

# Desalting of saline waters—applications to New Mexico

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## Abstract

Diminishing fresh water supplies in parts of New Mexico have sparked an interest in desalting of saline ground waters and oil field produced waters to supplement fresh water supplies. This paper briefly discusses desalination processes that have achieved commercial success around the world that might be used in New Mexico. These include multi-stage flash distillation, multiple effect distillation, vapor compression, electrodialysis, and reverse osmosis. Other minor processes include freezing, membrane distillation, and solar humidification. Brackish water desalination typically costs between \$1.00 and \$2.40 per thousand gallons, and seawater desalination typically costs between \$0.80 and \$12.00 per 1,000 gal of fresh water. In New Mexico in 2001, 26,862,407,960 gal of oil and gas field produced water were pumped out of the ground. If desalted and treated to standards for human consumption or other purposes, this produced water would contribute to solving future water supply problems in New Mexico. However, the dissolved hydrocarbons in this water presently make desalination difficult. Research into solving desalination problems pertinent to New Mexico is ongoing and will undoubtedly see both successes and failures in the next decade or two.

## Introduction

As New Mexico's population and industrial base grows, we are heading toward a limited availability of fresh water. New Mexico has few fresh water streams and a finite supply of fresh ground water. More than 120,000 acre ft of ground water is pumped out of the ground each year and not replaced by the city of Albuquerque (Titus, 2001). This ground-water pumping has resulted in decreasing ground-water levels in the city wells, and conservation measures are being implemented. Lately interest has been increasing in the possibility of desalinating saline ground water to provide the fresh water needed for New Mexico.

Large volumes of saline waters underlie approximately two-thirds of the continental United States, including New Mexico (Feth, 1970). Few aquifers in New Mexico contain only fresh water. Most also contain significant volumes of saline water, often at relatively shallow depths (Hood and Kister, 1962). Another large source of saline water in New Mexico is oil field produced water. According to the U.S. Environmental Protection Agency (EPA) Office of Water Underground Injection Control Program, for every barrel of oil produced

in the United States approximately 10 barrels of brine are produced. The volume of produced water from gas wells may be even higher. In New Mexico during 2001, 639,581,142 barrels of oil and gas-related produced water were pumped out of the ground (New Mexico Oil and Gas Division).

We use water in several ways including domestic, commercial, industrial, and for public services such as fire fighting and in public buildings. The average water usage in the United States for these categories is 58 gal (220 L), 69 gal (260 L), 8 gal (30 L), and 24 gal (90 L) per capita per day respectively (Lin, 2001) for a total of 159 gal (600 L) per capita per day. To put this in perspective, if all of the water produced as a byproduct during oil and gas operations in New Mexico could be treated for human consumption and distributed, it would provide all the water needed each year for 462,866 people—almost one-third of New Mexico's population.

Limited fresh water supplies are not unique to New Mexico. Less than 2% of the world's water supply is fresh water suitable for drinking (Fetter, 1988). The rest is too saline for human consumption, having total dissolved solids (TDS) greater than 1,000 milligrams per liter (mg/L). Therefore, as world population grows, especially in arid or semiarid areas, fresh water supplies are commonly being used up faster than they can be naturally replaced. It is increasingly important that cost-effective methods be developed and implemented for use on saline or other impaired waters in order to ensure adequate future water supplies for the people of the state of New Mexico, as well as the rest of the world.

Removal of dissolved solids from highly concentrated waters is called desalination (also spelled desalinization) or desalting. Desalination technology received a big boost when the United States Office of Saline Water (and successor organizations) was created and funded in the 1960s. Funding from the Office of Saline Water provided for basic investigation and development of several different technologies for desalting water (Buros, 2000), and by the late 1960s, commercial units based on thermal processes capable of producing as many as 2 million gal of fresh water a day were being installed in various parts of the world. In the 1970s electrodialysis and reverse osmosis plants began operation. Now, there are desalination operations in use in over 100 countries with a total pro-

duction capacity for fresh water of six billion gallons per day (Buros, 2000).

Waters are typically classified by dissolved solids content, and there are a number of different classifications in use. For example, the Water Quality Association classifies water as:

- Fresh water is less than 1,000 mg/L TDS
- Brackish water is between 1,000 and 5,000 mg/L TDS
- Highly brackish water is between 5,000 and 15,000 mg/L TDS
- Saline water is between 15,000 and 30,000 mg/L TDS
- seawater is between 30,000 and 40,000 mg/L TDS
- Brines are between 40,000 and more than 300,000 mg/L TDS

Although this is a useful classification, most of us are more familiar with the simple classification that fresh water is less than 1,000 mg/L TDS, brackish water is between 1,000 and 10,000 mg/L TDS, and brines are above 10,000 mg/L TDS. In this paper we will use the latter classification, and the term saline water will refer to any water with a TDS greater than 1,000 mg/L.

The major barrier to desalination is cost. It is much less expensive to use, with minimal treatment, fresh water from a lake or stream, or ground water. If water must be desalted before use, the lower the dissolved solids content, the less difficult and expensive it will be to desalinate the water. It is likely that lower TDS saline waters will be the first to be commercially desalinated in New Mexico.

## Conventional desalination methods

Several successful desalination processes are in use today throughout the world. These include multi-stage flash distillation, multiple effect distillation, vapor compression, electrodialysis, and reverse osmosis (Buros, 2000). Other minor processes include freezing, membrane distillation, and solar humidification. In this section of the paper we will briefly discuss the basic principles of operation of each of these methods.

Multi-stage flash distillation, multiple effect distillation, and vapor compression are all thermal processes. Approximately one-half of the water desalted each year uses heat to distill fresh water from seawater (Buros, 2000). All thermal methods are a variation of the simple process of heating water to the boiling point to produce water vapor, which is then cooled to produce fresh water. The salt does not evaporate

and remains behind. Distillation methods produce water with between 1.0 and 50 mg/L TDS.

### Multi-stage flash distillation (MSF)

In this process saline water is heated, and it then flows into another vessel where the atmospheric pressure has been reduced. The sudden introduction of the heated saline water into the chamber causes it to rapidly boil or “flash” into steam. Not all of the water is turned into steam. Therefore multiple stages are used to increase efficiency (Fig. 1).

Commercial MSF desalination plants have been constructed since the 1950s. Typical installations produce between 4,000 and 57,000 m<sup>3</sup>/day (between 1 and 15 million gal per day). Saudi Arabia, the United Arab Emirates, and Kuwait depend on MSF facilities to supply fresh water to urban areas (Buros, 2000).

One of the problems with MSF desalination is the scale produced by the evaporation process. Scale formation and corrosion increase with increasing operating temperatures during MSF, so they place a limit on process efficiency (Buros, 2000).

### Multiple-effect distillation (MED)

Like MSF, MED takes place in stages and uses evaporation and subsequent condensation to produce fresh water. The atmospheric pressure is reduced more in each of the successive stages so that the saline water will boil in each stage without increasing the heat after the first stage. Between eight and 16 stages are used in a typical plant (Buros, 2000).

There are several designs for MED plants, and improvements have been made recently that involve the ability to operate at lower temperatures thus reducing scale formation and corrosion. MED plants typically have capacities between 2,000 and 20,000 m<sup>3</sup>/day (between 0.5 and 5 million gal per day; Buros, 2000).

### Vapor compression distillation (VC)

This process is usually used in combination with other processes or by itself for small and medium-scale seawater desalination applications (Buros, 2000). Heat is generated by compression of vapor in a mechanical compressor, and this heat is used to evaporate the water. The water vapor is then condensed and collected as fresh water. VC units are made in a variety of configurations. Figure 2 shows a simple VC configuration.

Compressors are expensive to acquire and operate, so, to keep costs low, pressure increases in VC plants are limited. Most VC plants have only one compressor stage, although some of the newer ones use multiple stages. VC units are commonly used at resorts and industrial sites where fresh water is not available (Buros, 2000).

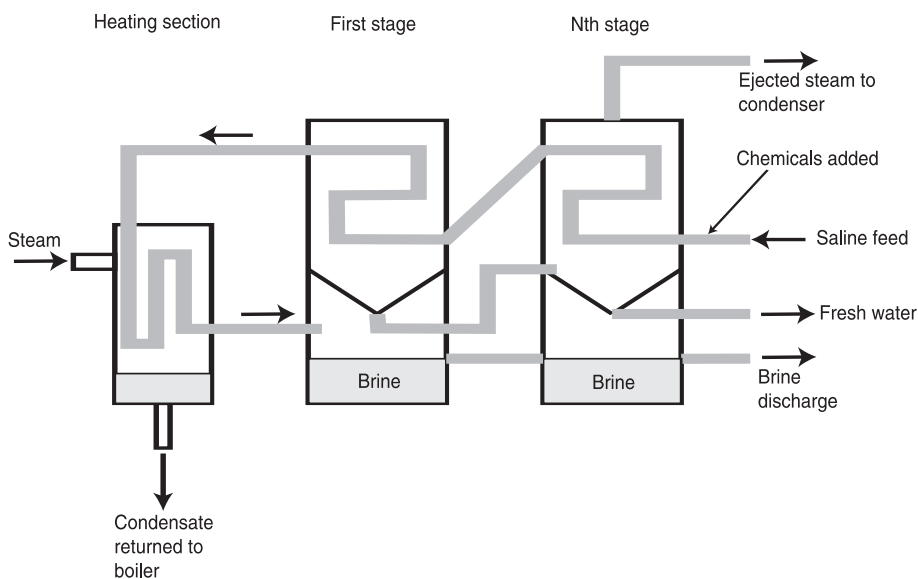


FIGURE 1—Schematic of multi-stage flash distillation process (redrawn after Buros, 2000).

### Electrodialysis

Electrodialysis uses an applied current to force charged ions dissolved in water, such as Na<sup>+</sup>, Cl<sup>-</sup>, or Ca<sup>++</sup>, to migrate toward electrodes. Selective membranes that will allow either negatively charged ions (anions) or positively charged ions (cations) to pass (but not both) are placed between the electrodes. Anions enter the channel between the membranes from one side, and the cations enter from the other resulting in a stream of concentrated brine that is disposed of as a waste. The feed water on the other side of the membranes is depleted in dissolved ions and is thus purified (Fig. 3). The combination of the

electrodes and membranes is called a stack. A number of these stacks are used in one system. An important improvement in electrodialysis was the development of current reversal techniques that help prevent membrane fouling and extend membrane life.

The water to be treated by electrodialysis must be filtered to remove particles that might clog the membrane. After electrodialysis the purified water must also be treated to remove gases and possibly to adjust the pH. Electrodialysis works best for brackish waters. It is not generally suitable for saline waters above 10,000 mg/L TDS.

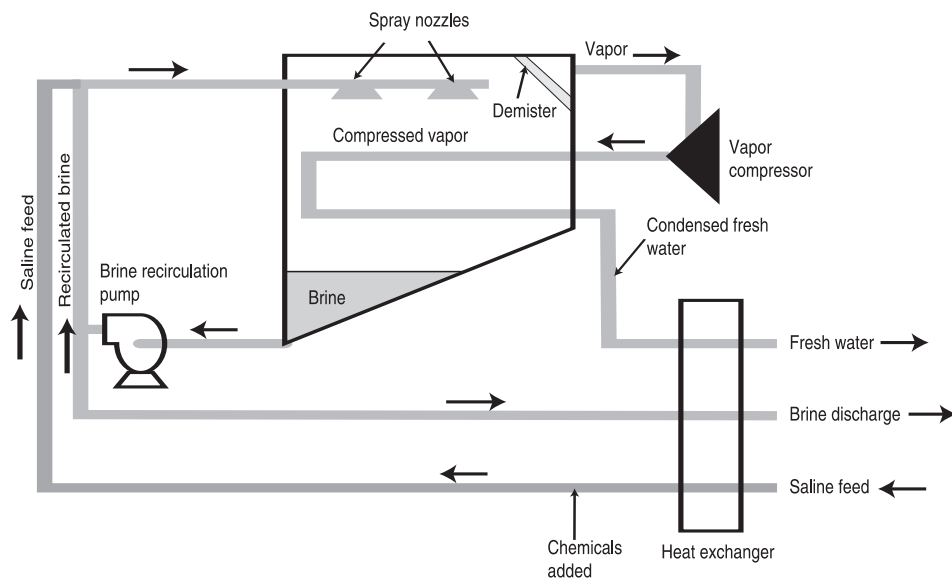


FIGURE 2—Schematic of a vapor compression distillation process (redrawn from Buros, 2000). In the figure brine is sprayed into a chamber containing a heat exchanger bundle (labeled compressed vapor in the drawing) to promote evaporation. The heat in this tubing bundle is obtained by compressing the purified water vapor and then sending the compressed stream through the heat exchanger bundle in the chamber.

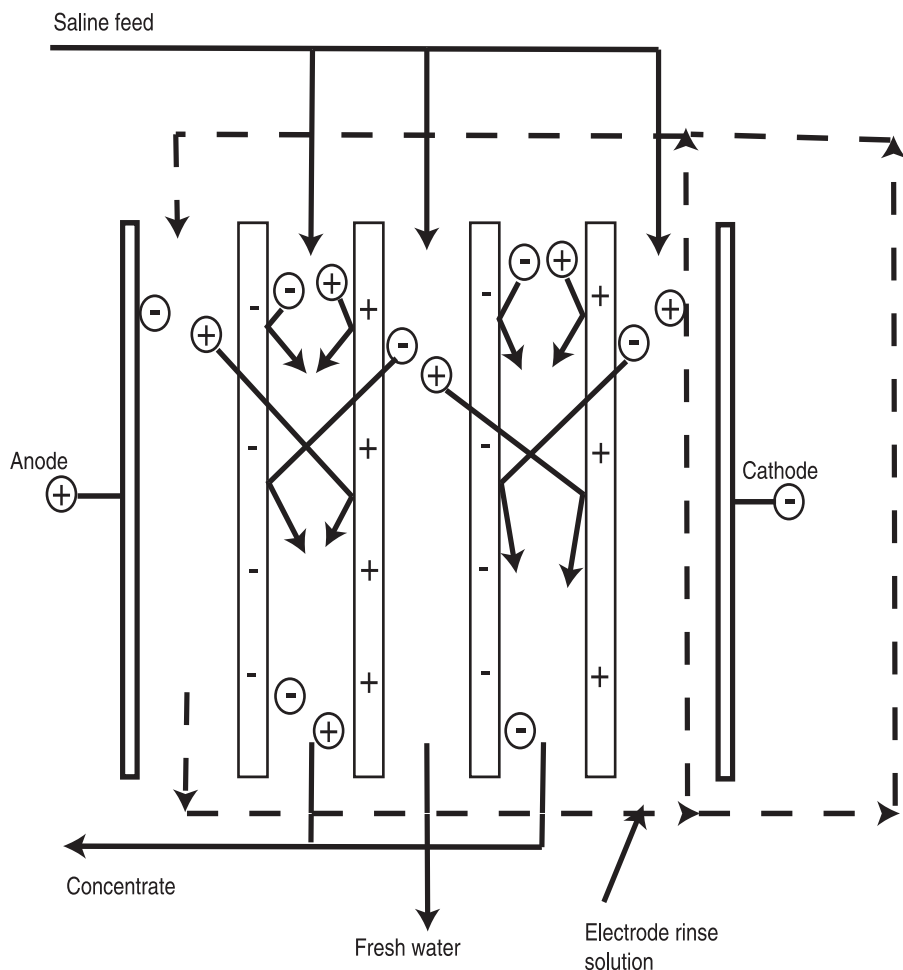


FIGURE 3—Schematic of electrodialysis process (redrawn after Seader and Henley, 1998)

### Reverse osmosis

Reverse osmosis is a relatively new process. It was first commercialized in the 1970s. In this process a high-velocity, pressurized flow of saline water passes along a membrane (Fig. 4). A spacer is placed adjacent to the membrane to ensure turbulent flow. The membrane will pass water more easily than the dissolved salts. Therefore, the water that passes through the membrane is purified. The water input into the system is called the feed water, the water that passes through the membrane is called the permeate, and the water that passes through the system without passing through the membrane is called the concentrate. The concentrate is the waste

stream. Reverse osmosis produces fresh water with a TDS content between 10 and 500 mg/L.

Various reverse osmosis membrane module configurations have been developed with the objective of maximizing the membrane area so as to maximize the volume of water treated. The two most popular configurations are spiral wound and hollow fiber. In the spiral wound configuration, the membrane and associated spacers are sealed into an envelope and then wound around a tube. In the hollow fiber modules, the membrane is in the form of hair-size hollow fibers. The flow is directed into the hollow fibers, and the permeate is collected outside the fibers.

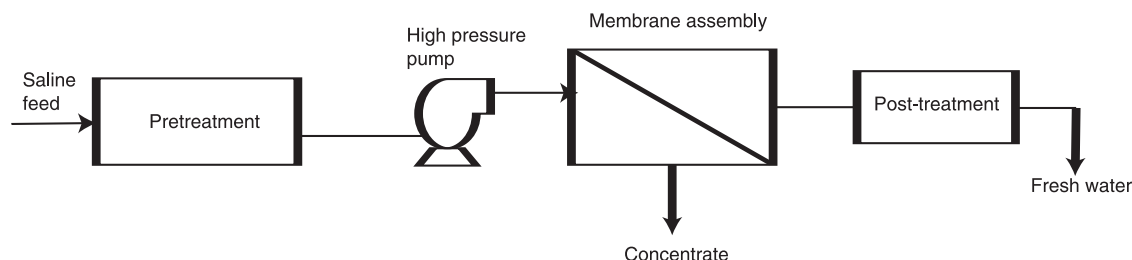


FIGURE 4—Basic components of a reverse osmosis plant (redrawn from Buros, 2000).

Reverse osmosis is generally considered viable for desalination of waters as concentrated as seawater (35,000 mg/L TDS) and, in some cases, as high as 50,000 mg/L TDS. It is a common process for desalination of seawater. However, reverse osmosis plants need to be designed for the water to be treated. As in electrodialysis, the water must be filtered and is then usually pre-treated with chemicals designed to prevent precipitation of low-solubility minerals on the membrane. Commonly post-treatment is required as well.

Tao et al. (1993) studied the possibility and economics of converting oil field produced brines to fresh water by reverse osmosis. They found that the dissolved organics in the produced water damaged polymer reverse osmosis membranes and limited their usefulness. Thus, conventional reverse osmosis may not be a suitable desalination method for oil field produced waters in New Mexico, yet it might work well for some saline ground waters.

The economic factors involved in reverse osmosis are the energy needed to pressurize the water, the chemical nature of the water (what pretreatment is needed), and the lifetime of the synthetic membranes.

### Freeze desalination

When water freezes dissolved salts are excluded from the structure of the forming ice crystals. In the 1950s and 1960s much research was done to investigate freezing desalination (Buros, 2000). It was determined that, under controlled conditions, cooling saline water to form ice crystals can desalinate seawater. Before the entire mass of water is frozen, it must be rinsed to remove the salt clinging to the ice crystals. The ice can then be allowed to melt to produce fresh water.

Several freeze desalination plants have been built, but the process has not been a commercial success (Buros, 2000). However, in the right situation, it may prove a viable desalination technique.

### Membrane distillation

Developed and introduced commercially on a small scale in the 1980s, membrane distillation has not been a commercial success (Buros, 2000). This process combines distillation and membranes. Saline water is warmed to enhance vapor production, and

the vapor passes through a membrane that will not pass liquid water. The vapor is then condensed to produce fresh water. Membrane distillation is a simple process that needs only a small temperature differential to operate. Experiments have been conducted using solar energy to warm the saline water (Buros, 2000). However, the efficiency of membrane distillation is low when a low temperature differential is used.

### Solar humidification

Small solar stills have been used for years on life rafts. On a larger scale, solar humidification units are constructed so the sun's rays heat the water, and the water vapor condenses on the glass and is collected as fresh water. These facilities are expensive to construct and require a lot of space. For every million gallons of water produced per day, 250 acres of land is needed (Buros, 2000). Thus, assuming average water usage, a town the size of Socorro, New Mexico (population about 9,000), would require a solar humidification facility that covered 356 acres.

### Environmental impact

Perhaps the largest single problem with desalination, especially in a land-locked state such as New Mexico, is disposal of desalination wastes. Every desalination process discussed so far produces a brine concentrate as a waste. This waste brine must be disposed of in an environmentally appropriate manner, and concentrate disposal should be planned for during plant design. Depending on the feed water concentrations and the desalination process, concentrate streams can have TDS from several thousand to almost 100,000 mg/L. Chemicals used as feed water pretreatment will also be present in the concentrate. These may include biocides, coagulants, and sulfur dioxide. Also, if dissolved metals are present in the feed water, there is the possibility they will be concentrated in the waste stream. In parts of New Mexico, arsenic might be concentrated in the waste stream as well.

Disposal of desalination waste streams in New Mexico will often be difficult. When the concentrate has a low TDS, surface disposal may be acceptable. Most livestock, for example, can drink waters with TDS between 3,000 and 7,000 mg/L and some livestock (beef cattle and sheep) can drink water between 7,000 and 14,000 mg/L TDS (Aquaculture Groundwater Resource Atlas). However, when the concentrate has a high TDS or contains metals or arsenic at greater than allowable concentrations, other means of disposal will be required. These might include deep well injection or evaporation with subsequent disposal of the salt. It is possible that the salt could be sold as a product to partially recover desalination costs.

### Economics of desalination

An obvious factor in desalination is energy costs. One way to reduce energy costs is to design the facility so that more than one use can be made of the same energy. This is called co-generation. Most of the desalination plants built in the Middle East and North Africa since the 1960s have incorporated co-generation to reduce costs (Buros, 2000). Most of these facilities produce both fresh water and electric power.

Factors that affect desalination economics include: necessary production capacity, process type, plant location, feed water quality, feed water gathering costs (wells, etc.), labor, energy costs and availability, concentrate disposal, plant reliability, and cost of financing. The cost of producing fresh water from seawater (35,000 mg/L TDS) is usually three to five times the cost of producing fresh water from brackish water (less than 10,000 mg/L TDS; Buros, 2000).

Data suggest that, in 1999 dollars, the average cost in the United States for brackish water desalination systems in the 4,000–40,000 million gal per day range is from \$1.00 to \$2.40 per 1,000 gal (Buros, 2000). These average costs include capital recovery. seawater desalination plants in the United States with capacities between 4,000 and 100,000 million gal per day cost between \$0.80 and \$12.00 per 1,000 gal.

### Research horizons

"Everything that can be invented already has been." This statement was released by the United States Patent Office in 1899. This was before the invention of solid state electronics, the computer, television, reverse osmosis, membrane distillation, the cell phone, and a host of other important items we use every day. Fortunately, research into solving desalination problems is ongoing and will undoubtedly see both successes and failures in the next decade or two. Other than development of an inexpensive energy source, important areas for desalination research are: 1) improvement of existing desalination technology, 2) development of new desalination methods—hopefully ones that do not have a brine waste stream, and 3) development of methods for reducing the brine waste stream from both existing and future desalination processes.

One such research project is underway at New Mexico Tech and is being conducted in the Petroleum Recovery Research Center and the New Mexico Bureau of Geology and Mineral Resources. This project is investigating the use of natural clays as reverse osmosis membranes for desalination of oil field produced waters.

Another interesting project with implications for small-scale desalination for isolated ranches and other facilities in parts of New Mexico is wind-powered reverse

osmosis. A prototype system constructed on Coconut Island, off the windward coast of Oahu, Hawaii, used a windmill to power a pump and a Filmtec ultra low pressure membrane module and produced 0.7 gal per minute of fresh water from a brackish feed water with a TDS of 3,100 mg/L (<http://www.hawaii.edu/wrrc/desalination.html>). This is approximately enough water to supply a family of four by current U.S. standards. Such installations may prove useful in rural New Mexico.

### Summary and conclusions

Because of its semiarid climate and limited available fresh water, New Mexico will need to apply desalination technology to purify available saline ground waters to provide fresh water for its citizens. In New Mexico much of the population is concentrated in the larger cities, and the rest of the state is essentially rural. Large-scale desalination plants can be used to provide fresh water to populated areas. However, the rural population of New Mexico needs desalination technologies that can be used for small communities and at isolated ranches. Desalination installations for small communities and single-family dwellings need to be designed to operate automatically and with a minimum of operator contact.

Large-scale desalination facilities provide economy of scale and typically can produce fresh water at lower costs than small-scale installations. Desalination costs for the larger installations generally range from \$1.00 to about \$12.00 per 1,000 gal, depending on the nature of the saline water and the desalination method chosen. Smaller desalination units may have significantly higher costs per 1,000 gal.

Currently, there is no "best way" to desalinate saline waters. Rather, the method chosen depends on the water chemistry and available resources. Electrodialysis and reverse osmosis are most often used to desalinate brackish waters. Distillation and reverse osmosis are most often used to desalinate seawater or brines containing more than 10,000 mg/L TDS. However, conventional reverse osmosis is currently limited to waters with TDS concentrations of probably no more than 50,000 mg/L TDS and perhaps less, and reverse osmosis does not work well on oil and gas produced waters that contain hydrocarbon compounds.

More research into both improving existing desalination methods and in developing new, effective, and economical methods is needed for desalination to be successful in more than a few limited locations in New Mexico. Desalination research is ongoing and is reasonably well-funded by the federal government. The authors have no doubt that, given time, better desalination methods will be developed and applied in New Mexico and that

production of fresh water by desalination of saline waters will benefit the economy of the state.

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