Chapter 1

Introduction

OVERVIEW

General Trends

Over the last few decades desalination technologies have been used increasingly throughout the world to produce drinking water from brackish groundwater and seawater, to improve the quality of existing supplies of fresh-water for drinking and industrial purposes, and to treat industrial and municipal wastewater prior to discharge or reuse. In the early 1950s there were about 225 land-based desalination plants worldwide with a combined capacity of about 27 million gallons per day (mgd). There are now about 3,500 plants worldwide with a production capacity of about 3,000 mgd. As the demand for freshwater increases and the quality of existing supplies deteriorates, the use of desalination technologies will increase.

Seawater distillation plants dominated the early desalination market, which was primarily overseas. However, due to lower energy requirements, a desalination process called reverse osmosis (RO)[2] now appears to have a slightly lower cost than distillation for seawater desalination (unless a dual purpose electric power/desalination plant is being built). For brackish water desalination, RO and another desalination process called electrodialysis (ED) are both competitive. Other desalination technologies are used less widely due to their rudimentary development and/or higher cost. However, there is no single desalination technology that is considered "best' for all uses. The selection of the most appropriate technology depends on the composition of the feed water (prior to desalination), the desired quality of the product water, and many other site-specific factors. Desalination technologies cannot produce water where there is none.

Brackish water can be most economically desalinated on a large scale (e. g., 1 mgd, or larger) at well-operated, centralized RO or ED plants at an overall cost (including both capital and operating costs) of about $1.50 to $2.50 per 1,000 gallons; for seawater, large scale distillation and RO both cost about $4 to $6 per 1,000 gallons.[3] Although there are no developing desalination technologies that will generate major reductions (e. g., 50 percent) in water treatment costs, industry experts believe that the costs of RO and ED should continue to decrease as membranes, treatment equipment, and operational procedures are improved. Future cost reductions for distillation processes will probably be modest.

Domestic Use of Desalination Technologies

Relative to many areas of the world the United States has plentiful, and therefore inexpensive, supplies of freshwater. Since the colonization of the United States, the use of freshwater has generally increased along with our population growth and industrial development. As water use increases and the availability of renewable supplies decreases, the cost of developing new supplies of surface and groundwater increases. These trends will probably continue. Water pollution also requires increasing levels of water treatment, including the use of some desalination technologies. In some areas of the country (e. g., southern California) it may be cheaper to use desalination technologies to treat either brackish water or irrigation drainage water than to develop new supplies of surface water (via reservoirs and diversions).

As the cost of developing and treating water supplies increases, the use of desalination technologies will probably increase in this country in the following six areas:

1. RO and ED of brackish groundwater will supply drinking water for some small to midsize inland communities in the water-limited ***West***

'See box A on p. 2 for definitions of scientific terms.

'Different desalination technologies are described briefly in ch. 2 and in more detail in app. A.

[3]Under less-than-ideal operating conditions these costs may be higher. Unless otherwise stated all dollar values in this report are given in terms of 1985 dollars.

and for some rapidly growing, mid-size communities along our coasts.

2. A few large municipalities in the West will increasingly use RO or ED to demineralize and treat wastewater from sewage treatment plants (and perhaps from irrigation operations) for direct or indirect reuse as drinking water.
3. With more stringent Federal regulations on drinking water, public and private suppliers throughout the United States will increase their use of RO, ED, and perhaps a desalination process called ion exchange, at centralized plants to remove contaminants (e. g., dissolved minerals, heavy metals, dissolved organics, and pathogens) from both surface water and groundwater supplies.
4. As water quality regulations become more stringent, industries may increase their use of RO, ED, and other water treatment processes to remove potentially toxic contaminants from wastewater prior to reuse or discharge.
5. Small RO and distillation units will be used increasingly in homes for "point-of-use' treatment of drinking water in response to individual concerns about water quality.
6. Industries will continue to use desalination technologies to treat the water used in the manufacture of various products, such as paper, pharmaceuticals, and food products.

Box A.—Definition of Scientific Terms

Brackish water—in this report, water containing significant levels (i. e., greater than 500 ppm) of salt ***and/or*** dissolved solids, but 1ess than that found in seawater (35,000 ppm dissolved solids). Less brackish water (i.e., containing between 500 ppm and 3,000 ppm dissolved solids) mayor may not require desalination depending on the water use; moderately brackish water (i. e., containing between 3,000 ppm and 10,000 ppm dissolved solids) usually requires desalination prior to use; highly brackish water (i.e., containing between 10,000 ppm and 35,000 ppm dissolved solids) would probably require a level of treatment comparable to seawater.

Desalination-processes used to remove salt and other dissolved minerals from water. Other contaminants in water (e. g., dissolved metals, bacteria, and organics) may also be removed by some desalination processes.

Freshwater—water with levels of dissolved salt and other minerals that are low enough (typically less than 500 ppm) to make desalination unnecessary for most uses. However, depending on its quality, freshwater may have to be treated in some way prior to use.

Ions—positively or negatively charged atoms or groups of atoms that are often found dissolved in water. Cations are positively charged; anions are negatively charged.

Potable water—water suitable for drinking that generally has less than 500 ppm of dissolved minerals (including salt).

Product water—the freshwater produced from a desalination operation.

Seawater—water that is withdrawn from the ocean (with about 35,000 ppm salt and dissolved solids).

Waste concentrate—salty wastewater that is produced by desalination operations and must be disposed of. Salt concentrations in waste concentrates can exceed 50,000 ppm.

Much of the development of desalination technologies in the past three decades was sponsored by the U.S. Government. In fact, since 1952 the Federal Government has spent just over $900 million (in 1985 dollars) in support of desalination research, development, and demonstration projects. Federal funding for most desalination research was discontinued in 1982. This research program was primarily responsible for the development of reverse osmosis, and for many advances and improvements in distillation technologies. The United States still holds a technological advantage in some, but not all, areas of desalination. U.S. industry investment in desalination R&D is now probably about $5 million to $10 million per year.

There are now about 750 desalination plants in the United States with a combined production capacity of about 212 mgd. This water is used primarily for industrial uses, and secondarily for drinking water. There are desalination plants in 46 States and on two island territories. Between 70 and 80 percent of this capacity is provided by RO (33). The amount of desalinated water produced in this country is equivalent to about 1.4 percent of the

15,000 mgd that is consumed[4] for domestic and industrial purposes. The use of desalination technologies for treating fresh, brackish, and contaminated water supplies will continue to increase in the United States. However, large-scale seawater desalination will probably not be cost-effective in this country for some years to come.

Overseas Use of Desalination Technologies

In predominantly arid regions of the world, and especially in the Middle East, where conventional sources of fresh water (e. g., rivers, lakes> reservoirs or groundwater) are not readily available, seawater desalination will continue to supply drinking water. In some countries, desalinated water may also be used for government subsidized agricultural operations where self-sufficiency and national security are primary objectives. However, desalinating irrigation water for traditional open-field agriculture will probably not be economically competitive in the foreseeable future anywhere in the world. In the absence of free market constraints (e. g., government subsidies), it is usually more cost-effective to import crops from water-rich agricultural regions.

In most lower-tier developing countries the vast majority of water will continue to come from essentially salt-free surface and groundwater supplies. It is estimated that about half of the people in these countries do not have adequate (e. g., disinfected) drinking water supplies; about 70 percent have inadequate sanitation facilities. Water treatment, if there is any, generally involves the use Of more conventional technologies, such as sedimentation, filtration, and disinfection. However, relatively small desalination plants may be of particular value for tourist hotels, construction sites, and certain isolated communities that have no other readily available sources of freshwater. In very remote areas small solar stills or solar-powered desalting units may be an appropriate desalting alternative.

[4]Water may be withdrawn from a supply, used for some purpose such as cooling, and then discharged directly or indirectly into a water body so that it can be reused later. Water is consumed when it is withdrawn, used up perhaps in a manufacturing process, and is not available for reuse.

The majority of industrialized countries are located in temperate zones where supplies of freshwater are adequate. Therefore, desalination technologies will be used in these countries primarily for industrial purposes, and secondarily for treating drinking water.

Scope of This Study

This report provides a state-of-the-art evaluation of technologies that were developed to desalinate water. Many of these same technologies can also be used to remove contaminants other than salt from water supplies. Water treatment techniques that remove contaminants other than salt and/or dissolved minerals are beyond the scope of this study. The policy implications associated with the use of desalination technologies are briefly addressed in the chapter discussing future prospects for desalination in the United States.

Generalizations about the capabilities and uses of desalination technologies have been made to the extent possible, recognizing that there are exceptions to most generalizations. Selecting the most appropriate desalination technology for a particular use depends on many site-specific factors that must be evaluated in detail by qualified engineers and scientists. In other words, this paper should not be used as the only source of information when evaluating different desalination technologies for a specific use.

HISTORICAL BACKGROUND

The hydrologic cycle provides the Earth with a continuous supply of fresh, and for the most part, distilled water. The sun drives the cycle by providing the energy to evaporate water from the ocean and from water bodies on land. This water vapor, which accumulates as clouds, condenses in the cooler upper atmosphere and falls to the Earth's surface in the form of rain or snow.

Man has distilled freshwater from seawater for many centuries. Egyptian, Persian, Hebrew, and Greek civilizations all studied various desalination processes. Aristotle and Hippocrates both advocated the use of distillation in the 4th century B.C. (37). During the 1700s both the United States and British navies were making simple stills from pots and by the mid- 1800s small stills were being built into shipboard stoves. By the turn of the century various types of land-based distillers were being used in several arid parts of the world (4).

By the 1940s all major naval vessels and passenger ships had their own stills. During World War II the U.S. Navy built a 55,000 gallons per day (gpd) distillation plant on Johnston Island (87) and several smaller stills on other Pacific islands. Prior to 1953 there were only about 225 land-based desalination plants worldwide with a combined capacity of about 27 mgd (24). In the late 1950s desalination took on added importance with the construction of several large distillation plants in the Middle East where freshwater supplies are extremely limited.

As the demand for freshwater increased and production costs decreased in the 1960s, the use of desalination increased, especially in arid regions of the world. The development of nuclear power at this same time also brought visions of inexpensive electricity to power distillation plants (90). It was hoped that in the coming decades "dual purpose' reactors would produce power and distill seawater at costs ranging from $0.35 to $1.00 per 1,,000 gallons; abundant supplies of distilled water would "make the deserts bloom and the cities thrive' (23,32,70). However, the optimism of the 1960s mellowed considerably in the 1970s when it became evident that the costs of desalination using nuclear power would be much higher than many had expected.

The costs of distillation were significantly reduced during the 1960s through advances in plant design, heat transfer technology, scale prevention, and corrosion resistance. Worldwide desalination capacity grew from about 60 mgd in the early 1960s to about 1,000 mgd supplied by 1,500 plants in the late 1970s (22,24,33,87). Although distillation plants dominated the early desalination market, RO and ED began to take over an increasing market share in the early 1970s (33,50).

In 1986 there were 3,500 desalination plants in 105 countries worldwide (operating or under construction) with a combined capacity of about 3,000 mgd.[5] Almost 60 percent of this capacity is located in the Middle East. Saudi Ar'abia alone has about 800 plants that produce a total of about 915 mgd, or about 30 percent of the world's desalinated water. Saudi Arabia's 40-unit Al Jubail II is the world's largest desalination facility in operation with a capacity of almost 250 mgd. The United States and its territories have about 750 plants that account for about 10 percent of the world's capacity.

[5]This total capacity for the world includes all the desalination plants ever built; the older plants since retired have not been subtracted from this total. Therefore, the actual total is probably about 10 percent to 15 percent less than the 3,000 mgd. For the total desalination capacity in the United States it was assumed that plants built prior to, and after 1970, had operating lifetimes of 10 years and 15 years, respectively. Also, the United States total does not include the 72 mgd RO plant at Yuma, AZ, which is not yet operational.

GENERAL WATER USE IN THE UNITED STATES

Sources of Fresh and Brackish Water

Precipitation within the 48 contiguous states averages nearly 30 inches a year, or about 4.2 billion mgd. The majority of this precipitation falls in the East. In fact, most areas of the United States west of the Great Plains receive less than 20 inches of rainfall a year; during periodic droughts rainfall is even less. In addition to this renewable supply, about 150 trillion gallons of freshwater are stored in surface lakes and reservoirs (89). and 200 to ***600*** times this amount is stored in aquifers of fresh groundwater (56,89).

Potentially developable brackish aquifers are known to occur in many parts of the United States (25). However, limited data suggest that brackish groundwater is quite a bit less abundant than fresh groundwater. Furthermore, the occurrence of brackish aquifers varies considerably from one region of the country to another. The presence of brackish groundwater may be particularly important in those arid and semiarid areas of the country where existing supplies of freshwater are scarce and/or largely utilized. These areas are found in the following western States: Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North and South Dakota, Oklahoma, Oregon, Texas, Utah, Washington, and Wyoming.

Water Consumption (69)

According to data collected in 1980, about 450 billion gallons of fresh and saline water, or about 2,000 gallons/person, are withdrawn from surface and groundwater supplies each day for various commercial and domestic uses. Much of the freshwater that is withdrawn is discharged after use into adjacent surface supplies for subsequent reuse in downstream areas. However, about 100,000 mgd of freshwater are actually consumed (e. g., via plant transpiration, evaporation, etc.) and are not readily available for reuse. Consumptive uses of water include:

- ***Irrigation:*** About 81 percent (i. e., 81,000 mgd) of freshwater consumed in this country irrigates about 58 million acres of farmland, mostly in the West. About 60 percent of this water comes from major surface water diversions; the rest comes from groundwater aquifers.
- ***Industry:*** About 8 percent (i. e., 8,000 mgd) of all freshwater is consumed by industry. The level of water treatment required by industry depends on its particular use and the location of the industry. Most industries that require large volumes of processing water are located where water supplies are naturally abundant.
- ***Domestic Use:*** Over 200,000 public water systems in the United States sell about 34,000 mgd to more than 200 million customers for domestic use, for public and municipal use, and for some industrial and commercial uses.

  Average domestic use in this country is believed to be between 120 and 150 gpd per person (85). About 7 percent (i. e., 7,000 mgd) of all freshwater consumption is for domestic uses.
- ***Rural Use:*** There are about 40 million people living in rural areas of the United States. About 90 percent of all rural water systems depend on groundwater from about 12 million private wells for drinking water, livestock, and other uses (besides irrigation). Rural use accounts for 4 percent (i. e., 4,000 mgd) of all freshwater consumption.

Water Quantity/Water Quality Linkage

Only about 20 percent of water withdrawn for use is actually consumed. The rest is generally discharged into rivers, lakes, and estuaries as wastewater or irrigation return flows, and can be subsequently reused at downstream locations. Each time water is reused it can be expected that the concentration of pollutants (including salt) in the discharged water will increase. Water quality problems tend to be greater where the frequency of water reuse is high, such as in water-limited areas of the West, and along waterways adjacent to heavily industrialized areas.

In coastal areas most freshwater aquifers become increasingly brackish as they extend offshore. If the rate at which fresh groundwater is withdrawn exceeds the rate of freshwater recharge, more brackish water from offshore will move inland and progressively increase the salt concentration in the aquifer. Depending on the aquifer configuration and the brackish water withdrawal rates, increasing salinity levels in coastal wells may occur over a period of months to many years. Saltwater intrusion has been a significant problem for Long Island, NY, Florida, southern California, and several other coastal areas.

FUTURE WATER SUPPLY NEEDS

A comparison of past analyses of water use indicates that both water withdrawals and water consumption in the United States gradually increased through 1980. More recent data collected for 1985 indicate that both water withdrawals and water consumption have decreased somewhat since 1980. This shift may be due to more eflicient use of water, decreased precipitation over the last 5 years, a shift toward less water intensive industries in this country, and/or increased accuracy of the data collected (68).

Despite this apparent decrease in water use over the last 5 years, the demand for water will probably continue to increase over the next several decades. In fact, water demand exceeds available supplies during periodic droughts and in many water-limited areas of the country (e. g., most of the West). Droughts occur more frequently in the West. In areas of the country, where readily available supplies of surface and groundwater have already been developed, dams and other water diversions are becoming more expensive and time consuming to construct and often meet with opposition due to potential environmental impacts. For example, the Two Forks Project, a dam on the South Platte River southwest of Denver, has been in the planning process for about 10 years. Although $37 million has been spent on planning and preparation of an environmental impact statement, the project has yet to be approved (35). Water from this project is projected to cost about $10 per 1,000 gallons. As the cost of developing new supplies of water increase, the level of water treatment and reuse will also increase,