CRITERIA FOR THE IDENTIFICATION OF POTENTIAL SITES FOR IRRIGATION WITH SALINE WATERS IN NEW MEXICO

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ABSTRACT

New Mexico is an arid state with major groundwater resources and a very large land-area. Approximately 30 to 40 percent of the state's land-area would be suitable for irrigated agriculture if water were available. The problem is that 90 percent of the state's groundwater reserves are characterized as "saline".

Under the right conditions, saline water can be used in irrigated agriculture as an alternative to fresh water, as a supplement to a fresh water supply or in conjunction with better quality water. This last area holds the greatest promise for New Mexico. The combined planned and scheduled use of saline and fresh waters to irrigate common regional crops shows promise. This report is directed at identifying criteria for the selection of appropriate sites. The Tularosa Basin is used as an example area to test the criteria developed with appropriate land areas identified where the conjunctive use of fresh and slightly saline water is possible. Several other areas in the state also are identified where conjunctive use probably can be conducted without severe adverse environmental effects.

Key Words: saline water, freshwater, conjunctive use, environmental constraints, Tularosa Basin, Estancia Basin, Roswell-Artesian Basin

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INTRODUCTION

The Problem

A significant portion of the groundwater resources of New Mexico remain unused due to high salinity levels. Only a fourth of the state's 20 billion acre-feet of groundwater is classified as fresh or slightly saline (U.S. Department of Interior 1976). The remaining 15 billion acre-feet is characterized as moderately saline, to very saline, or brine. The potential use of this huge volume of water is largely unknown and much of the water is so saline that there has been little effort to utilize these aquifers for agricultural production.

Recent research by O'Connor (1980) focused on the range of the salinity of irrigation waters that can be utilized in traditional crop production. This research suggests that fresh water could be supplemented by saline water to irrigate crops while maintaining yields. Farmers in the Mesilla Valley in New Mexico now use shallow irrigation wells to supplement their surface supply from Elephant Butte Reservoir. The total dissolved solids content in this shallow aquifier is high in places with virtually all of it falling into one of the saline water classifications (Hernandez 1980). This type of supplemented irrigation is practiced in other places in New Mexico and West Texas.

At the other end of the spectrum, the sole use of saline waters for agricultural purposes has been considered. Good progress is reported in the literature on increasing the salt tolerance of common crops and on identifying native plants that demonstrate salt resistance and that have other characteristics that may be commercially exploited (O'Leary 1984).

There is a third possibility, the conjunctive use of fresh and saline waters. Lansford et al. (1986), in a companion study to this report, proposes the more extensive and well planned use of saline water in conjunction with fresh water. A more complete discussion of conjunctive use is provided later in this report.

The extent to which saline water can economically serve as an alternative to, in conjunction with, or supplemental to fresh water has not been thoroughly investigated. Sites where saline water could be employed in one of these three forms of irrigation have not been identified. The contraints that will impact on the agricultural use of poor quality waters are also unknown. The practical, large-scale use of saline water in New Mexico could be enhanced by the development of site-selection criteria. Then, an areal identification model based on exclusion contraints would be used to select geographic locations in the state where conditions are most favorable for irrigated agriculture using water with a relatively high total dissolved solids (TDS) content.

Rationale for the Study

Because New Mexico is an arid state with an abundant supply of saline groundwater, it is logical to try and locate those areas in the state that can be irrigated with saline groundwater. The rationale for this effort can be summarized as the:

1. Lack of unappropriated fresh water supplies that can be economically used for irrigated agriculture;
2. Vastness of the New Mexico lands that could be put to higher productive use if water were available;

3. Need for America to identify additional agricultural lands that may be farmed at a future date as irrigated acreage declines in other parts of the country;
4. Need to supplement and conserve fresh water to meet industrial and municipal demands with the limited supply found in New Mexico;
5. Need to use some of the saline waters of the state in order to prevent degradation of fresh water supplies by encroachment; and
6. Need to utilize all of the natural resources of the state to the extent possible subject to environmental and economic contraints.

Concept of Conjunctive Use

The term "irrigation with saline water" is intended to include the three possibilities:

1. The sole-use of a saline water as a source of supply to grow common regional crops or to grow plants that are halophytic;
2. The conjunctive use of fresh and saline waters to grow typical regional crops; and
3. The unscheduled periodic use of a saline water source to supplement an inadequate freshwater supply.

The first and last of these three are common concepts now practiced in the Southwest. The conjunctive use of a freshwater and a saline water source is a newer approach that has been tried on experimental plots in the Imperial Valley in California (Valentine 1984).

Lansford, et al. (1986) have proposed the more rigorous, programmed conjunctive use of fresh and saline waters to irrigate crops common to the region. The Lansford team of agricultural economists and engineers has developed a mathematical model for the scheduling and conjunctive use of supplies with widely differing dissolved solids contents (1000 mg/l and 5000 mg/l TDS). Under their approach, the total volume of water applied would be greater than that for conventional irrigation with fresh water. Depending on the crop involved, the area soils, the precipitation, and evapotranspiration characteristics, the volume of fresh water required could be reduced and partially replaced with a larger volume of saline water while still maintaining crop yields at or near those obtained from fresh water alone. For some crops it may also be possible to obtain increased yields by using greater volumes of water from combined fresh and saline sources.

In the Lansford, et al. (1986) conjunctive-use scheduling model, a positive salt balance will develop in the plant soil system when the salinity of the supply and/or the rate of application of water fails to flush sufficient salt from the root zone. This buildup in salinity, if allowed to continue, will result in a decrease in plant transpiration that will lead to a decrease in yield relative to non-stressed conditions. The irrigation scheduling model is designed to predict this situation and to respond by: 1) requiring an increase in the saline water application rate so as to increase the leaching factor (LF), or 2) calling for a fresh water irrigation application in order to dilute the root-zone salinity.

This conjunctive-use approach has the following advantages:

1. Reducing an irrigator's dependency on a fresh water source characterized by large year-to-year variations in supply;
2. Reducing the total fresh water demands making it available for use in other farming operations;
3. Maintaining productivity at or near fresh water levels and, for some crops, an increase in yields may be obtained;

4. Maintaining and, in some cases, increasing total net benefits while using less freshwater; and
5. Using a saline water source that may otherwise degrade a freshwater supply.

Current Use of Saline Water for Irrigation

A few farming operations in New Mexico now use saline water in conjunction with a fresh water supply. Some of these farms are found in the lower portion of the Mesilla Valley, in the Carlsbad area and in the Roswell Artesian Basin. By employing the more sophisticated techniques suggested by the Lansford team (1986), it is conceivable that more extensive use of saline waters in true conjunctive use could result.

Some slightly saline waters (1000 mg/l to 3000 mg/l TDS) are now used as the sole-source for irrigation in a number of major river basins in the West Texas-New Mexico region. Locations in New Mexico where 1,000 to 3,000 mg/l TDS waters are used as the sole source for irrigation are parts of the Tularosa Basin, the Carlsbad Irrigation District, the Estancia Basin, the Northern extension of the Roswell Artesian Basin and the Crow Flats area in Otero County.

Moderately saline water (3,000 mg/l to 10,000 mg/l TDS) is also used by a few farmers in some of these same regions to supplement fresh water supplies. While there may not be a significant increase in the acreage irrigated with these poorer quality waters in the next decade, a number of other factors could lead to greater acceptance and application. These are

1. Progress being made in the development of salt tolerant crops that will result in greater yields and a greater range of choice in crop selection and rotation;

2. Progress being made in implementing farming practices and management that will allow the use of waters with higher concentrations of dissolved solids; and
3. The availability of sophisticated irrigation scheduling models that permits the conjunctive use of saline and fresh waters.

It should be noted that U.S. Environmental Protection Agency's 1984 groundwater strategy and its groundwater injection control program and New Mexico's water statutes call for the protection of the existing quality of groundwaters where the TDS content is currently equal to or less than 10,000 mg/l. The implication of this action is that both the state and federal government anticipate that waters with dissolved solid contents up to 10,000 mg/l may be used in the future as potable sources of supply. Saline resources in this range also deserve long-term protection for use as potential sources for irrigated agriculture. This study, however, will focus on groundwaters with TDS contents between 1,000 and 5,000 mg/l as being saline waters that are most likely to be developed for agricultural purposes in the near future.

CRITERIA FOR SITE-SELECTION FOR SALINE WATER.IRRIGATION

To answer the question of how to run a successful farming operation in an arid area using saline water, several factors must be considered, including the normal constraints of farm practices and economics, and general welfare, water conservation and environmental concerns. The following subsection provides three lists of criteria used to determine the success of saline irrigated farming. In the succeeding sections, some of the more important criteria will be discussed in greater detail. It should be noted that the same site characteristics (such as the quality of farm soils) may appear in more than one list because of its multifaceted impact. Those criteria that could be expected to be site constraining have been noted with an asterisk (*).

Crop Production Criteria

1. Site soils
    - *a. Deep surface and subsoil (60 to 80 inches),
    - b. Texture of fine sandy-loam or loamy-sand,
    - c. Good soil fertility and soil tilth,
    - *d. Well drained soils that are moderately permeable to air and water,
    - e. Very few rock-fragments greater than three inches,
    - f. Moderately alkaline soils derived in part from calcareous materials,
    - *g. Some, but low plasticity with little potential for shrink and swell,
    - h. Pre-irrigation soil salinity (expressed as electrical conductivity) of less than 4 mmhos/cm in the saturated soil extract from the root zone is desirable, and
    - i. Soils with an organic matter about 0.5 to 1 percent.
2. Site water-quality
    - a. Fresh water source available for germination, if possible,
    - b. Fresh water source available for conjunctive use, if possible,

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NOTE: *The asterisk is used to indicate criteria that are considered to be constrainting in the selection of a site for irrigation with saline water.

*c. Salinity not to exceed 5,000 mg/l TDS,

d. Preferable cations are calcium and magnesium and low in sodium,

e. Preferable anions are carbonates, bicarbonates and sulfates, but not chloride,

f. Low or no residual sodium carbonate, and

g. Low sodium-adsorption ratio, and

h. Absence of specific ions that may be toxic to plants, wildlife and fish.

3. Site location with a significant effective precipitation is desirable.

4. A freeze-free season of more than 200 days is desirable.

Economic and Farm Efficiency Factors

1. Area water supply

   a. The transportation of freshwater to farm-sites by gravity is desirable,

   *b. The depth to the saline water source should not exceed 100 to 150 feet unless the aquifer is under artesian pressure,

   *c. The transmissivity of the saline water aquifer system should be great enough for wells to yield at least 500 gallons per minute (gpm) while limiting the drawdown in the well to not more than 50 to 100 feet when the well is pumping,

   *d. The total pumping lift should not exceed 250 feet, and a total well depth of great than 350 to 400 feet is not desirable,

e. The thickness of the aquifer should be at least 200 feet unless under artesia pressure,

*f. The water supply should be sufficient to provide field deliveries of a minimum of 5 gpm per acre irrigated; a 500 gpm well would be able to provide water for about 80 acres and not more than 100 acres (ideally, the supply should provide 10 gpm/acre irrigated),

g. A long conveyance systems that requires ditch lining or a pipe-line to prevent losses should be avoided, and

h. A highly efficient pumping plant and water system is necessary; the use of high capacity wells and a surface storage basin is desirable to allow for nighttime pumping when lower power-rates are obtained.

2. Farm-size, terrain and location

a. The farm-size for a full-time operation should be on the order of 400 to 500 acres,

*b. The area selected should have relatively low-cost, irrigatable land available in unit sizes of 400 to 500 acres that can be farmed as a single operation,

c. Land slope should be limited to 1 to 3 percent and areas with profiles other than flat or gently undulating should be avoided,

d. Site terrain should allow for the application of alternative farm practices,

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NOTE: *Indicates criteria that are considered to be site constraining.

e. Farm areas should be relatively near potential markets and labor sources to permit the cultivation of labor intensive crops, and

f. Farm areas should be near major natural gas transmission pipelines or near high-voltage power lines, if possible.

Public Welfare, Conservation and Environmental Concerns

*1. Sites for saline irrigated farms should not be located over shallow water-table aquifer systems that would suffer serious adverse water quality changes because of percolation of saline irrigation return-flows,

2. Sites should be selected in areas where location and present quality of the groundwater system is not attractive for uses other than irrigated agriculture,

3. Sites should be selected in areas where there is now a problem with the management saline waters that are causing a significant degradation in the quality of a fresh water source (for example, sites should be selected to use power-plant cooling water, irrigation tail-water, irrigation drain return-flows, or where confined saline zones that are encroaching on a freshwater aquifer)

4. Sites that are already farmed and where a forced reduction in the use of freshwater has occurred would be ideal,

5. Sites with high recreational, water fowl or wildlife habitat potentials should be avoided,

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NOTE: *Indicates criteria that are considered to be site constraining.

6. Sites with soils that have a high erosion potential are undesirable, and
7. Sites that are now farmed with fresh water and where a saline water source is also available, would be ideal as they could allow the conjunctive use of water from the two sources and the application of greater amounts of water to a part of the farmed-area, the farming of additional acreage, or multiple cropping within a year.

METHODOLOGY EMPLOYED TO IDENTIFY POTENTIAL SITES

The initial methodology used to identify potential farm-sites was to employ a computer graphics system to delineate areas from a series of maps that meet one or more acceptability criteria for the use of saline water for irrigation. These maps were taken from the 1976 assessment of New Mexico's water resources by the Department of Interior (DOI). Modifications are shown in figures 1 through 5.

These maps provide information on the areal extent of regions where fresh water and saline water of various classifications are available. However, the maps do not provide information such as the depth to groundwater zones other than that of the surface or upper aquifer, the potential yield of wells in lower saline aquifers, or the quality of overlying formations. Detailed data of this type can only be obtained for specific geologic units from studies of the hydrogeologic systems. Soil quality, land area, land ownership, precipitation and potential evaporation information are available in the map format. Again, however, detailed local investigations are the only feasible means of obtaining adequate soils data.

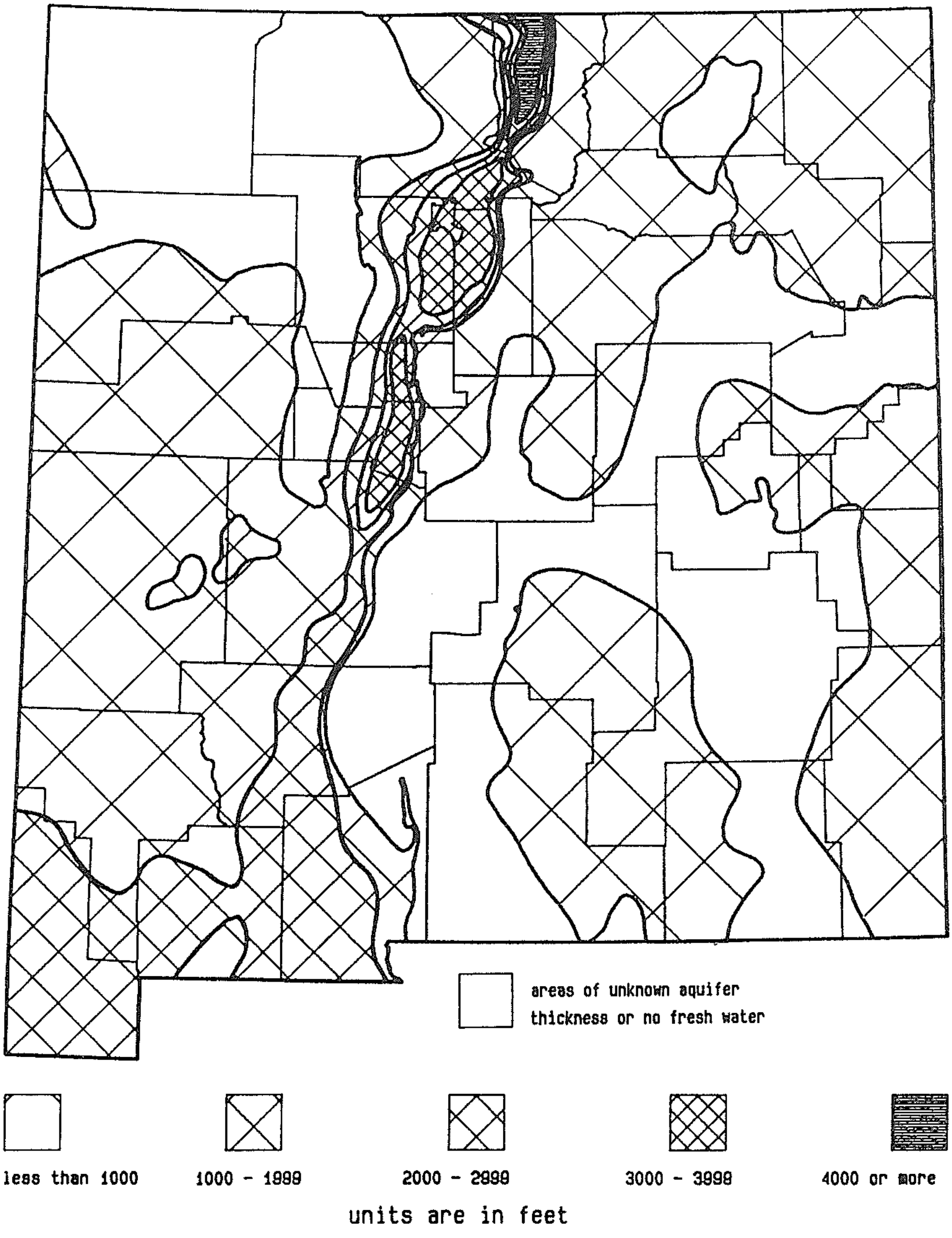

FIG. 1. ESTIMATED THICKNESS OF AQUIFERS WITH FRESH GROUNDWATER

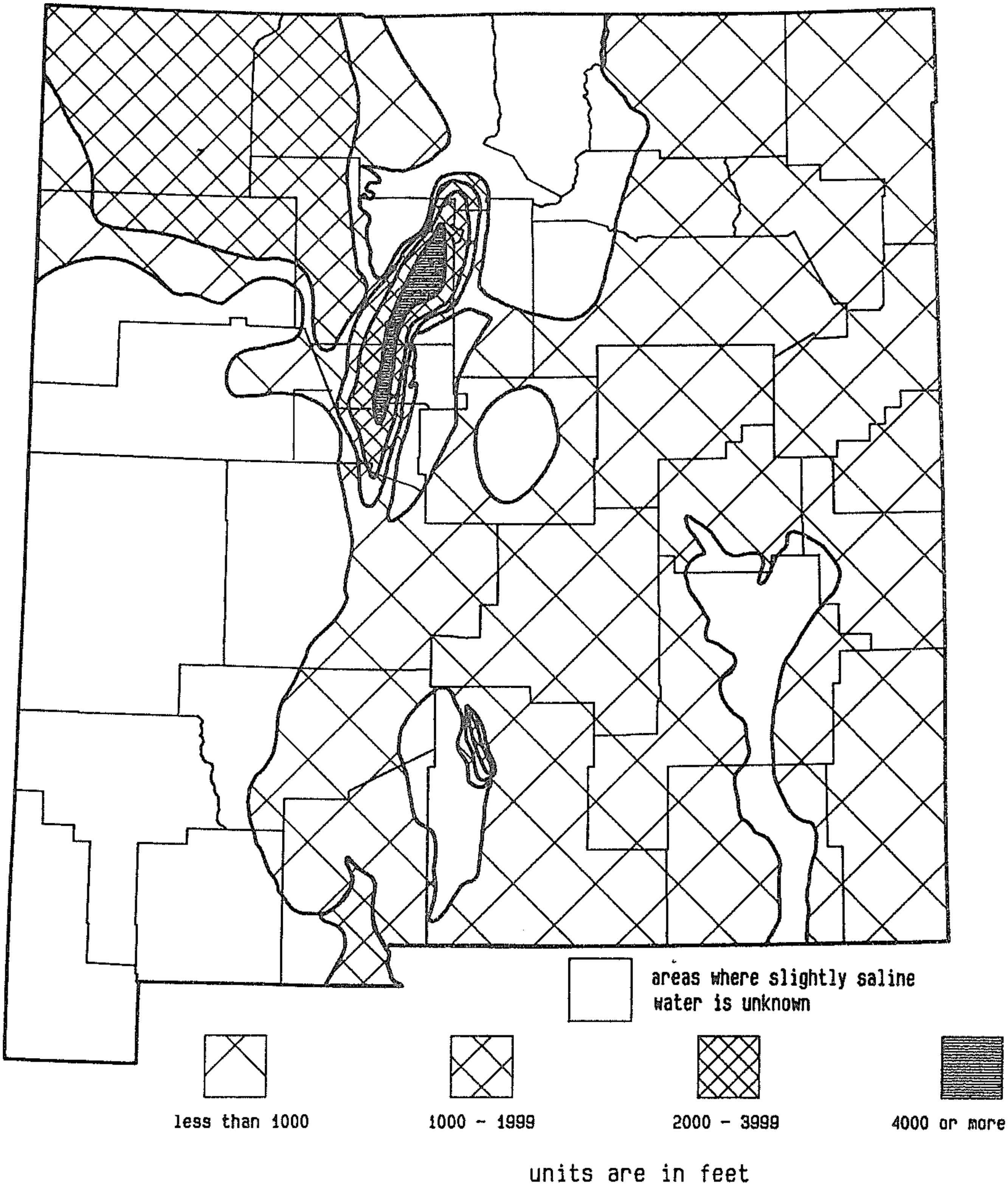

FIG. 2. ESTIMATED THICKNESS OF AQUIFERS WITH SLIGHTLY SALINE GROUNDWATER

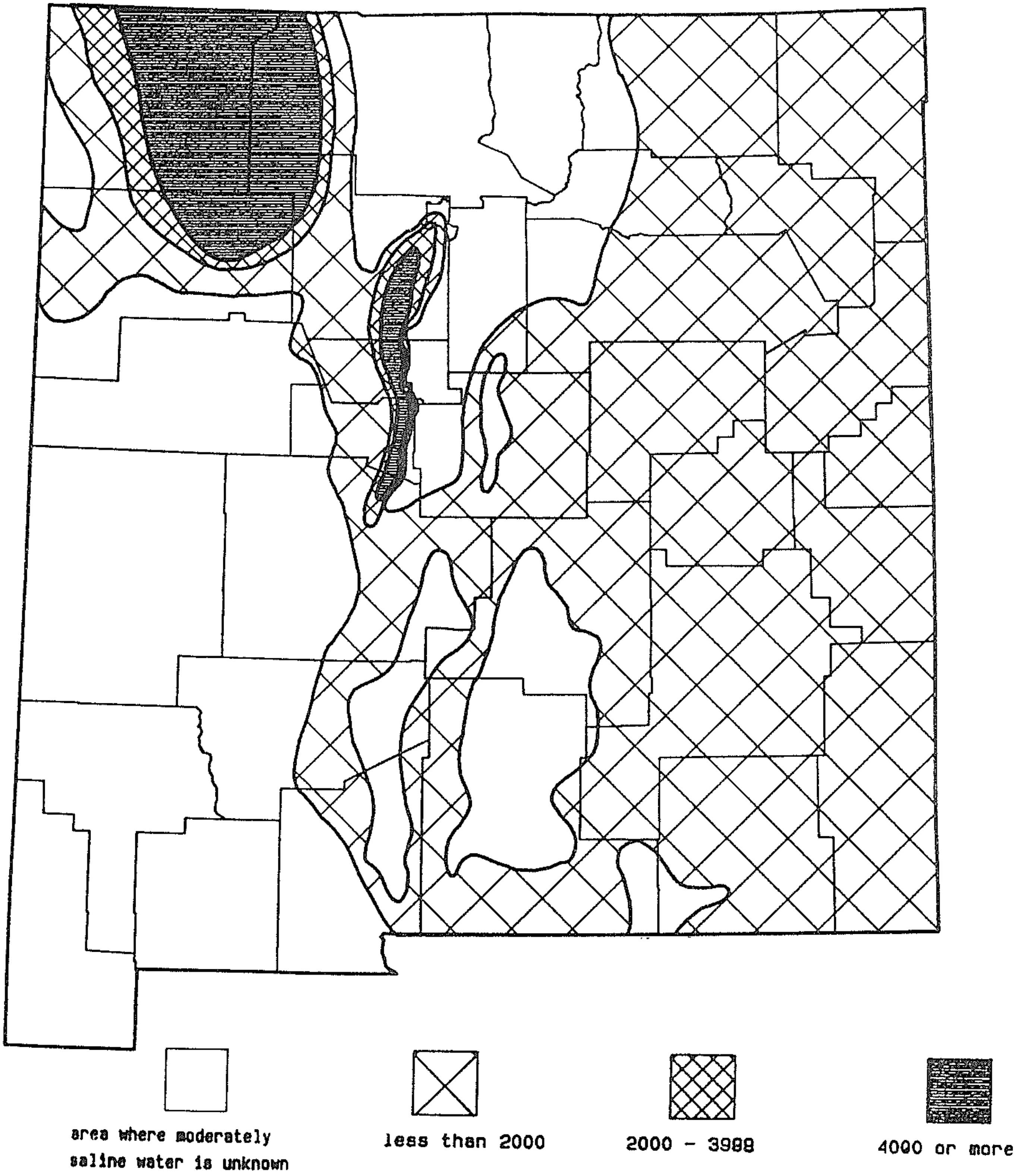

FIG. 3. ESTIMATED THICKNESS OF AQUIFERS WITH MODERATELY SALINE GROUNDWATER

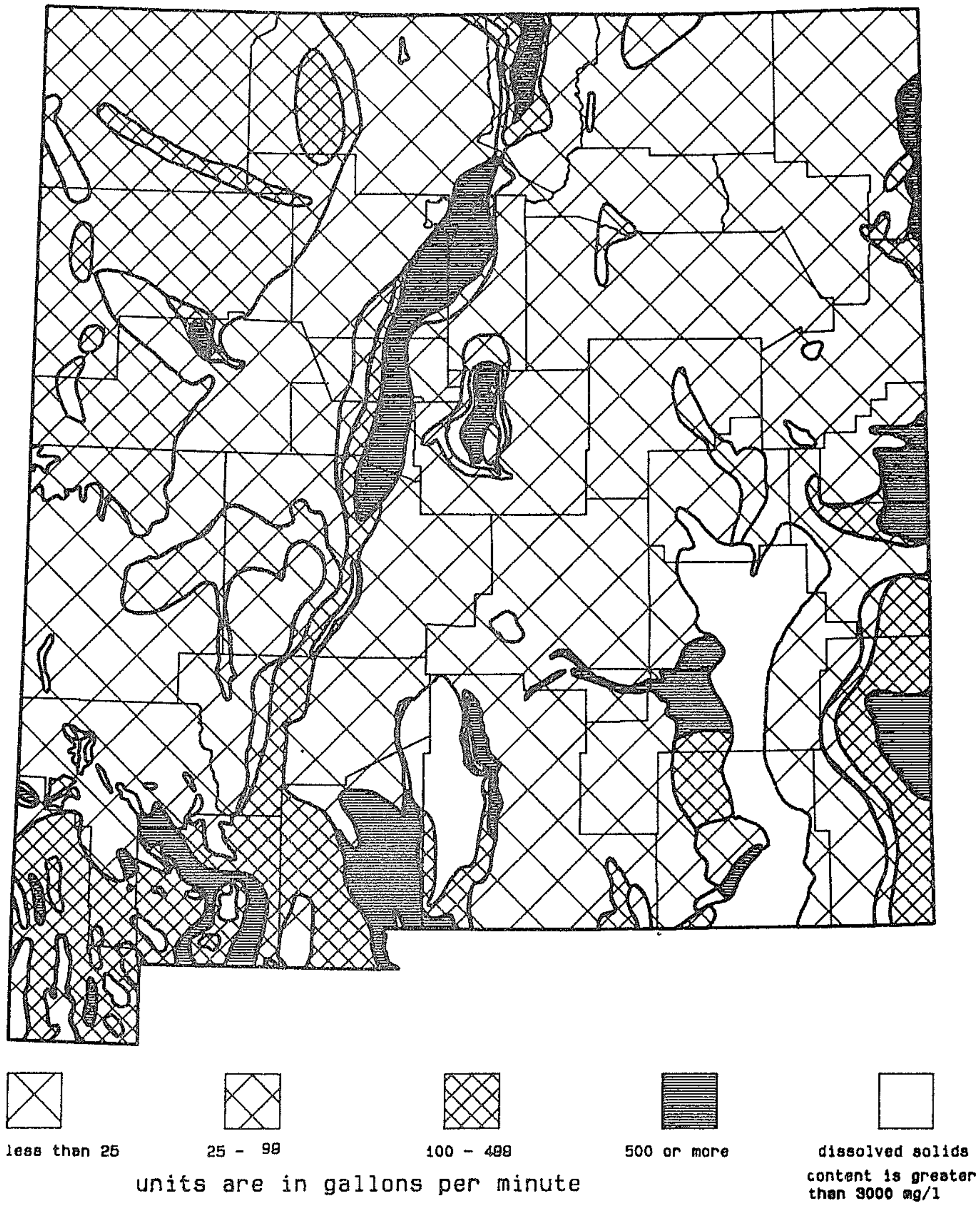

FIG. 4. ESTIMATED POTENTIAL YIELD OF WELLS WHERE TOTAL DISSOLVED SOLIDS CONTENT IS LESS THAN 3000 MG/L

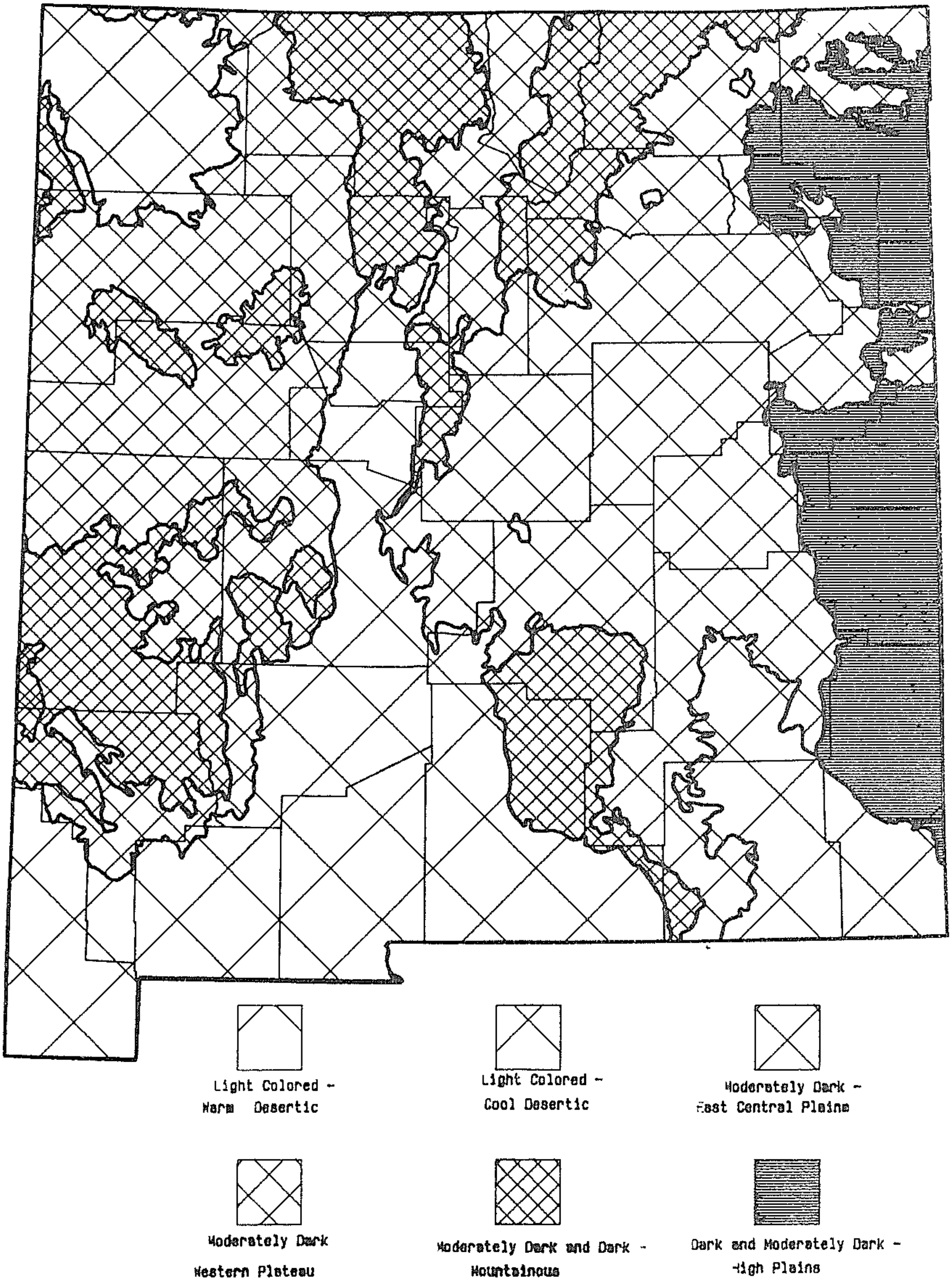

FIG. 5. GENERAL SOILS BY REGION

Figure 1 - Estimated thickness and areas of aquifers that contain fresh groundwater.

Figure 2 - Estimated thickness and areas of aquifers that contain slightly saline groundwater.

Figure 3 - Estimated thickness and areas of aquifers that contain moderately saline groundwater.

Figure 4 - Esimated potential yield of water wells.

Figure 5 - General soils map.

Figure 6 - Declared groundwater basins in New Mexico.

Figure 7 - Map of the Tularosa Basin.

Our initial work demonstrated that the technique is clearly feasible; however, the time commitment and computer expense precluded full application. The alternative approach adopted was to overlay a map showing favorable areas that meet the various criteria onto a consolidated map. The Tularosa Basin was considered in some detail in this fashion. A more complete discussion of the data developed is provided in the last section of this report as an example. Two conclusions were quickly derived with respect to this basin using the overlay technique:

1. The multiple criteria for the selection of potential sites for irrigation with saline water are, as a whole, so restrictive that the likelihood of locating a completely acceptable site of any geographical magnitude is remote; and
2. The generalized information available on state-wide maps does not provide sufficient detail to make critical decisions on acceptability of a specific farm area.

When it became apparent that graphical technique would not suffice, detailed reports on a number of potential areas in the state were obtained and reviewed. As an example, a detailed review is provided in this study on possible sites in the Tularosa Basin using saline water for irrigation.

SALINE WATER SUPPLY CHARACTERISTIC AS A SITE CONSTRAINT

General Approach

Water quantity and water quality are only two of the many factors that determine whether or not a specific crop can be successfully grown on the soils at a particular geographical location using a pre-selected farming practice that establishes the method of water application as well as the rate and frequency of application. Other factors that affect germination, plant growth and yields include the sodium absorption-ratio (SAR), the exchangeable ions in the soils, the effects of the precipitation of calcium carbonates from soil solutions, the partial pressure of carbon dioxide in soil-air, soil aeration conditions, water quality and stage of plant growth, depth of the root-zone, depth to the groundwater table, height of the capillary fringe, and soil temperature. The interaction of farming practices, plants, soils, growing season, climate, and water quantity and quality are far too complex to predict. The best solution is to identify general water quantity and quality criteria and to examine these and other relationships a crop-by-crop and site-by-site.

Well Yield and Pumping Lift

The characteristics of the saline water source available at a particular site for use in irrigating crops is probably the most single important factor in selecting or rejecting the area. First, the supply must be sufficient. Wells should yield at least 500 gpm and the pumping-lift should not exceed 250 feet. A common rule-of-thumb is that the water supply capacity must be on the order of 5 to 10 gpm for every acre irrigated. The water supply must be able to meet summer-time maximum rates of evapotranspiration without requiring 7-day week, 24-hour day operation of irrigation wells. Providing 10 gpm per acre also allows pumping during off-peak periods for electrical demand when lower power rates can be negotiated.

The pumping lift is an economic consideration. Net returns per acre (not taking capital recovery into account) in many irrigated areas of New Mexico and West Texas range from negative values to about $400 per acre depending on the crop, farm size, the source of water supply, and the quality of area soils (Maple 1984, Libbin, et al. 1982). Maple (1984) gives examples of the differences in the costs of pumping against a 125-foot lift and a 200-foot lift for farms with relatively efficient irrigation pumping systems. The differences in cost for the 75-foot increase is $8.16 per acre-foot or an additional cost of $28.56 for the volume (3.5 acre-feet) needed to irrigate typical crops in the region. It is clear that pumping lifts in excess of 150 to 250 feet will seriously decrease the profitability of a farming operation. An inefficient pumping plant will also seriously erode profitability.

The following subsections discuss a number of other water supply characteristics. A review of the availability of saline and fresh water supplies and the role they play in the selection of potential sites also is presented.

Saline Water Classifications

The U.S. Geological Survey has assigned word descriptions to the various degrees or ranges of salinity found in natural waters. The term "fresh water" characterizes supplies that have less than 1,000 mg/l of TDS in solution. With a few exceptions, "fresh water" can be assumed to be satisfactory for virtually all crops grown in New Mexico, for drinking water purposes and for most industrial processes.

The next classification is "slightly saline" water where the TDS content ranges from 1,000 to 3,000 mg/l. Water with TDS contents between 3,000 and 10,000 mg/l are considered to be "moderately saline," from 10,000 to 35,000 mg/l is classed as "very saline" and waters with concentrations greater than 35,000 mg/l are called "brines. The groundwaters of particular interest in this study are the "slightly saline" and "moderately saline" resources that are not now being used for irrigation.

Saline Water Characteristics

In the past, the quality of western rivers has been described in terms of tons of dissolved salt per acre-foot of water. A current and readily measured estimate of salinity of water is the electrical conductivity or the specific conductance of the dissolved salts in solution. Table 1 provides an approximate relationship between electrical conductivity (EC in mmhos per cm at 25°C) and TDS in mg/l and tons of salt per acre-foot of water (H.E. Dregne 1969). The conversion of TDS to EC in mmhos/cm is an approximation because the electrical conductivity of water depends on the charge of the various ions in solution and their activity.

Table 1

Conversion Table for Salinity of Water*

Electrical Conductivity (EC) in mmhos per cm at 25°C	Total Dissolved Solids** TDS in mg/l	Tons of Salt*** Per Acre-Foot of Water
0.75	480	0.65
1.00	640	0.87
1.50	960	1.30
2.00	1280	1.74
2.25	1440	1.96
2.50	1600	2.17
3.00	1920	2.61
4.00	2560	3.48
5.00	3200	4.35
6.00	3840	5.22
7.00	4480	6.09
8.00	5120	6.96
9.00	5760	7.86
10.00	6400	8.70

NOTES

*Taken from H. E. Dregne 1969.

**Conversion from EC to TDS is to multiply EC by 640.

***Conversion from TDS to tons per acre-foot is to divide by 735.

Other measures, besides specific ion concentrations, used to describe the interrelationship of soil and water quality with respect to irrigation are the use of the sodium adsorption-ratio (SAR), the exchangeable sodium (in milliequivalent per 100 grams of soil), and the salt balance. The SAR is a measure of the relative concentrations of sodium and calcium in a soil solution and is of interest because of the impact of sodium on soil texture and drainage characteristics. Exchangeable sodium is of interest for similar reasons. The sodium-adsorption ratio (SAR) is calculated to be:

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\left(\frac{\mathrm{Ca}^{+2} + \mathrm{Mg}^{+2}}{2}\right)^{1/2}} \qquad (1)$$

where all concentrations are expressed in milliequivalents per liter. In general, a low SAR is desirable in an irrigation water supply as the higher the SAR, the greater the sodium hazard, at least in low carbonate waters (Dregne 1969).

The salt balance is a measure of the build-up of soluble salts in the crop root-zone and is typically calculated at the start or end of an irrigation season. To prevent the development of unacceptable levels of salinity in the active or upper part of the soil column, it is necessary to provide additional water to leach salts from this zone. The salt balance equation (Bresler 1979) requires that the total weight of dissolved constituents on the left side of the equation be equal to or less than the terms on the right hand side. As an operating rule, S_r, the residual soil-salts should not increase year-to-year in the root-zone column.

$$S_p + S_i + S_r + S_d + S_f = S_{dw} + S_c + S_{ppt} \qquad (2)$$

S_p = Dissolved solids in natural precipitation

S_i = Dissolved salts in irrigation water

S_r = Residual soil salts

S_d = Salts dissolved from weathering of soil minerals

S_f = Salts in fertilizers

S_{ppt} = Salt precipitated as slightly soluble soil minerals

S_{dw} = Salts in the drainage water

S_c = Salts removed in the harvested crop.

Fresh and Saline Water Reserves in New Mexico

In establishing the volume of water available for use, the New Mexico state engineer has included both "fresh water" (less than 1,000 mg/l TDS) and "slightly saline" waters (1,000 to 3,000 mg/l TDS) in estimates made by his office of available reserves. New Mexico follows the doctrine of prior appropriation in establishing the right to use water and does not make any quality distinction between "fresh" and "saline" water in its methods of assigning priorities and in recognizing rights for the use of surface or groundwaters. However, for almost all purposes, waters in the two classifications of "fresh" and "slightly saline" constitute the available, useable water with respect to quality. "Moderately saline" waters (3,000 to 7,000 mg/l) are sparingly used for irrigation and domestic water supplies at this time. As noted previously, both the state of New Mexico and the EPA require the protection of groundwater with up to 10,000 mg/l of TDS as potential future drinking water sources.

Table 2 provides a summary of the surface water supply available for use in New Mexico, virtually all of which has been fully appropriated and committed to beneficial use. Some stream systems in New Mexico have limited quantities of water that may still be appropriated for beneficial applications. By and large, these waters are available through contracts with the U.S. Department of the Interior or with the state of New Mexico and are relatively costly. Table 2 provides a summary of these surface flows and the availability.

The location of the state's groundwater reserves are relatively well known, but the magnitude of these resources has not been rigorously assessed on a state-wide basis. Large areas in the state are still open to new production wells without requiring prior permission from the state engineer to drill and to use the water. These are the undeclared basins where the groundwater supply available is poorly known, but where it is unlikely that major new reserves will be discovered. The northeast quadrant of New Mexico falls into this category. Figure 6 shows the declared groundwater basins in the state.

These are a number of declared basins where new groundwater appropriations are possible. To appropriate this water, an application must be filed with the state engineer who must find that the requested water resource is available, that existing uses are not impaired, and that the proposed water application is not contrary to the conservation of water in the state and not contrary to the public welfare. In many of these areas, groundwater mining occurs, that is, present withdrawals far exceed the recharge of the aquifer system being tapped. The state has set a policy of continuing to allow water to be taken from these "mined" basins as long certain criteria are met, including a maximum allowable water level decline that is permitted during a year.

Table 2

Surface Water Resources of New Mexico Available for Benficial Use*

Major River Basin	Estimated Total Useable Surface Supply in Acre-Feet	Basin Area in Square Miles
Rio Grande	540,400	49,755
Pecos	205,000	25,962
Texas Gulf	13,800	5,409
Upper Colorado	669,000**	9,530
Lower Colorado	78,300**	13,338
Arkansas-White-Red	313,000**	17,636
Total	1,818,500	121,630

NOTES

*Taken from Table 7, pg. 91, New Mexico Water Resources Assessment for Planning Purposes, Department of Interior, U.S. Bureau of Reclamation, November 1976.

**River basins where some surface water is or will be available for appropriation (in most cases through a U.S. Department of Interior or State contact).

Table 3

Unappropriated Surface Waters of New Mexico

Major River Basin and Sub-basins	Surface Flow Available For Appropriation in Acre-feet Per Year	Surface Water Appropriated But Available for Contract in Acre-feet Per Year
Arkansas-White-Red		
Canadian River	20,000	27,000*
Dry Cimarron River	18,800	
Lower Colorado		
Black Creek	5,000	
Puerco River	5,400	
Zuni River	11,100	
Carrizo Wash	2,600	
Upper Colorado		
San Juan River		49,000**
Animas-La Plata		34,000***
Gila River		18,000****

*Available for a 25-year period from the New Mexico Interstate Stream Commission.

**Available to the year 2005 from the Secretary of Interior.

***Volume available through the Secretary of Interior when this project is completed.

****Volume available through the Secretary of Interior when the Central Arizona Project is completed.

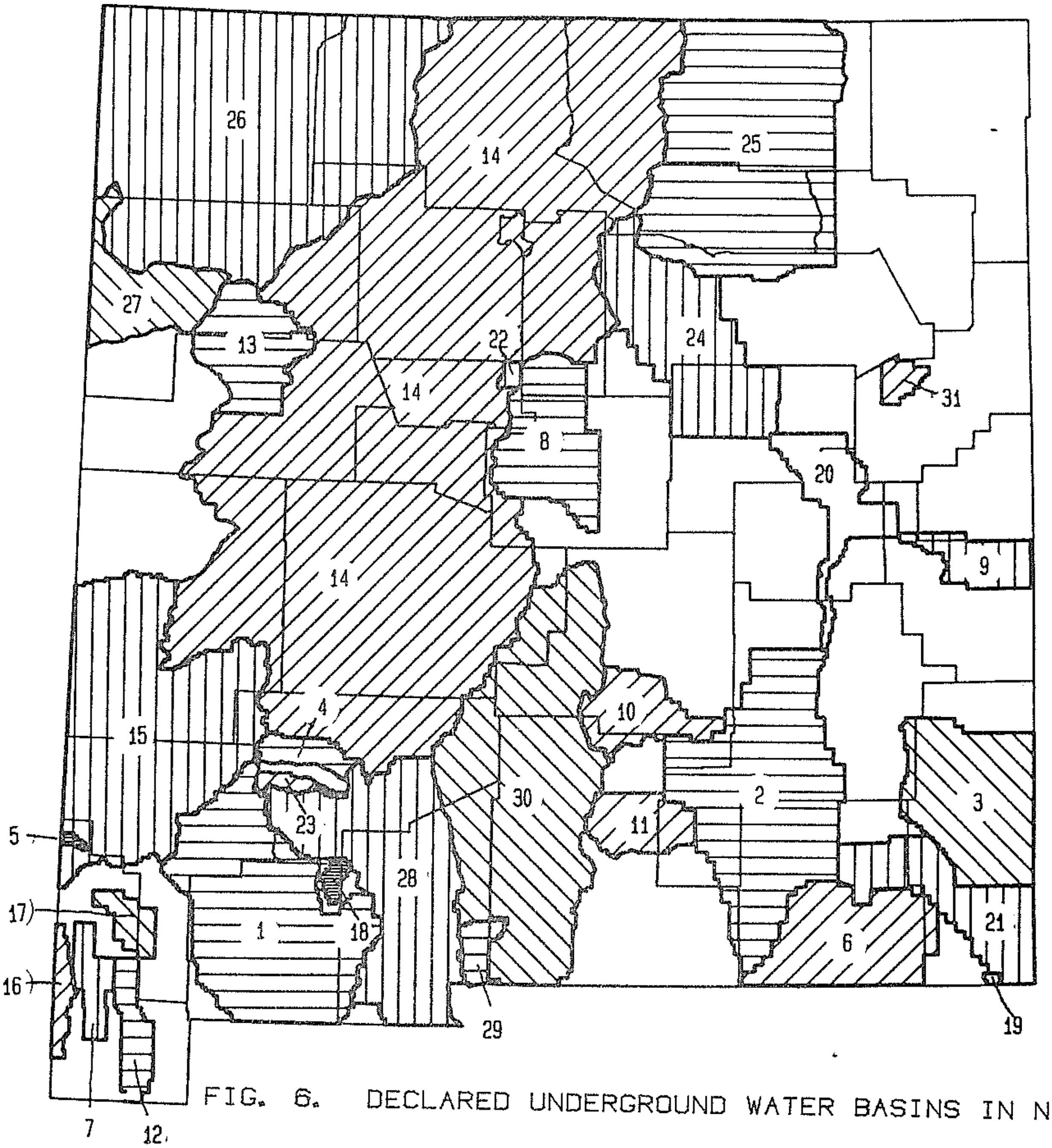

FIG. 6. DECLARED UNDERGROUND WATER BASINS IN NEW MEXICO

BASIN	AREA IN SQUARE MI.
1 MIMBRES VALLEY	4,279
2 ROSWELL	4,281
3 LEA COUNTY	2,160
4 HOT SPRINGS	265
5 VIRDEN VALLEY	19
6 CARLSBAD	1,965
7 ANIMAS	426
8 ESTANCIA	1,724
9 PORTALES	628
10 HONDO	801
11 PENASCO	723
12 PLAYAS VALLEY	515
13 BLUEWATER	1,318
14 RIO GRANDE	26,209
15 GILA - SAN FRANCISCO	5,659

BASIN	AREA IN SQUARE MI.
16. SAN SIMON	263
17. LORDSBURG	329
18. NUTT - HOCKETT	139
19. JAL	16
20. FORT SUMNER	1,059
21. CAPITAN	1,550
22. SANDIA	79
23. LAS ANIMAS CREEK	131
24. UPPER PECOS	2,708
25. CANADIAN RIVER	6,625
26. SAN JUAN	9,727
27 GALLUP	1,439
28 LOWER RIO GRANDE	3,658
29 HUECO	255
30 TULAROSA	6,070
31 TUCUMCARI	177
	84,723

If the state engineer finds that a new proposed taking of groundwater will deplete the supply in a fully appropriated river system, he may require that the impact of the new groundwater withdrawal be off-set by retiring sufficient surface water rights. The administration of the declared basins in the Rio Grande and tributary drainage offers a good example of this policy. In effect, the long-term volume of water available for use from a groundwater aquifer in a stream connected basin, should not be greater than the surface discharge available for appropriation. Some additional groundwater can be initially taken from storage, but as soon as the withdrawals begin to effect the river flow, it must be offset by retiring an equivalent volume of surface rights.

Table 4 provides a list of the stream related groundwater basins and the volume of surface rights potentially available for conversion to groundwater withdrawal through the retirement process. Table 5 gives estimates of the volume of the "fresh" and "slightly saline" groundwater that is available in the indicated basins for appropriation without retirement of surface-water rights. This availability exists because the aquifers in question are not directly stream connected.

The saline water resources are much more poorly known than the "fresh water" reserves, but estimates have been made. Hale, et al. (1965) set the volume of saline water at about 17 billion acre-feet compared to 3 billion acre-feet of "fresh" water. While the discussion in this paper is limited to "slightly" and "moderately" saline waters, the maps found in the 1976 New Mexico Water Resources Assessment for Planning Purposes published by the U.S. Department of the Interior provide insight into locations where very saline and brine waters can be found.

Table 4

Stream Related Groundwater Basins Where the Effects of New Groundwater Depletions Must Be Offset by Retirement of Surface Water Rights

Major River Basins and Sub-basins	1980 Surface Supply Depletions Available for Conversion to Ground-Water Withdrawals - This is Assumed to Be the Annual Volume of Surface Water Use That Can Be Retired to Offset the Effects of New Appropriation of Groundwater in Acre-feet
Lower Colorado	
Gila-San Francisco	18,000*
Rio Grande	
Above Otowi Bridge	44,200
Otowi to Elephant Butte	126,630
Below Elephant Butte	173,920
Pecos River	83,300
Upper Colorado	
San Juan Region	**

*Available when the Central Arizona Project is completed and when New Mexico enters into a contract with the Secretary of Interior.

**A more complicated situation exits, but new groundwater appropriations of significant magnitude are possible.

Table 5

"Fresh" and "Slightly Saline" Groundwater Reserves* and Amount of Groundwater Available for Appropriation Without Surface Water Retirement in Declared Uderground Basins Under Present Administrative Criteria

River Basin and Sub-basin	Amount of Recoverable "Fresh" Groundwater in Storage in the Idicated River Basin in Millions of Acre-feet	"Fresh Water" Available for New Appropriation in Groundwater Sub-basins Where Mining Exists in Millions of Acre-Feet	Amount of Recoverable "Slightly Saline" Ground-Water Reserves in Storage in the Indicated River Basin in Millions Acre-Feet
Arkansas-White-Red	75		160
Tucumcari Basin		0.40	
Texas Gulf	30		55
Lea County Basin		0.77	
Pecos	25		345
Jal Basin		0.04	
Rio Grande	2,515		580
Estancia Basin		2.04	
Tularosa Basin		10.70	
Hueco Bolson		6.20	
Mimbres Basin	70	3.7***	
Nutt-Hachett Basin		0.13	
San Juan Structural Basin**	420		760
Lower Colorado			
Lordsburg Valley	4.9	0.60***	
Animas Basin	7.9		

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*"Fresh" water has less than 1,000 mg/l total dissolved solids; "slightly saline" water has 1,000 to 3,000 mg/l TDS.

**Includes San Juan and Little Colorado River Basins.

***Amount available based on a pumping lift of 230 feet or less; this is deemed to be the upper limit for economic farm operation.

Column 3 of Table 5 gives the "slightly saline" reserves available in five of the major river basins. These "slightly saline" waters have 1,000 to 3,000 mg/l total dissolved solids and are used for virtually all beneficial uses in the state. They exceed the "fresh water" reserves in all basins, but the Rio Grande and the total reserves of "slightly saline" water in storage probably exceed 2 billion acre-feet. Figure 2 provides a map showing the areas in New Mexico where "slightly saline" waters can be found. The shading provides an estimate of the thickness of the aquifers with "slightly saline" water and this offers a relative estimate of the reserve at any one location. This map cannot be used to predict the depth to the slightly saline zone nor the yields likely to be obtained in wells.

Figure 3 is a similar map of the "moderately saline" waters in the state (3,000 to 10,000 mg/l TDS). A comparison of figures 2 and 3 indicates many overlapping areas; the "slightly saline" water generally lies above the "moderately saline" zone. In many regions, a fresh water lense rests above the "slightly saline" zone. Exceptions to this observation include a few places where saline water is found above a fresh water zone. Examples of such locations are the lower Mesilla Valley near Canutillo and in the Estancia Basin.

A few other generalizations are worth mentioning with respect to the availability of saline groundwaters that may or may not hold at any specific site. In most river valleys and for most of the plains areas, the depth to groundwater is less than 200 feet (New Mexico Assessment 1976). Well yields and water quality are usually closely related to the geological features and the geological history of the area.

In most areas, knowledge of the site and the regional geology can be used to predict aquifer characteristics.

Saline water can be found in most of the declared underground basins. Typically, salinity increases with depth and the rate of change is gradual, but there are exceptions (New Mexico Assessment 1976). Wells tapping saline waters are likely to have smaller yields (transmissivities also are lower) than do fresh water zones. At geological boundaries, rapid transitions in aquifer characteristics should be expected, making it more difficult to speculate about the availability of water resources in a specific area.

Additional information on the saline groundwater reserves of an example basin (the Tularosa) is in the last section of this report. Specific details on an area are best obtained by a review of the literature for a given basin. However, a good general source is the 1976 New Mexico Assessment as it provides a large number of references in addition to other maps similar to Figures 1, 2, and 3.

Irrigation Water Quantity Requirements

The amount of water used in irrigation is accounted for at various points in the delivery system:

1. Diversions from the source of supply,
2. Farm deliveries,
3. Field water requirements,
4. Consumptive use, and
5. Leaching water requirements.

For groundwater sources, the amount of water pumped is usually taken to the farm delivery volume. The field water requirement is the farm delivery less any ditch or storage losses plus the effective precipitation or the rainfall during the irrigation season. The volume applied to the field is the consumptive use plus the water used to leach dissolved salts through the root zone. This formula is known as the leaching fraction (LF) and is the drainage from the root-zone that appears as the irrigation return-flow or as percolation back to the shallow groundwater-table. As an operating rule, the minimum LF is taken to be 0.1 or 10 percent of the water applied for irrigation.

The leaching requirement (LR) is the fraction of the irrigation water that must flow through the root zone to control salinity to a specified level and is typically less than the LF value. An equation for LR that assumes no appreciable contribution or loss of salts to precipitation in the soil column follows:

$$LR = \frac{100\ V_{dw}}{V_{iw}} = \frac{100 \times EC_{iw}}{EC_{dw}} \qquad (3)$$

where

V_{dw} = volume of drainage water

V_{iw} = volume of irrigation water applied

EC_{iw} = electrical conductivity of the irrigation water

EC_{dw} = electrical conductivity of the drainage water

The consumptive use of a crop is the evaporation from the soil system plus the transpiration of water by the plant. Evapotranspiration (consumptive use) varies with the crop, the leaf cover, the soil moisture, the soil temperature and the net incoming solar radiation. There are a number of equations employed to estimate seasonal evapotranspiration (ET) with the Blaney-Criddle being one that is commonly used to obtain regional values for consumptive use during the frost-free growing season (Sammis 1979). The Blaney-Criddle equation relates U, the seasonal consumptive use to two coefficients K (an empirical crop consumptive-use coefficient) and F (the sum of the monthly consumptive-use factors) so that

$$U = KF \tag{4}$$

It appears that K is related to the stage of plant growth, and to the mean air temperatures that prevail during various periods in the growth cycle. More sophisticated approaches utilizing measures of the energy available (air temperatures and percent of day-light hours) have lead to the determination of monthly values for these coefficients. Research reported by Mapel (1984) notes that it is possible to separate the evaporation losses from the transpiration requirements of a crop. Transpiration is reported to be a better estimator of consumptive use such that linear relationships between yield and transpiration can be derived (Maple 1984).

It is also possible to measure the rates of evapotranspiration (ET) in the field and this has been done for major crops at regional agricultural experiment stations in New Mexico. An example of measured monthly ET values for cotton at Las Cruces, New Mexico, for 1976-1977 (Sammis 1979) is given in Table 6.

The field water requirement may be computed knowing the consumptive use or evapotranspiration (ET) the effective (irrigation season) rainfall the volume of the drainage water and any changes is soil moisture that will occur. In terms of a water balance

$$ET = I + R - D \pm \Delta SM \tag{5}$$

Table 6

Monthly Evapotranspiration (ET) in Inches of Water For Cotton at Las Cruces, New Mexico, 1976-77 Avearge Values

Month	Apr	May	June	July	Aug	Sept	Oct	Seasonal Total
ET (inches)	0.2	1.3	3.0	9.8	10.6	5.4	2.5	32.8
% of Seasonal Total ET	0.6	4.0	9.0	30.0	32.3	16.5	7.6	100

while ET is the evapotranspiration, I is the irrigation water applied, D the drainage water, R the effective precipitation, and ΔSM is the change in soil moisture all in a unit depth measurement. Crop production versus water applied relationships have been developed for various locations (H. E. Dregne 1969) with most being linear to a point where additional quantities of applied water fail to result in proportional increases in crop yields. Where these relationships are linear, they take the form:

$$Y = a + b(ET) \tag{6}$$

where Y is the yield in tons per acre, ET is the evapotranspiration and a and b are crop, location, climate, soil and water quality sensitive coefficients that may vary from year-to-year.

As noted earlier in this section, the field water requirements also include the water needed to meet the LR. The LF is the actual volume that flows through the plant root-zone carrying away salts to prevent an adverse buildup in the soil column. The LF is usually greater than the calculated LR and is almost always equal to or greater than 10 percent. O'Connor (1979) believes that the equations used to calculate LR result in a conservative overestimate of the flows needed for leaching, particularly where some of the salts are immobilized in the soil column through precipitation. However, virtually all of the salts in the water applied for irrigation eventually must be leached through the soil column to drainage. For a given crop with a known salt tolerance, the greater the salinity of the irrigation water, the larger the leaching requirement and the greater the volume of the drainage water. The relationship will be discussed at length in the following two subsections.

Irrigation Water Quality Criteria

In terms of expressing water quality effects and the tolerance of crops to salinity, one of the most commonly accepted measures is the average root-zone salinity (Maas and Hoffman 1977, and Rhoades 1977). O'Connor (1979) notes, that for many plants, the salinity of the upper portion of the root zone is of greater importance than is the dissolved solids concentration at greater depths. Plant response to salinity is a function of the total osmotic potential of the soil-water and not to any specific ion although examples of ion toxicity to certain plants does exist (Mass and Hoffman 1977).

The concentration of salts in the root zone is typically evaluated by measuring the electrical conductivity (EC) of a saturation extract of plant soils. A high dissolved salt content in the soil-water paste from the root zone appears to be the controlling factor that leads to modified plant performance and the conditions that may result in plant damage and reduced crop yields. Maas and Hoffman (1977) report the most commonly noted effect to a general stunting of plant growth.

As water passes through the root-zone soil-column, the salt content in the soil-solution increases as a result of plant transpiration. The root-zone salinity can be determined in the field or in the laboratory or it may be estimated if the EC of the drainage water is known. For purposes of estimating the average root-zone TDS, the salt content of the lower portion of the root zone may be assumed to be about half that of the EC of the irrigation return-flow (EC_{dw}). The average for the root-zone, $EC_{avg.rz}$, is the average of the EC of the applied irrigation water (EC_{iw}) and the EC in the lower root-zone.

The salt content of the drainage water is controlled by increasing or decreasing the LF or that part of the applied irrigation water that passes through the plant root-zone by reducing or increasing the volume of the field water applied. It should be noted that rainfall, frequency of irrigation, rate of application and method of application tend to alter the LF.

Crop yield is typically insensitive to salinity levels in the saturated extract until some threshold value is reached and then a linear decrease in productivity occurs with an increase in the TDS in the root-zone soil-solution. As noted earlier, the effects on crop yield are considered to be osmotic and related to the total concentration of dissolved solid rather than the effects of any specific ion. Other ion effects (such as toxicity, sodicity and nutrient imbalance) may also occur as well as physiological effects such as leaf burn and defoliation. Effects may vary as plants behave differently in how salinity damage is manifested (Maas and Hoffman 1977). Physiological effects depend upon the stage of plant growth with the impact being crop specific (Maas and Hoffman 1977). A number of reports indicated that for certain crops, germination may be the critical period (O'Connor 1980). Where this is the case, conjunctive use of fresh and saline water may be an effective approach with fresh water irrigations used through the germination period and this followed by irrigation with saline water.

Table 7 is a summary from a much more extensive list of salt tolerance limits provided by Maas and Hoffman (1977). The table gives the relative threshold level for various crops of interest in New Mexico at which the growth (or yield as the case may be) begins to decline with an increase in root-zone salinity. The rate of this decrease in yield

Table 7

Salt Tolerance of Crops of Interest in New Mexico

Crop	"A" Threshold Salinity* Level at Which Yield (or Growth) Declines are Experienced Electrical Conductance (EC) in mmhos per cm	"B" Percent Decrease in Yield Per Unit Increase in Salinity Beyond the Threshold
Alfalfa	2.0	7.3
Barley Grain	8.0	5.0
Grain Corn	1.7	12
Cotton	7.7	5.2
Grapes	1.5	9.6
Lettuce	1.3	13
Onions	1.2	16
Sugar Beets	7.0	5.9
Sugar Beet-Germination	3.0	-
Wheat (crested)	6.0	7.1
Wheat-Emergence and Seedling State	4.5	-

*These are average root-zone salinities as determined by measurements of EC in the saturated soil extract.

(or growth) per unit increase in salinity is also given in Table 7. Maas and Hoffman (1977) provide an equation for using the values in Table 7 to estimate the relative decrease in yield (Y), in percent, for a given crop where the average root-zone soil-solution conductivity, EC, exceeds the threshold value, A, in Table VII, and where B is the percent decrease in yield per unit increase in salinity:

$$Y = 100 - B(EC-A) \tag{7}$$

The use of the average root-zone salinity as the criteria for determining whether or not crop damage will occur as a result of high irrigation water salinity may not always be the best choice. Alfalfa has a relatively long root and an ability to take water into its system in the upper section of the root zone where the water quality is better that at the lower part of the soil column. O'Connor (1979) notes that the density of the root systems on many plants decreases with depth so that water uptake is principally from the upper part of the root rather than uniformly at all depths. Thus, for some crops, the salinity of the irrigation water per se may be of importance while for others plants the concentration of dissolved salts in the deeper parts of the root zone may be of greater significance.

Volume of Saline Water Applied

One of the factors that will markedly influence the economics of a farming operation using saline water will be the volume of water applied for irrigation of a specific crop to obtain an acceptable yield on a particular farm soil. Yield, volume of water applied, and water quality are interrelated functions. A system of equations can be derived that will allow for maximizing income per acre farmed taking water quality, pumping lifts, volume of water applied and crops into account. The sparcity of data for irrigation with saline water precludes the derivation of such a system of equation for various crops and soil types for New Mexico. However, sufficient information is available to permit the generation of yield estimates for saline water irrigated crops at a few geographic points. Using field data for the Pecos Valley in New Mexico collected by H. E. Dregne (1969), it is possible to compute of the impact of water quality on the quantity of water that must be applied to maintain yields. Table 8 gives two examples for this type of calculation where an EC value for salt tolerance for the example crop is taken from column A of Table 7 (average root-zone salinity at which yields begin to decline), then calculations are made to determine the additional irrigation water that must be applied in order to maintain the salinity in the root-zone below the level of the value found in column A as the EC of the irrigation water increases.

LAND CHARACTERISTICS AND IRRIGATION WITH SALINE WATER

General Site Criteria

A number of land related concerns could have a marked impact on the acceptability of a site for a farm irrigated with saline water. The 1976 assessment of New Mexico's water resources by the Department of the Interior provides a map showing those areas in the state that are highly suitable for irrigated agriculture. These areas have negligible to moderate limitations for irrigation and they make up 10 to 15 percent of the state. These areas are found statewide in what appears to be a somewhat random-scatter distribution. It is interesting to note that much of the most favorable lands are found along major drainage courses.

Table 8

Examples of Calculations of Irrigation Water Quantities Required to Maintain Yields with Water of Varying Salinity

Definitions for Examples 1 and 2:

LR = leaching requirement

LF = leaching fraction, where the minimum LF_{min} = 0.1 or 10%

ET = evapotranspiration = consumptive use in inches of water

EC_{iw} = electrical conductivity of irrigation water in mmhos/cm

V_{iw} = volume of water applied for irrigation in inches

EC_{wa} = electrical conductivity of the water applied to the crop including effective rainfall

V_{dw} = volume of drain water in inches

EC_{dw} = electrical conductivity of drain water in mmhos/cm

$EC_{avg.rz}$ = average electrical conductivity in the root-zone saturation extract in mmhos/cm

$$EC_{avg.rz} = \frac{0.5\ EC_{dw} + EC_{iw}}{2}$$

F = field water efficiency

R = effective rainfall in inches

A = the threshold value for EC (in mmhos/cm) for the average root zone salinity where yield begins to decline (from table 7).

Example 1: For cotton grown in the Peco River Valley where ET = 20";

R = effective precipitation (ignored);

Table 8 (continued)

F = field water efficiency = 0.67

Field water requirement = 30 inches;

A for cotton = 7.7 mmhos/cm (see table 7)

Case 1 Will a reduction in the yield of cotton occur when LF = 0.1 and EC_{iw} = 1.50 mmhos/cm?

$$EC_{dw} = \frac{EC_{iw}}{LF} = \frac{1.5}{0.1} = 15 \text{ mmhos/cm}$$

$$EC_{avg.rz} = \frac{0.5\ EC_{dw} + EC_{iw}}{2} = \frac{7.5 + 1.5}{2} = 4.5 \text{ mmhos/cm}$$

For an irrigation water with an electrical conductance of 1.50 mmhos/cm, the average root zone salinity is 4.5 mmhos/cm and this is less than the threshold value of A (7.7 mmhos/cm from table 7) so that no reduction in yield will occur from using this source of irrigation water and a leaching fraction of 0.1.

Case 2 Find the LF needed to maintain the average root zone salinity at or below the value of A in Table VII for cotton when the electrical conductivity of the irrigation water EC_{iw} = 4 mmhos/cm.

A = 7.7 mmhos/cm from table 7.

$EC_{avg.rz} \leqq A = 7.7$ mmhos/cm

Tabe 8 (continued)

$$EC_{dw} \leqq 4A - 2EC_{iw} = 4(7.7) - 2(4) = 22.8 \text{ mmhos/cm}$$

$$LF = \frac{EC_{iw}}{EC_{dw}} = \frac{4\text{mmhos/cm}}{22.8 \text{ mmhos/cm}} = 0.18$$

Example 2: In the Pecos River Valley the irrigation of alfalfa has a field water requirement of 66 inches of water applied for a 100 percent yield when $EC_{iw} = 0.75$ mmhos/cm; ET = 46"; R = 9"; A = 2.0 mmhos/cm; B = 7.3 percent decreases in yield per unit increase in salinity.

Case 1 An irrigator uses 66" of water where $EC_{iw} = 1.0$ mmhos. Find the percent decrease in yield, if any, and take effective precipitation (R) into consideration. Assume LF = 0.1 (minimum).

(1) Find the average EC of the irrigation water applied, EC_{wa}, when the effective rainfall, R = 9" (rainfall has no dissolved solids).

EC_{WA} = electrical conductivity of water applied

$$EC_{WA} = \frac{V_{iw}EC_{iw}}{V_{iw} + R} = \frac{66''(1.0 \text{ mmhos/cm})}{66'' + 9''} = 0.88 \text{ mmhos/cm}$$

(2) Find the estimated salinity of the drain water, EC_{dw}.

$$EC_{dw} = \frac{EC_{WA}}{LF} = \frac{0.88}{0.1} = 8.8 \text{ mmhos/cm}$$

Table 8 (continued)

(3) Find the average salinity in the root-zone, $EC_{avg.rz}$.

$$EC_{avg.rz} = \frac{1/2EC_{dw} + E_{WA}}{2} = \frac{1/2(8.8) + 0.88}{2}$$

$$EC_{avg.rz} = 2.6 \text{ mmhos/cm}$$

(4) Find the reduction in yield as a percentage yield

reduction = $B(EC_{avg.rz} - A) = 7.3(2.6-2) = 4.4\%$

<u>Case 2</u> Same information as Case 1. To find LR and volume of irrigation water needed to maintain 100 percent yield with $EC_{iw} = 1.0$ mmhos/cm.

(1) Find EC_{dw} such that $EC_{avg.rz} \leqq 2.0$ mmhos/cm = A

$EC_{dw} \leqq 4EC_{avg.rz} - 2EC_{WA}) = 4(2.0) - 2(0.88)$

$EC_{dw} \leqq 6.2$ mmhos/cm

(2) Find the leaching requirement, LR in percent.

If we ignore the effective precipitation then,

$$LR = \frac{EC_{iw} \text{ X } 100}{EC_{dw}} = \frac{1.0 \text{ x } 100}{6.2} = 16\%$$

(3) The minimum value for LF = 10 percent. Find the additional water needed to maintain 100 percent yield.

Additional Water Requirement = (LR - 10%) (initial field water requirement)

= (.16 - .10)(66") = 3.9"

= 4" after rounding

(4) Find the new irrigation water application rate

New field water requirement = 66" + 4" = 70" of water.

The map in the 1976 assessment also identifies those lands that are moderately suitable for irrigation. The combination of these two classifications probably includes 30 to 40 percent of the state. It should be clear that there are large land areas in the state that could be satisfactorily irrigated if a water supply were available. For lands to be included in one of these two groups, they must have favorable soils, topography and drainage. Each of these charactertistics has important ramifications when a site is being considered for irrigation with saline water. The following subsections contain brief reviews of these three characteristics as criteria in site selection.

Soils

Hernandez (1971) provided data to show the change in net returns from the irrigation of crops on three different types of soils in the Pecos River Valley in New Mexico. Table 9 gives information for net returns from the production of alfalfa on each of the three soil-groups for irrigation water qualities ranging from EC_{iw} = 0.75 mmhos to EC_{iw} = 4.0 mmhos when 88 inches of water is applied per acre. This table also provides a brief description of each soil and the reason for its impact on yields. It should be noted that net returns decrease as soils become poorer and as the irrigation water becomes more saline. Although data is not shown, net returns also decrease as less water is applied per acre.

This table demonstrates the economic significance of soils and water quality; the poorer the quality of each, the greater the reduction in net returns. Because of the adverse effect of root-zone salts on plant growth, it is essential that high quality land be available if saline water is to be used for irrigation. Elements of greatest importance are soil drainage and permeability. Both must be good when using

Table 9

Net Return in Dollars Per Acre From Irrigation Of Alfalfa On Three Different Soil Groups Using Water Of Varying Water Quality* Pecos River Valley

Soil Group	Water Applied Per Acre (inches)	Water Quality as Electrical				
		0.75	1.50	2.25	3.00	4.00
		New Returns in Dollars				
I	88	160.61	127.09	85.84	44.59	-14.72
II	88	125.45	96.62	60.99	25.36	-25.97
III	88	53.12	39.37	14.34	-10.74	-39.57

Soil Group	Soil and Land Characteristics	Agronomic Characteristics
I	Almost-level lands; soils are deep, well drained, medium textured, highly fertile, and easily worked.	Soils have few characteristics that restict their use for irrigated crops.
II	Lands are on moderately steep slopes, highly susceptible to water and wind erosion, with subsoils of low permeability; soils are underlain by gypsum or calcareous materials, have low moisture-holding capacity, and are moderately deep (20-36 inches).	Soils have moderate restrictions that narrow the choice of crops, require special management practices that are difficult to effect and to maintain; time of planting, tillage, and/or harvest may be restricted.
III	Steep slopes, highly susceptible to water and wind erosion; severe effects of past erosion are common. Shallow soils, low moisture-holding capacity, severe sodium or salinity content, and low-permeability are typically found.	Soils have severe limitations that restrict crop choice; careful management is required. Conservation practices are difficult to apply and maintain; low productivity in relation to inputs.

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*Data taken from Hernandez, 1971.

high TDS water in order to prevent adverse increases of salts in the root-zone. Other factors are the soil texture, the absence of rock and stone, the effective soil-depth, the available water-holding capacity, the soil sodicity and the erosion potential.

Topography

Site topography is always a concern, but it becomes more important when high TDS water is applied for irrigation. One of the methods of combating the impact of salinity on crop yield is to seek alternative farming techniques and water application methods. Miyamoto, et al. (1984) describes some of the management methods that have been used in the Rio Grande Project lands near El Paso, Texas, where water with salinity up to 5 mmhos/cm conductance have been used successfully to grow alfalfa a relatively salt sensitive crop. Their success has been made possible in part by selecting appropriate farming technologies.

In general, smooth surface lands with little (1%) or no slope are desirable for irrigated agriculture. Farm areas should be large enough, and in a regular shape, so as to permit the use of equipment for cultivation and for water application.

PUBLIC WELFARE, CONSERVATION AND ENVIRONMENTAL CONCERNS

Public Welfare and Conservation

The New Mexico state engineer is required to consider public welfare and conservation in approving a new request to appropriate water, to change a point diversion or to change the purpose of use. The use of saline water for irrigation should be considered a conservation effort and in proper circumstances its use could be very much in the public interest.

There are a number of places in New Mexico where saline water encroachment into a fresh water aquifer is a very real concern. Hernandez (1971) has discussed the Roswell-Artesia Basin and the problems of excessive withdrawals from the high-quality artesian zone that has allowed salt water to move towards and into what were fresh water wells. Hernandez (1971) recommended the use of some of the saline water to reduce the differential hydraulic gradient between the fresh and saline zones. The conjunctive use of saline and high quality waters for irrigation could be one way to protect a fresh water aquifer; this would clearly serve the public interest.

Other locations in New Mexico where saline water movement does or could contaminate a fresh water aquifer are in the lower Mesilla Valley, the Tularosa Basin at a number of points and the Estancia Valley. A number of other sources of saline waters could be conjunctively used for irrigation: power plant cooling water, irrigation return-flow and tail-water, and industrial waste-waters.

Use of Saline Water and Environmental Issues

The concept of conservation of water in New Mexico is best served by the beneficial use of all of the water resources of the state including those waters with high TDS contents. Irrigation using saline waters for a part or all of the growing season will result in the preservation or savings of a comparable volume of "fresh" water for another use such as a municipal supply.

In general, a New Mexico water right in a declared basin permits the owner to take a certain amount of water annually from a particular point of diversion for a specific use at an indentified site. It does not guarantee that the water will be available either in terms of flow, yield or water-level, nor does it promise that the quality of the water obtained will be suitable, without treatment, for the purpose intended. Lansford, et al. (1985) have noted that New Mexico's statutes and regulations that place restrictions on the amount of water to be used do "not delineate between fresh and saline groundwater resources."

This does not mean that the administration of New Mexico's water rights, and the legal decisions on which management rests, are blind to water quality. The economic impact of the TDS content of irrigation water is well recognized (Hernandez 1971 and 1980).

The state engineer has taken a number of steps in the past to protect New Mexico's water resources from degradation by saline water. One administrative approach, that the author believes to be within the legal discretion of the state engineer, would be to allow new appropriations from saline aquifers so as to use these resources and to prevent their movement into fresh water zones. Another rational would be to permit the use of saline waters as a means of conserving a fresh water supply.

A recent landmark case that bears on water quality and on the appropriation of groundwater is Stokes and Blevins vs. Morgan and Sanders. Individually, Morgan and Sanders both asked the state engineer to allow them to move their points of diversion to new well sites. In the majority decision written by State Supreme Court Justice Federici (1984), he stated that the quantity of water involved was not significant, but that "the real issue in the case was whether termination of pumping at the moved-from wells and commencement of pumping at the moved-to wells would cause an increase in salinity in neighboring wells which would result in a decrease in crop yields" and whether this increase in TDS would "constitute impairment of neighboring water rights."

The New Mexico Supreme Court found that the factors that must be considered in determining impairment due to salinity include the nature of the aquifer system, the rate of movement of saline waters, the electrical conductivity of the water being used for irrigation, the concentration of specific ions, the composition of farm soils and the annual precipitation. The Supreme Court found the "new withdrawals which cause a minimal acceleration in the rate of salt water intrusion or a minimal increase in salinity do not constitute impairment as a matter of law. Because of the number of variables involved, it is impossible to set strict guidelines..." From this decision, it is clear that actions that lead to significant changes in water quality must be considered as potential sources of impairment of an existing water right. Irrigation drainage from the use of saline waters that leaks downward into a fresh water aquifer could lead to significant degradation and thus be considered an impair of an existing water right. Sites where the quality of a shallow fresh water aquifer will be subject to contamination by the use of saline water for irrigation are not acceptable.

Other Environmental Considerations

The build-up of specific ions in irrigation return-flows is of concern. A number of naturally occurring chemical constituents in water have no adverse effects on humans, fish and wildlife in the concentrations that they are normally found. However, unique situations do occur where these constituents are found in greater quantities and their concentration in irrigation return-flows may result in serious environmental problems. An example is the relatively high levels of selenium that have developed in wet-lands vegetation growing in irrigation drain waters in the central valley of California (Science, July 1985). Case by case evaluation appears to be the only means of preventing this type of problem from occurring.

EXAMPLE APPLICATION OF THE SITE SELECTION CRITERIA

The following sections describe the application of site-selection criteria for saline water use to a basin known to have a large varied saline water resource, the Tularosa Basin in New Mexico.

General Description of the Tularosa Basin Resources

The saline water resources of the Tularosa Basin have been the subject to a great deal of interest in the past two decades. The very large areal expanse of the basin (6,500 square miles), the thickness of the basin fill (up to 8,000 feet in places) the vastness of the volume of basin deposits (1,480 cubic miles) and the almost ubiquitous availability of saline water (of the 140 million acre-feet of water in storage, 98 percent has a TDS greater than 35,000 mg/l) makes the Tularosa a region with great potential for development. The most recent of these studies was the U.S. Department of Interior, Bureau of Reclamation's Tularosa Basin Water and Energy Study New Mexico; Appraisal Report, April 1984. A map of the basin is provided as figure 7.

The basin has been considered as a site for a nuclear plant where off-peak power would be used to desalt water. It has been considered as the location of solar energy related developments such as aquaculture and solar-saline ponds. It is a potential site for additional irrigated agriculture using saline waters either as the sole source or in conjunction with fresh water. The subsections that follow provide a description of the factors that will impact upon the use of the saline supply for

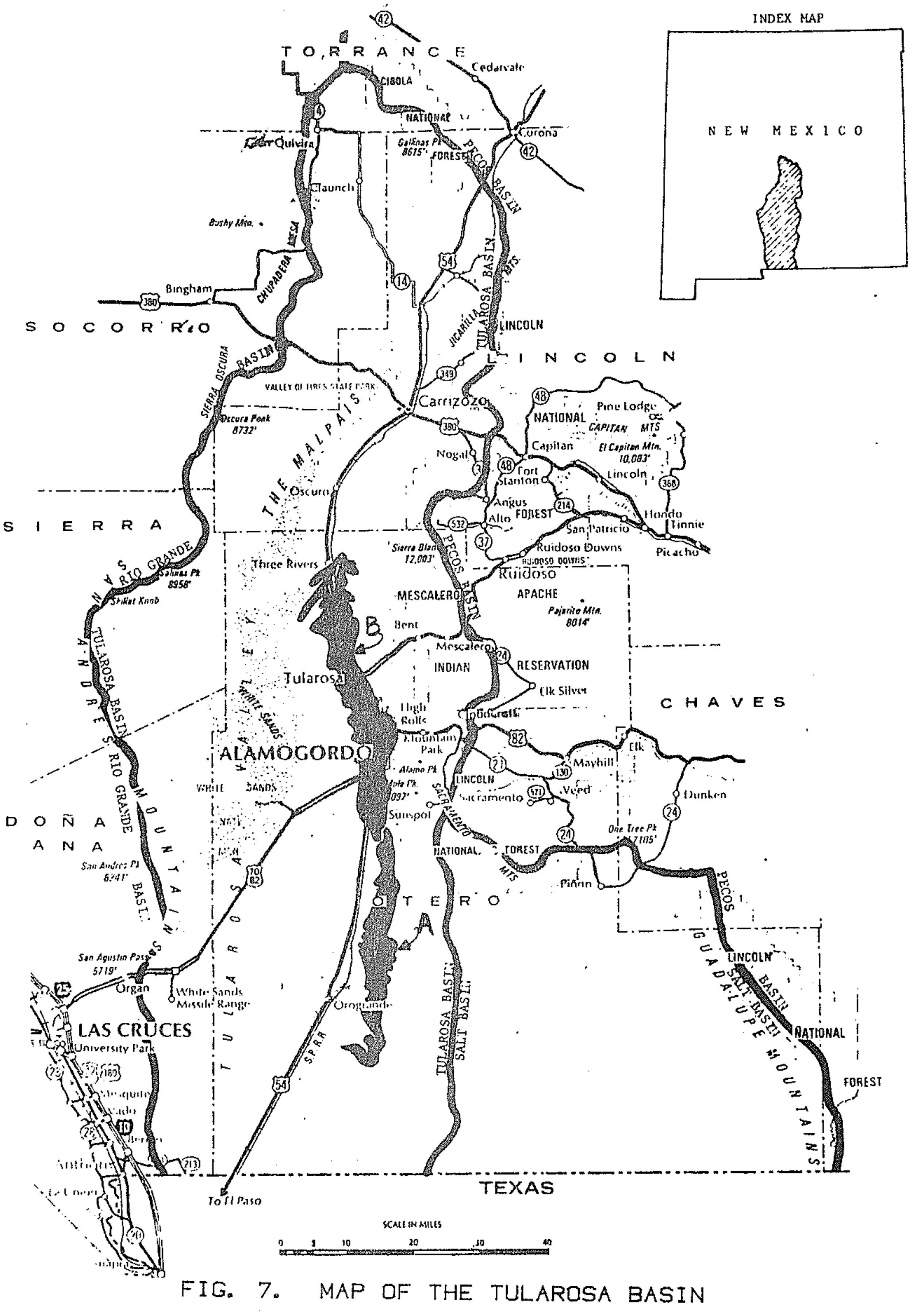

FIG. 7. MAP OF THE TULAROSA BASIN

this purpose. Because of the existence of the White Sands Missile Range, the westside and central area of the basin are not potential sites for irrigated aquaculture. The eastside does have a number of the elements needed for successful irrigated agriculture.

Climate

The basin floor is at an elevation of about 4000 feet above sea level and it extends in a north-south line from latitude 32°N to past 34°N. The growing season is approximately 210 days and the historic freeze-free days extend from early April to early November at Tularosa. The El Paso area, just to the south, averages 12 hours of sunlight per day, has an average day-time temperature of 20.2°C, an average daily temperature of 17.9°C, a relative humidity of 33.1%, and a daily average wind-speed of 4.2 meters per second.

Because the basin elevations range from less than 3900 feet to more than 12,000 feet, there is a significate range in the type of precipitation and the amounts received. The rainfall in the central part of the region is on the order of 10 inches per year and 25 inches in the mountains. Winter snows at higher elevations are the source of stream flow used for irrigation and much of the groundwater recharge. Summer thunder storms, that produce high runoff of short duration, are common. This hydrologic pattern does not result in a reliable source of effective precipitation for agricultural purposes.

Basin Lands and Soils

Much of the land area in the basin is not available for agricultural uses as it is part of the White Sands Missile Range and the White Sands National Monument. About 13,000 acres of land is now irrigated in the Tularosa Basin primarily in the areas along the mountain streams and where they enter the valley from the east and discharge into the alluvial fans that mark the transition from the Sacramento Mountains and the Sierra Blanca Mountains into the main north-south central valley. Irrigated croplands near Alamogordo total 9,650 acres; near Tularosa; 2,500; and 960 acres at Carrizozo.

Figure 7 shows (cross-hatched) an area along the eastside of the valley that has been found (DOI Appraisal Report 1984) potentially suitable for irrigation. The total acreage of the non-Indian lands that is suitable for irrigation in the basin is 371,595 acres. The lands of greatest interest in terms of groundwater quality are areas "A" and "B" on Figure 7 that have an area of 37,341 and 58,603 acres, respectively, that are classed as "most suitable" for irrigation. A part of area "A" is in the Fort Bliss Military Reservation and a small upper-arm of area "B" is within the White Sands Missile Range. Much of the "suitable" land is in private ownership but there is some state and federal property included in the area. It would appear that 40,000 to 50,000 "new acres of most suitable" lands for irrigation could be identified within the Tularosa Basin. "Suitable" lands lie in the following townships: T13S R9E; T14S R9E; T14S R10E, W 1/2; T15S R9E, E 2/3; T15S R10E; T16S R9E; T16S R10E; T17S R9E, E 1/6; T17S R10E; T18S R10E; T19S R10E; T20S R10E; T21S R10E and T22S R10E.

These two areas, "A" and "B", represent a variety of soil and land characteristics, but for the most part they are level to gently-sloping lands of alluvial valley fills. The soils are medium to fine textured and are strongly calcareous; subsurface layers of soils on the central valley floor contain some gypsum. The better valley soils can be classed as light brown loam or clay loam. The soils on the steeper slopes that are adjacent to the basin floor are light brown to reddish-brown calcareous silty loam or loam. Soil salinity is slight to moderate although gypsum is common in the lower zone of the subsoil.

Tularosa Basin Water Resources

The Tularosa Basin encompasses parts of three counties: Dona Ana, Lincoln and Otero with the bulk of the available water supply being in Otero County. Surface water depletions in Otero County in 1980 were only 10,000 acres-feet with irrigated agriculture being the principal user (almost 7,000 acre-feet). Urban water supplies used another 1500 acre-feet. All of the surface water supply originating on the eastside of the basin is already appropriated for beneficial use, mostly for irrigated agriculture.

Groundwater depletions in 1980 in the county were almost 28,000 acre-feet for a total consumptive use of about 38,000 AF. Again, the bulk of the water was used for irrigated agriculture. The groundwater supply is relatively large: the fresh water in storage is on the order of 10 million acre-feet.

The three classes of water of interest in this study are "fresh" (less than 1,000 mg/l TDS), "slightly saline" (1,000-3,000 mg/l TDS) and "moderately saline" (3,000-10,000 mg/l TDS) waters. Table 10 is a summary of the data provided by McLean (July 1970) in his indepth study of the groundwater resources of the Tularosa Basin. Table 10 gives the quality of water available in each township in a north to south line along the eastern edge of the floor of the Tularosa Basin. This is the area that has been indentified as having soils that are suitable for irrigated agriculture. The areas with favorable soils for irrigated agriculture are noted on Table 10 with the term "suitable soils" in

Table 10

Tularosa Basin
Groundwater Characteristics

Location		Groundwater Characteristics			
Township and Range	Sections	Potential Well Yield-GPM	Depth to Groundwater Described Feet	Water Quality TDS in mg/l	Notes and Remarks
T14S R10E	5,6,7,8 17,18,29 30,31,32	300-700	150-200	1000-3000 No moderately saline water	Sacramento Mts. to the east, thickness of slightly saline zone varies from zero at Mts. to 2500 ft. thick; suitable soils
T14S R10E	19,20	>700	150-200	1000-3000	Existing irrigated acreage; suitable soils
T14S R9E	W 1/2 of twp and Sec 3,5, 10	300-700	50 or less	1000-3000 Some moderately saline water in lower zones	WSMR, 500-1000 ft. thick slightly saline zone; suitable soils
T14S R9E	2,11,13 14,27,34	300-700	50-100	1000-3000. No moderately saline water in lower zones	Rio Tularosa; existing irrigation; 1500-2500 ft. thick slightly saline zone; suitable soils
T14S R9E	22-23	>700	100-150	1000-3000	Rio Tularosa; existing irrigation; suitable soils
T14S R9E				2,168 mg/l	Tularosa groundwater supply

Table 10 (continued)

Location		Groundwater Characterics			
Township and Range	Sections	Potential Well Yield-GPM	Depth to Groundwater Described Feet	Water Quality TDS in mg/l	Notes and Remarks
T14S R9E	1,12,24 25,35,36	300-700	100-150	1000-3000	1200-2500 ft. thick; suitable soils
T15S R9E	1,2,12 13,24	300-700	100	1000-3000	No moderately saline water in lower zone; slightly saline water 800 to 1200 ft. thick; suitable soils
T15S R9E	W 2/3 twp and sections 11,14, 23,25,26,35 36	W 1/3 >100 gpm	50 or less	1000-3000	West 1/3 of twp is WSMR, slightly saline zone is 0 to 800 ft. thick; no moderately saline zone; suitable soils in E½.
T15S R10E	W 1/3 of twp	300	100-150	1000-3000	1400 to 2000 ft. thickness of slightly saline water; no moderately saline lower zone; suitable soils
T15S R10E	4,9,16 21,28,33	500	150-200	1000-3000	Some irrigation wells, La Luz Canyon area, slightly saline zone 2200-2400 thick; no lower moderately saline zone, no fresh water; suitable soils

Table 10 (continued)

Location		Groundwater Characteristics			
Township and Range	Sections	Potential Well Yield-GPM	Depth to Groundwater Described Feet	Water Quality TDS in mg/l	Notes and Remarks
T15S R10E	3,10,11,14 15,22,23 26,27,34 35	500-750	200 or greater	1000-3000	0-2400 ft. thick; no moderately saline zone; small community wells; suitable soils
T16S R9E	NW 1/4, S 1/2 of twp	150	50 or less	1000-3000	Transmissivity 900 gpd/ft., storage coefficient 6%; no freshwater; 0-1200 ft. of slightly saline water
T16S R9E	1 2,12 3,11,13 10,14 15	500 300-500 300 300 300	200 150 125 100 50	1000-3000	No freshwater above this slightly saline water that ranges in thickness from 0-2000 ft.; transmissivity ranges from 1500 to 2500 gpd/ft., storage coefficient 8-9%; suitable soils
T16S R10E	Foothills of the Sacramentos to W 1/3 of twp	500-1000	150-200	1000-3000	Thickness of slightly saline aquifer is 0-2000 ft.; no freshwater available; City of Alamogordo wells transmissivity 2500-20,000; suitable soils

Table 10 (continued)

Location		Groundwater Characteristics			
Township and Range	Sections	Potential Well Yield-GPM	Depth to Groundwater Described Feet	Water Quality TDS in mg/l	Notes and Remarks
T17S R9E	W 5/6 of twp	150	50 or less	3000-10,000	Transmissivity 900 gpd/ft storage coefficeint 6%, 0-500 ft. of moderately saline water, no freshwater and only limited areas of slighlty saline water
T17S R9E	E 1/6 of twp	300	50-100	>1,000	Transmissivity 1500 gpd/ft., storage coefficient 8 %; freshwater 0-400 ft. thick; slightly saline water below fresh zone; small community wells; suitable soils
T17S R10E	W 1/6 of twp	500	100-150	>1,000	Transmissivity 2500 gpd/ft; storage coefficient 9%; 200-800 ft. of freshwater; zone of slightly saline water below fresh, 0-600 ft. thick; suitable soils

Table 10 (continued)

Location		Groundwater Characteristics			
Township and Range	Sections	Potential Well Yield-GPM	Depth to Groundwater Described Feet	Water Quality TDS in mg/l	Notes and Remarks
T17S R10E	Foothills of Sacramento Mts. to sections 5,8,17,20, 29,32	1000	150-200	<1,000	Alamogordo Canyon; 800 - 1000 ft. of freshwater; 600 feet of slightly saline water below fresh; suitable soils
T18S R9E	W 1/2 of twp	<300	50 or less	1000-3000	No freshwater; slightly saline zone thickness of 0-600; lower zone of moderately saline 1000-1500 ft. thick
T18S R9E	E 1/2 of twp	300-700	50	1000-3000	Freshwater in upper zone in sec. 1 and 2; lower zone of moderately saline water 2000 feet thick.
T185 R10E	5,6,7,8	300-700	100-200	<1000	Sacramento Foot Hills 800-1000 ft. fresh and 600 ft. of slightly saline; lower zone of moderately saline; suitable soils
T18S R10E	17,18	300-700	100-150	<1000	0-400 ft. of fresh unlain by 600 ft. of slighlty saline water; lower zone moderately saline; suitable soils

Table 10 (continued)

Location		Groundwater Characteristics			
Township and Range	Section	Potential Well Yield-GPM	Depth to Groundwater Described Feet	Water Quality TDS in mg/l	Notes and Remarks
T18S R10E	19,20,29, 30,31,32	300-700	50-100	1000-3000	Limited freshwater in some sections up to 200 ft. thick; slightly saline zone 300-500 ft. thick; lower zone of moderately saline water; suitable soils
T18S R10E	E 1/2 of twp	700-1000	200-250	<1000	Foothills of the Sacramentos with 0-1200 ft. of freshwater; suitable soils
T19S R9E	13,24, 25,36	300-700	100-150	1000-3000	0-200 ft. of slightly saline water, no freshwater; lower zone of moderately saline water 1000 ft. thick.
T19S R10E	4,5,6,7,8	300-700	100	1000-3000	No freshwater, slightly saline water 200-600 ft. thick; lower zone moderately saline water 2000 ft. thick.
T19S R10E	3,9,10, 16,17,18 29,30,31, 32	300-700	150	<1000	Grapevine Canyon; 200-600 ft. of freshwater; lower zone of slightly saline and moderately saline water 1000 to 2000 ft. thick; suitable soils

Table 10 (continued)

Location		Groundwater Characteristics			
Township and Range	Sections	Potential Well Yield-GPM	Depth to Groundwater Described Feet	Water Quality TDS in mg/l	Notes and Remarks
T19S R10E	E 1/3 of twp	>700	200	<1000	Fresh-water 850-1000 ft. thick; lower layer of slightly saline and moderately saline water 2500-3000 ft. thick, Grapevine Canyon area; suitable soils
T20S R9E	W 1/2 of twp	<300	50-100	3000-10,000	Moderately saline zone 250-500 ft. thick; no slightly saline water
T20S R10E	1,2,3	300-700		<1000	800-1000 ft. of freshwater over 500 ft. of slightly saline water; suitable soils
T20S R10E	4,5,6,7, 8,9,17, 18,19	300-700		<1000	0-600 ft. of freshwater; slightly saline zone 500 ft. thick lower zone of moderately saline water 0-500 ft. thick
T21S R10E	N 1/3 of twp	<300		<1000	200-400 ft. of freshwater over a 500-1000 ft. zone of slightly saline water and a 0-500 ft. thick layer of moderately saline water; suitable soils

Table 10 (continued)

Location		Groundwater Characteristics			
Township and Range	Section	Potential Well Yield-GPM	Depth to Groundwater Described Feet	Water Quality TDS in mg/l	Notes and Remarks
T21S R10E	SW 1/4 of twp	<300		<1000	200-400 ft. of freshwater over 1000 of slightly saline water; 0-500 ft. of moderately saline water; suitable soils
T22S R9E	All sections	<300		1000-3000	0-1000 ft. of slightly saline water over 0-500 ft. of moderately saline water
T22S R10E	All sections			1000-3000	Foot hills of the Sacramentos; suitable soils

the remarks column. Table 10 also gives potential well yields, depth to groundwater, some information on storage coefficients and transmissivity, and estimates of the thickness of each succeeding water quality strata. Groundwater in the Tularosa Basin still may be appropriated and put to beneficial use if an applicant can show that water is available, that existing water rights will not be impaired and that the proposed use is not contrary to the public welfare of the state nor the conservation of water.

A review of the information in Table 10 shows the following:

1. All three classes of groundwater (fresh, slightly saline, moderately saline) are available at various points in the basin;
2. There are areas where all three classes of water are available particularly if freshwater is transported a mile or so;
3. Well yields in the range of 300 to 700 gallons per minute can be obtained in a number of areas; that the highest yields are typically associated with the better water quality zones; and that the higher yields are typically found at greater depths along the mountain fronts;
4. The pumping lifts are acceptable for irrigated agriculture in areas where well yields on the order of 300 to 700 gpm are obtained and where groundwater with salinities in the range of 1,000 to 4,000 mg/l are found;
5. The zones where "slightly" and "moderately" saline water occur are sufficiently thick to provide a long-term water supply for irrigated agriculture;

6. Soils of suitable quality are found in most of the townships were an appropriate water supply exists; and
7. Areas can be found where the quality of the groundwater below a potential farm-site is relatively poor ("slightly" or "moderately" saline) such that the impact of irrigation drain return-flows will not preclude some other down-gradient use of the aquifer system.

Conservation and Environmental Concerns

Saline water use in the Tularosa Basin can be in the public interest and the use of these waters could, in fact, contribute to the conservation of fresh waters. If good site selection is made, adverse environmental impacts can be avoided.

The verified overlayering of waters of different qualities in the Tularosa Basin permits ready access to waters that range from a little less than 1,000 mg/l TDS to very high salinities. Table 10, shows that "fresh" water is not available in all of the townships along the eastern side of the basin. The upper zone is fresh water in the foothills and canyon areas. The upper layer becomes "slightly" saline, then "moderately" saline and finally "very saline" as you move from east to west from the mountains out into the basin floor.

This overlayering of water quality zones, and the east to west transition, also permits the selection of potential farming sites where irrigation drain-flows will not result in a significant potential for degradation of the water quality even where the supply source is "slightly" to "moderately" saline. The selection of well locations and the layout of farm fields could be made so as to lessen any potential impact on groundwater quality by irrigation return flows.

Economic Consideration

The lack of large-scale irrigated agriculture using groundwater in the Tularosa Basin raises questions about the economic feasibility of new developments using saline waters. Appropriate land areas in private ownership that have soils susceptible to farming appear to be available along the eastside of the basin as does an appropriate supply for conjunctive use of fresh and saline water.

A 1982 study (Libbin, 1982) shows a net operating profit for a small (50 acres) part-time farm operation in Otero County using a groundwater supply. The study results demonstrate a positive return on investment (for land and equipment) of 7.37 percent when land costs are not greater than $1,000 per acre. This rate of return is based on two area crops: alfalfa (70% of farmed area) and oat hay. It would appear that economic farm-units can be developed in Tularosa basin areas that meet the site-selection criteria and that contain lands that do not exceed the costs limits suggested by Libbin (1982).

Summary

The preceeding subsections discuss the climate, lands and soils, water resources, environmental aspects and economics of irrigated agriculture in the Tularosa Basin using saline water. While not an ideal site in all respects, it does meet the basic criteria for site selection as follows:

(a) the growing season is long enough (200 days plus);
(b) privately owned land in relatively large tracts is available;
(c) soils suitable for irrigation are available,

(d) a groundwater supply of both fresh and saline water is available that will provide well yields on the order of 300 to 700 gpm;

(e) the pumping lift from these groundwater zones is not excessive; and

(f) environmental concerns can be dealt with by careful farm-site selection.

A significant number of townships in the Tularosa Basin have been identified where the sole use of saline water for irrigated agriculture is possible in that all of the site criteria can be met. The conjunctive use of fresh and saline water also could be practiced in a number of townships. The unknown issue is farm economics; a detailed site-by-site study will be required to determine potential returns from irrigated agriculture because of the variation in land prices likely to be found in the area.

CONCLUSIONS

The original objective of this study was to identify sites in New Mexico where saline water is available and where other site characteristics are suitable for irrigation using the available, high total dissolved solids water supply. Unfortunately, decisions on site suitability cannot be made without detailed study of each potential area.

Criteria have been presented for the identification of areas suitable for irrigation with saline waters. While the selected sites for this study has been the arid southwestern state of New Mexico, these criteria can be applied to any region. There are both generalized and highly specific studies available for New Mexico on the soils, climate, water quality, geohydrology and on other important factors that will impact on suitability. Because of the complex interaction of these factors, it is difficult to reach a firm decision on site acceptability on the basis of generalized information only. Highly site-specific data is required. An example of this type of information is provided for the Tularosa basin in New Mexico.

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