing the charge of both substances involved.
Particles: Dissolved and suspended solids found in the feedwater.
Potable water: Water clean enough to drink.
Pretreatment: A method of removing suspended solids and other potential fouling substances.
Product Water: Desalinated water.
Receiving water: The body of water into which brine is disposed.
Reverse Osmosis: A desalination process where high pressure forces the water through a membrane, leaving the larger molecules of the salts and minerals behind.
RO: Reverse Osmosis
Scale: An accumulation of partially insoluble salts in a membrane.
Source water: The body of water from which the feedwater comes.
Suspended solids: Small particles found within the feedwater that are not dissolved. They can be removed via filtration.
Transmissivity: A measure of how much water can be transmitted horizontally in an aquifer.
TCEQ: Texas Commission on Environmental Quality
TWDB: Texas Water Development Board
VC: Vapor Compression Distillation

Appendix A: Desalination Methods

Multi-Stage Flash Distillation (MSF)

In multi-stage flash distillation, seawater is heated in a container called the brine heater. The heated water then flows to a second container, called the stage, where the pressure is lower. The lower pressure causes a portion of the water to boil because at a lower pressure, water has a lower boiling temperature. In fact, the water boils so quickly it is said to "flash" into steam. The remaining water is then moved to the next stage, where the pressure is even lower, causing more water to flash into steam. Most MSF plants involve between 15 and 25 stages, each having a lower pressure than the previous. The vapor produced from the boiling is condensed on tubes of heat exchanges. MSF plants produce on average 1 to 15 million gallons per day (Mgd).

Multiple Effect Distillation (MED)

Multiple effect distillation is similar to MSF because it takes place in a series of containers (called effects), each at a lower pressure than the previous one, and utilizes the processes of evaporation and condensation. An effect is made up of a container and a heat exchanger. The feedwater is usually added in equal amounts to each effect, of which there are between eight and 16. Some of the feedwater in each effect boils, producing steam. The steam condenses, giving rise to freshwater, and the condensation releases heat to evaporate water in the next effect.

Vapor Compression Distillation (VC)

Vapor compression distillation is commonly used in small to medium sized plants. During the distillation, a mechanical compressor or a steam jet compressor generates heat for evaporation. Feedwater is added and partially evaporates. The vapor then condenses into freshwater.

Electrodialysis (ED) and Electrodialysis Reversal (EDR)

In electrodialysis and electrodialysis reversal, the membranes are subject to an electric charge. Salt and other minerals are ionic, and are attracted to the charge and therefore pulled through the membrane, leaving desalted water behind.

Reverse Osmosis (RO)

In reverse osmosis, high pressure forces the water molecules through a membrane, leaving the larger molecules of the salts and minerals behind.

Advantages and Disadvantages of Various Desalination Methods

Method	Advantages	Disadvantages
Multi-Stage Flash Distillation	• recent improvement in scale control has made it more efficient • economies of scale in capital costs • no waste from cleaning pretreatment filters • can use lower quality feedwater than RO • less scaling than MED	• extremely energy intensive • scaling and corrosion are serious concerns because the evaporator components are directly exposed to the feedwater • thermal discharges
Multiple-Effect Distillation	• no waste from cleaning pretreatment filters • can use lower quality feedwater than RO	• extremely energy intensive • scaling and corrosion are serious concerns because the evaporator components are directly exposed to the feedwater • thermal discharges
Vapor Compression Distillation	• simple, reliable • ideal for small operations, such as resorts • no waste from cleaning pretreatment filters • can use lower quality feedwater than RO	• not efficient for a large-scale operation • extremely energy intensive • scaling and corrosion are serious concerns because the evaporator components are directly exposed to the feedwater • thermal discharges
Electrodialysis/ Electrodialysis Reversal	• higher water recovery than RO • can treat water with a higher level of suspended solids than RO • unaffected by **non-ionic** substances • reduced or no impact from thermal discharges • (EDR only) intermittent **flushing** of the system minimizes need for pretreatment chemicals and membrane fouling • (EDR only) less prone to fouling than RO	• (ED only) prone to fouling and scaling • does not remove microorganisms or small suspended particles • can result in product water with a higher concentration of bacteria than the feedwater • generally used for only brackish water, not seawater • most membranes cannot tolerate strong oxidants, such as chlorine
Reverse Osmosis	• lower energy requirements than distillation • reduced or no impacts due to thermal discharges • fewer problems with corrosion than distillation • higher water recovery rates than distillation • can remove contaminants such as bacteria and pesticides • plant takes up less land area than a distillation plant	• membranes must be periodically replaced, a costly repair that requires part or all of the plant to shut down • greater pretreatment needs (costs) than distillation • greater sensitivity to poor quality feedwater than distillation • wastes may include toxic chemicals and metals

(Buros, 2000; California Coastal Commission, 2004; Department of the Army, 1986; Gleick, 2000; Pantell, 1993; Shea, 2004)

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