DEVELOPMENT AND UTILIZATION OF SALINE GROUND WATER RESOURCES

David W. Miller*

This afternoon I plan to discuss the role that local saline ground water resources will play when the costs of converting these waters become competitive with the costs of importing fresh water from distant sources. There has been much discussion in newspapers and magazines that any program for saline water conversion will necessarily involve the construction of very long pipelines. These pipelines would either bring the untreated salt water to inland conversion plants or would distribute fresh water from coastal conversion plants. This is a misconception that should be corrected.

In the first place, costs for building pipelines for water transmission and pumping water over distances of hundreds of miles are exhorbitant and probably always will be. Except for only a few large cities, pipelines more than a few miles in length are uneconomical. This has been shown by the fact that many towns only a few miles from the tremendous fresh-water supply of the Great Lakes suffer water shortages year after year. If it were economical to build long transmission lines for water supply all over this country, there would be little need to discuss saline water conversion because we already have enough fresh water stored in many parts of the nation to satisfy all of our demands. Thus, inland areas which now lack adequate fresh water will undoubtedly have to resort to converting local saline water supplies if the costs become reasonable.

Where, however, are saline waters to be obtained in these inland water-short regions? One logical source, whose potential value has not been fully appreciated, is the vast reserve of saline waters contained in extensive geologic formations in many parts of the country. Saline ground water, because of its abundance in so many critical areas, offers the distinct advantage of being available for conversion directly at or near points of demand.

Furthermore, energy costs in many of the conversion processes are proportional to the mineral content of the water. For this reason, increasing interest is being shown in the demineralization of "marginal" saline waters rather than sea water or brine. Our underground reservoirs contain the most important reserve of slightly saline and brackish waters and this potential resource may eventually be utilized in lieu of sea water even in coastal areas.

What is saline water? This question is a great deal more complex than it sounds, for there are many different standards and definitions

*Consulting Ground-Water Geologist with Geraghty, Miller and Hickok, and Chairman of Ground-Water Committee, Water Resources Council, New York City, New York

for salinity, depending upon the contemplated use of the water. For example, the U.S. Public Health Service has established certain limits on concentrations of chemical constituents which have been widely adopted for public supplies in general. They recommend that the content of dissolved solids should not exceed 500 ppm and chloride 250 ppm in water for drinking purposes, except in areas where such water is unobtainable. Actually, however, most people cannot taste chloride unless the concentration is higher than 350 ppm. In fact, some public and rural supplies contain more than 500 ppm of chloride and 3,500 ppm of dissolved solids and have been used for many years with no apparent harmful effects to the consumers.

A completely different set of quality standards has been applied to irrigation waters. In this case, the tolerance for salinity, and sodium chloride in particular, depends upon the characteristics of the soil, the types of plants involved and many other factors including drainage and climate. Water containing less than 700 ppm of dissolved solids can be used under almost any conditions for irrigation but in certain areas and especially in the southwestern United States, water containing several thousand ppm is being applied to crops with some degree of success.

Industrial processes, on the other hand, demand water of very high quality. For example, the production of rayon requires water containing less than 100 ppm of dissolved solids. Tolerances for the chemical industry in some cases are even more severe, and in most paper-making processes, chlorides should not exceed 50 ppm and dissolved solids 200 ppm. Consequently, it is often necessary for an industrial plant to chemically purify water which by other standards is considered fresh.

Areas may be rated by the Public Health Service and other governmental agencies as having a surplus of water, and this may be perfectly true when only use for public supply is being considered. However, in view of the strict chemical tolerances imposed by certain manufacturing processes, these same areas may be regarded as deficient in water supply by industry.

Thus, the terms "fresh water" and "saline water" may take on different meanings to the farmer, the industrialist, and officials concerned with public water supply. This ambiguity must be recognized in planning regional water-supply developments, for the past, money has been spent on the construction of water supply facilities and treatment plants which have benefited only a small portion of the major users.

Usually, the term "slightly saline" designates water with a dissolved solids content of less than 3000 ppm, and brackish or moderately saline is used to designate a range of 3000 to 10,000 ppm. The average salt content of sea water is 35,000 ppm and waters are considered "saline" when the dissolved solids content falls between 10,000 and 35,000 ppm. Waters above 35,000 ppm are referred to as brines.

Waters covering the full range of salinity outlined in the categories above can be found in many of the ground-water reservoirs of the United States, and their origins can be attributed to several geologic and hydrologic factors. Many of the sediments which now make up the geologic formations of the world were originally deposited in salt-water seas. After these ancient seas had retreated, the sediments were subjected to various processes including consolidation, folding and faulting. Nevertheless, some of these formations retain the original salt water in which they were deposited. Water which has remained in sediments since their deposition is referred to as connate. Most of the sediments containing connate water are either deeply buried or else contain structural and stratigraphic traps that have confined the original water. Other sediments, which at one time were completely saturated with salt water, have only been partly flushed by fresh-water recharge from precipitation. For example, some of the sand and gravel aquifers of the Gulf coastal region have emerged above sea level only recently, geologically speaking, so that the period of exposure to fresh-water recharge has not been very great. In these aquifers, brackish and saline ground water may be found far inland from the coast at relatively shallow depths.

Many geologic periods have included epochs when salt was precipitated from evaporating waters in closed basins, forming beds of evaporites such as salt, gypsum and anlydrite. Some of the geologic formations which now crop out at land surface were formed in this manner. Also in many of the existing closed basins of the west, evaporation and transpiration by plants has tended to concentrate salts in the shallow water-bearing beds. Streams flowing over these beds dissolve the salts and if water from these streams percolates into the ground, it becomes saline ground water. Where salt beds are buried, slowly moving ground water may dissolve the salts and carry them some distance away.

The shoreline areas in most parts of the United States are underlain by natural saline ground water bodies whose occurrence and extent are due to a hydraulic balance between discharging fresh ground water and the adjoining salty surface water bodies. Generally, the saline ground water occurs in the form of wedges some of which extend inland for many miles in the deeper formations. The natural saline ground waters underlying the coastal plain from Long Island to Florida originated in this manner.

In many parts of the United States, encroachment has caused braskish and saline ground waters to move some distance inland from the shoreline. This encroachment into fresh-water aquifers has been caused by a lowering of the fresh-water head resulting from pumping, drainage, or drought. For example, heavy pumping in the coastal basins near Los Angeles, California, has lowered water levels more than 50 feet below sea level, has reversed the natural seaward direction of ground water flow, and has caused sea water to move into the ground water reservoir.

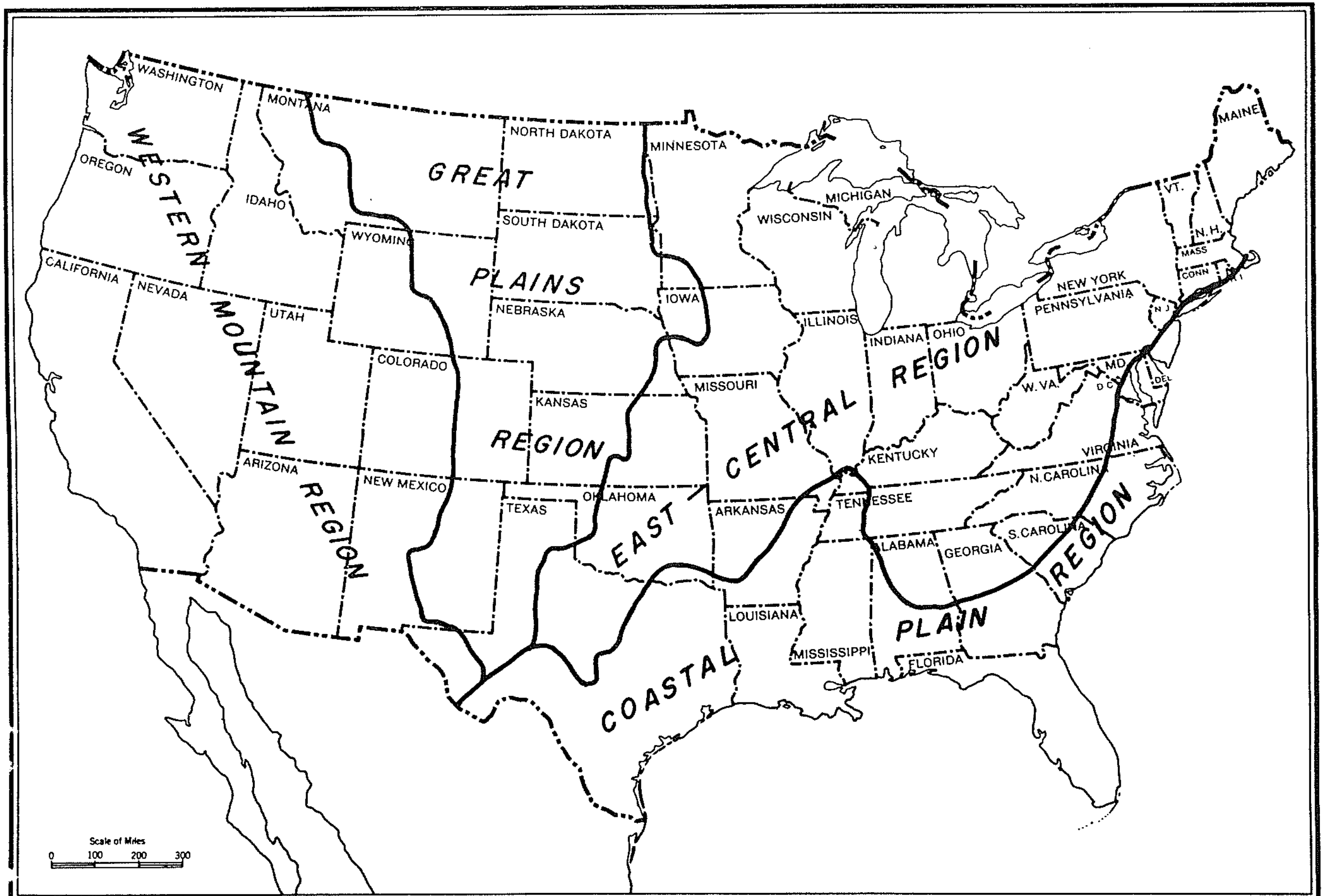
Salt-water encroachment at Miami, Florida, on the other hand has been caused mainly by the construction of drainage canals. Discharge of fresh ground water into these canals has lowered the head in the principal aquifer by removing stored fresh water. Also, during dry periods the canals have carried salty surface water from the ocean inland for several miles and have allowed this salty water to leak into the ground water formations.

Salt-water encroachment has also occurred in areas where fresh ground water bodies are directly or indirectly in contact with connate saline ground-water bodies. This type of encroachment has affected large areas in the western United States, including the San Joaquin Valley in California and parts of New Mexico and Texas. Heavy pumpage and drought conditions have caused connate water to move vertically and horizontally into fresh-water aquifers, sometimes through beds which previously had been thought to be relatively impermeable. Fresh-water heads have been lowered to such a degree in these critical areas that the problem of contamination by saline waters has become severe.

From the foregoing discussion on occurrence, we can understand why the United States has reserves of salty ground water ranging in quality from slightly saline to brine. Because my time is limited today, I will not attempt to do more than briefly summarize some of the findings of an inventory of saline waters of the United States conducted by the U.S. Geological Survey, the results of which were recently published as Water Supply Paper 1374. The major ground water regions that will be discussed are shown in figure 1. Both fresh and saline ground water resources will be outlined for each area in order to give a more complete picture of the ground water situation.

The Atlantic and Gulf Coastal Plain region has the greatest reserve of fresh ground water in the entire country, but also includes many areas of serious overdevelopment. In general, slightly to moderately saline ground water is available in large quantities from the thick and permeable sand, gravel and limestone formations in many parts of the region. A narrow belt along the coast from New England to Texas, almost the entire States of Louisiana and Florida, and large parts of Alabama, Mississippi, Arkansas and Texas have in addition to large supplies of fresh ground water, tremendous quantities of saline water at moderate depths.

In the east-central region, the principal sources of fresh water are the glacial sand and gravel deposits north of the Ohio River, and extensive sandstone and limestone formations where they occur at shallow to moderate depths. The unglaciated part and to some extent, the glaciated part of the region are areas of barely adequate ground water supply, especially in some industrial localities where existing supplies have been overdeveloped. Except in the New England States, the Blue Ridge and Piedmont provinces, and those parts of Minnesota and Wisconsin that are underlain by crystalline rocks, moderate to large quantities of saline water are available from the sedimentary rocks.



GROUND-WATER REGIONS OF THE UNITED STATES

In the absence of more suitable supplies, many towns and villages in parts of the Mississippi Valley presently are using slightly saline ground water.

In the Great Plains region fresh ground water supplies are generally deficient, except in some areas underlain by unconsolidated and semi-consolidated sands and gravels. The most extensive aquifers are the Dakota sandstone and the Ogallala formation of the southern half of the region. Both formations yield water that is highly mineralized. The Ogallala is underlain by older formations which contain saline water at moderate depths. In the Roswell artesian basin of southeastern New Mexico, limestone is the source of large quantities of water, much of which may be classified as slightly saline to brackish.

In the Western Mountain region, which occupies approximately the western third of the United States, the principal sources of fresh ground water are the lava flows of the Columbia Plateau, the valley-fill deposits of the Basin and Range and Pacific Mountain provinces, and the glacial deposits of the Pacific Northwest. The southern half of the region is an area of perennial water shortage, a condition which has been aggravated by recent increases in ground water pumpage for municipal and irrigation purposes. In many parts of the region, surface water is fully appropriated, and fresh ground water is completely developed or overdeveloped. In the Plateau province which extends from Montana to Arizona, slightly saline water is present in all the formations at moderate depths. Slightly to moderately saline ground water also occurs in many of the closed basins of New Mexico, Utah, Nevada, California, and Arizona. Ground water supplies of the Colorado Plateau are generally of good quality; however, fresh to moderately saline water is produced from several aquifers which underlie much of the region.

The significant conclusion gained from this survey is that supplies of saline ground water are available in most parts of the United States. These saline supplies have a great potential value for demineralization particularly in heavily populated and high industrialized areas where fresh-water resources have been depleted or have become contaiminated. In such places, the demand for good water already exists, so that the greater costs of saline water conversion may soon be acceptable. Therefore, we may see some of the first full scale saline-conversion plants constructed in areas where once-ample supplies of fresh water have deteriorated over the years.

In many parts of the country, saline ground water will be the only readily available source of water for conversion. Undeveloped sources of fresh water are becoming more remote and the rising cost of constructing pipelines to transport this water is approaching some of the predicted capital costs for saline-water conversion of local supplies. This is particularly true in the southwest where few untapped sources of fresh water remain. Small supplies of up to about ten mgd (million gallons per day) will especially require on-the-spot water for demineralization because of prohibitive transmission costs. Thus, local ground water supplies which up to now have been of below standard quality will become increasingly important.

Even in coastal areas with an unlimited abundance of sea water nearby and in other places where brackish or saline river waters are readily available, ground water may have distinct advantages over surface water as a source of supply for demineralization. One principal advantage is that ground water is usually free of turbidity and suspended matter, thereby reducing initial treatment costs. Also important is the fact that temperatures and chemical quality characteristics of ground water are not subject to the wide variations commonly observed in surface waters. For some demineralization processes, these stable qualities would simplify plant operation.

However, the most significant reason for considering saline ground water for conversion in many parts of the country is it's low content of dissolved solids as compared to sea water. Conversion costs in some processes are directly related to the dissolved solids content of the raw water and consequently the lower the salinity the cheaper the operation. In the ion exchange method, for example, the cost of converting water containing 3500 ppm of dissolved solids is estimated to be only about 20% of the costs of converting ocean water.

Therefore, whenever a salt-water conversion plant is to be constructed, all potential sources of water supply, both surface and ground water, should be investigated as to availability, dependability and quality. Even on small islands completely surrounded by salt water, some slightly saline and brackish ground water is usually available, often in quanities entirely adequate to satisfy the needs of a conversion plant.

This brings us to the problems involved in actually developing a ground water supply for use in the saline-water conversion plant. As is required in any new ground water development, a thorough geologic and hydrologic investigation should be made before the well facilities are designed. The purpose of such investigations is to determine the hydraulic characteristics of the water bearing formations, to provide data showing the extent and degree of interconnection of these formations, and to establish the maximum rates at which pumping can be maintained without depleting the ground water supply or lowering water levels severely. These studies become even more essential when desalinization is being considered because capital costs for a conversion plant are so much larger than those for normal water supply facilities, and economic considerations dictate that the source of water be dependable.

Aside from the usual considerations involved in developing ground water supplies, certain other specialized problems may arise in pumping brackish or saline ground water. For example, this pumping may directly affect associated fresh ground water bodies. In some areas where encroachment is occurring, the effect will be beneficial because the withdrawals of saline ground water will tend to equalize pressure differences and either retard or prevent further contamination of the fresh-water unit. However, in other areas, where the storage capacity of the saline ground water aquifer may be small and recharge possibilities limited, the pumping of saline ground water may induce fresh water to move toward the wells and thus deplete the fresh water supply. Here again, preliminary hydrologic investigations before construction of the installation and proper management after development should provide adequate warning of any such dangers.

Another problem that may arise in the pumping of brackish or saline ground water supplies is corrosion of equipment in wells. Special pumps, screens and other materials have already been designed for use in wells pumping brackish or saline ground water, but initial and replacement costs are sometimes high. However, improvements are being made and this should be less of a problem in the future.

The disposal of brine residues from conversion processes may be a problem in some areas and may significantly increase the costs of conversion. The success of many of the methods proposed for disposal such as injection into underground strata or discharge into pits and basins will depend on an adequate evaluation of local ground water conditions. Generally, the requirements for an injection system are properly constructed wells, elimination of suspended solids and chemical compatibility between the injected water and natural ground water. With regard to the recharging of brine residues into pits and basins, care must be taken to guard against contamination of local fresh ground water supplies. Because ground water can move great distances in certain types of aquifers, such as those composed of limestone or fractured shales, a thorough knowledge of water-table gradients, effects of nearby pumping, and infiltration characteristics of the surficial materials should be gained before waste pits or basins are located. In some cases, the underground migration of contaminants has affected nearby wells used for potable supplies and has resulted in serious problems.

In the past, studies of our ground water resources have, of course, stressed the availability of fresh water. However, now that we have entered the era of saline water conversion, we should be adequately prepared with regard to data on the location, quantity and quality of our saline ground water reserves. The U.S. Geological Survey has already published several reports on saline water resources. One, which I have already mentioned, is a generalized reconnaissance on the entire United States; others describe the occurrence of saline water in various states including Texas and New York. The Geological Survey is also conducting studies of a similar nature in North Dakota, New Mexico and Oklahoma. Although these general reports are invaluable, they can not provide all the data needed with regard to the development of saline water. Water supply needs are spot problems and the feasibility of converting saline water will depend upon conditions at the point of use. Therefore, studies will have to be made at individual sites with regard to water source conditions, power costs, waste disposal and the various other factors involved in saline water conversion.

Large quantities of saline ground water are already being used for industrial cooling and agricultural purposes. Thus, saline ground water resources are an important part of our national water picture. With the desperate need for new sources of potable water, and the anticipated decline in costs of desalinization, saline ground water reserves will become even more important and will play an increasing role in future programs for water supply development and management.