EVALUATION OF AVAILABLE SALINE WATER RESOURCES FOR THE CONSTRUCTION OF LARGE-SCALE MICROALGAE PRODUCTION FACILITIES IN NEW MEXICO

by

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SUMMARY REPORT

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DISCLAIMER

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ABSTRACT

The major objective of the research was to select potential sites for 1,000-hectare (2,470 acre) microalgae production facilities in New Mexico using saline water resources. The emphasis of the research was twofold.

First, a data base was created with respect to the Solar Energy Research Institute (SERI) criteria for location of microalgae production facilities in New Mexico. Specific criteria included location, depth-to-water, aquifer characteristics, saturated thickness of aquifers, salinity, ionic composition, well-yields, growing season, topography, and land ownership.

Second, the data base was digitized for map construction. The desirable water supply for algae culture was limited to moderately or more saline groundwaters (3000 mg/l total dissolved solids or greater), because of the existing societal demands for the limited supply of better quality water.

After a review of the location of the 15 billion acre-feet of saline water resources in the state, areas that appeared to generally meet the SERI criteria for site selection were narrowed to the following--the Tularosa Basin in south-central New Mexico, the Estancia Basin in central New Mexico, the San Juan Basin in northwestern New Mexico, the Tucumcari area in Quay County on the eastside of New Mexico, the area east of the Pecos River Basin in eastern New Mexico, and the Crow Flats area in southern New Mexico.

A detailed analysis was completed for the six locations. Three basins were eliminated for failing to meet all the criteria developed for the study--Pecos Basin, San Juan Basin and the Tucumcari Area. Of the remaining basins, the Tularosa was judged best suited for a microalgae production facility, Crow Flats, the next best, and Estancia, the poorest of the three choices because of a short growing season.

The reserves of saline waters ranging from 2.3 million acre-feet to 5.0 million acre-feet were identified for the large-scale microalgae production areas in New Mexico.

Key Words: microalgae, saline water resources, microalgae potential production area, Tularosa Basin, Estancia Basin, Crow Flats, Pecos Basin, San Juan Basin, Tucumcari Basin

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INTRODUCTION

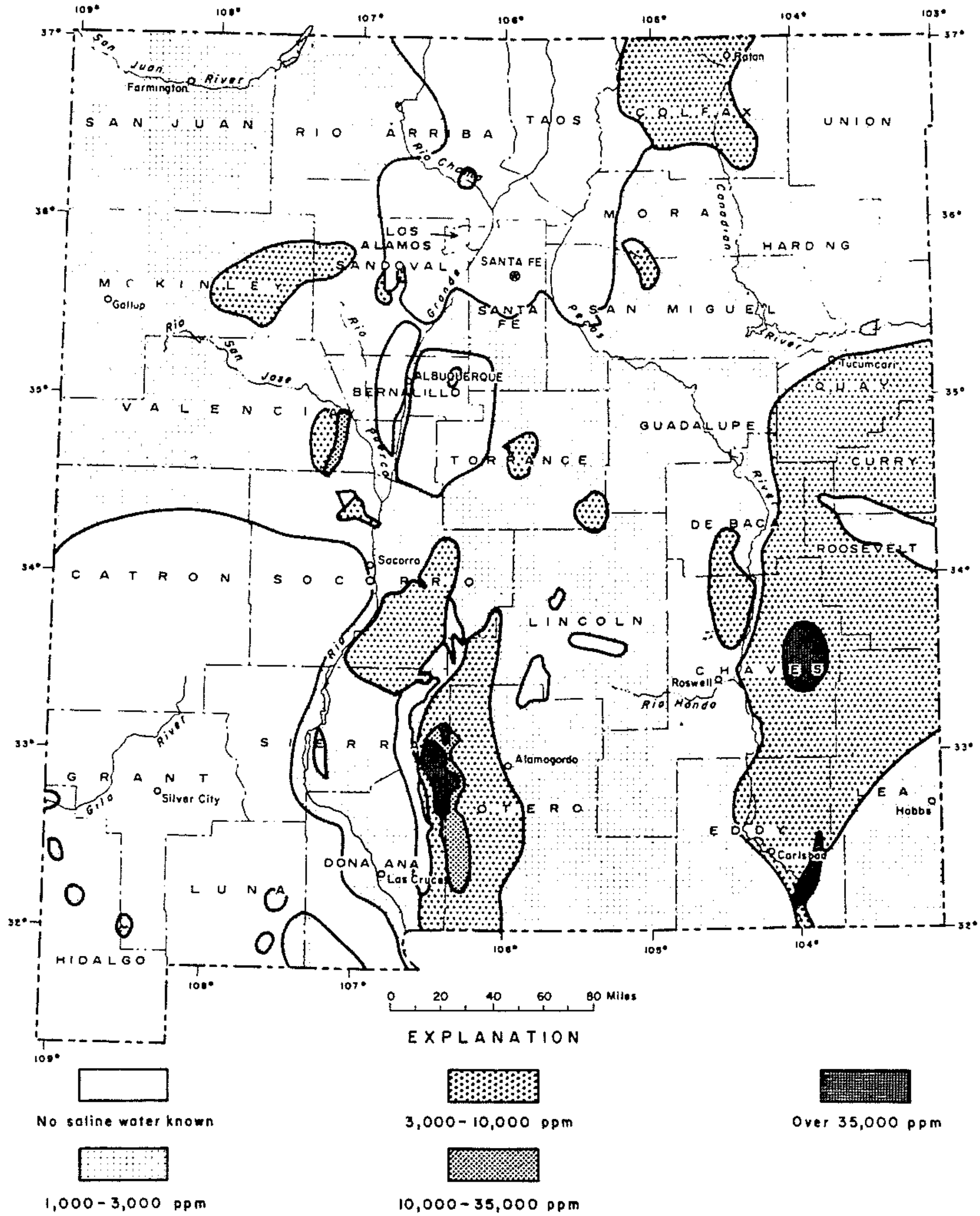
This report represents a contribution to the task of inventorying the saline water resources in New Mexico and screening them in terms of their suitability for large-scale (1,000 hectares or 2,470 acres) microalgae production facilities. This report is a condensed version of a larger report by the same authors titled, "Evaluation of Available Saline Water Resources in New Mexico for the Production of Microalgae." The larger report can be obtained from the Solar Energy Research Institute (SERI), 1617 Cole Boulevard, Golden, Colorado 80401.

Approximately 25 percent of the estimated 20 billion acre-feet of groundwater reserves in New Mexico is classified as fresh or slightly saline. The remaining 15 billion acre-feet of unutilized water is characterized as moderately saline, very saline and brine (Bureau of Reclamation 1976). The location of the state's saline groundwater reserves are relatively well known (figure 1), but the magnitude of these resources and aquifer characteristics have not been rigorously assessed on a state-wide basis. The recoverability of these saline groundwater reserves is also not well known because little effort has been made to utilize these aquifers.

OBJECTIVES

The major objective of this report was to identify potential site locations for large-scale (1,000 hectares or 2,470 acres) microalgae production facilities in New Mexico using unappropriated saline water resources.

The specific objectives of the research, as dictated by SERI, were:



Source: W. E. Hale, et al., 1985.

Figure 1. General Occurrence of Saline Groundwater in New Mexico.

1. Define areas within the state of New Mexico with saline aquifers with average depths-to-groundwater of less than 500 feet.

2. Determine those areas delineated in objective 1 that would provide water yields of less than 4 million gallons (12.3 acre-feet) per day (MGD), those areas with yields of 4-12 MGD, and those areas with yields greater than 13 MGD (40 acre-feet), without a serious decline in groundwater pumping levels and without a requirement for a large number of low-capacity wells.

3. Define the chemical composition (major ions and nutrients) of the groundwaters in areas that meet objectives 1 and 2.

4. Determine those areas delineated in objective 1 that would have land surface slope of less than 2 percent.

METHODOLOGY

The emphasis of the research was twofold. First, a data base was created with respect to the SERI criteria for location of a microalgae production facility. Specific site characteristics include data on location, depth to the aquifer of interest, saturated thickness of aquifer, aquifer characteristics, growing season, salinity, ionic composition, well-yields, topography and ownership. Second, the data base was digitized for the construction of the required maps. Maps for all characteristics can be found in Lansford, et al. (1986).

Specific SERI criteria included location, depth-to-water, aquifer characteristics, saturated thickness, salinity, ionic composition and well-yields, growing season, topography, land ownership, and facility size. The data base was digitized for the construction of maps. The desirable water supply for algae culture was limited to moderately or more saline groundwaters (3,000 mg/l TDS), because of the existing societal demands for the limited supply of better quality water.

The research tasks based upon specific criteria set up by SERI, and translated into working format, were ordered in the following fashion:

1. Basins were chosen based on reports and verbal communications with the State Engineer Office and other federal and state water agencies. Guidelines for basin selection were based on the availability of potential unappropriated water and the feasibility of applying this water to beneficial use.

2. The second task was to define depth to groundwater. Where possible, the depth-to-saline water was mapped in isorythmic form based on data from individual wells. The economic recoverability criteria of 500 feet of depth were adjusted by individual basin and calculations of total dynamic head (TDH) were made where possible.

3. Well-yields were mapped in isorythmic form and were based on data for specific wells. Further, a calculation was made to determine the well-yields needed for a 1,000 hectares facility in a region with a given rate of evaporation. General minimum allowable well-yields for 1,000 hectares, given 15 wells per section were approximately 200 gallons-per-minute (gpm) (assuming 24-hour pumping).

4. Basins were further limited by climate criteria. Data on growing season, precipitation, solar energy, temperature and evaporation were collected from the state climatologist and isorythmic maps were constructed. Length of growing season was the criteria considered closely here; while no cutoff was given, a growing season of approximately 200 days was considered optimal.

5. The next constraint for site selection concerns the maximum slope criteria of no greater than 2 percent land slope as set forth by SERI.

6. Potential sites for microalgae production facilities were further delineated by land ownership. Ownership was described as private, federal or state and mapped accordingly. The land ownership description helped limit large basins to areas suitable for locating facilities, e.g., no location on federal military reservations. Land ownership within a study area was used as a descriptive device rather than a constraint.

7. Water quality in terms of salinity (TDS) and ionic composition data was gathered for individual wells and isorythmic maps were constructed.

8. The final task was to briefly describe the environmental and legal issues for areas that were selected as potential sites.

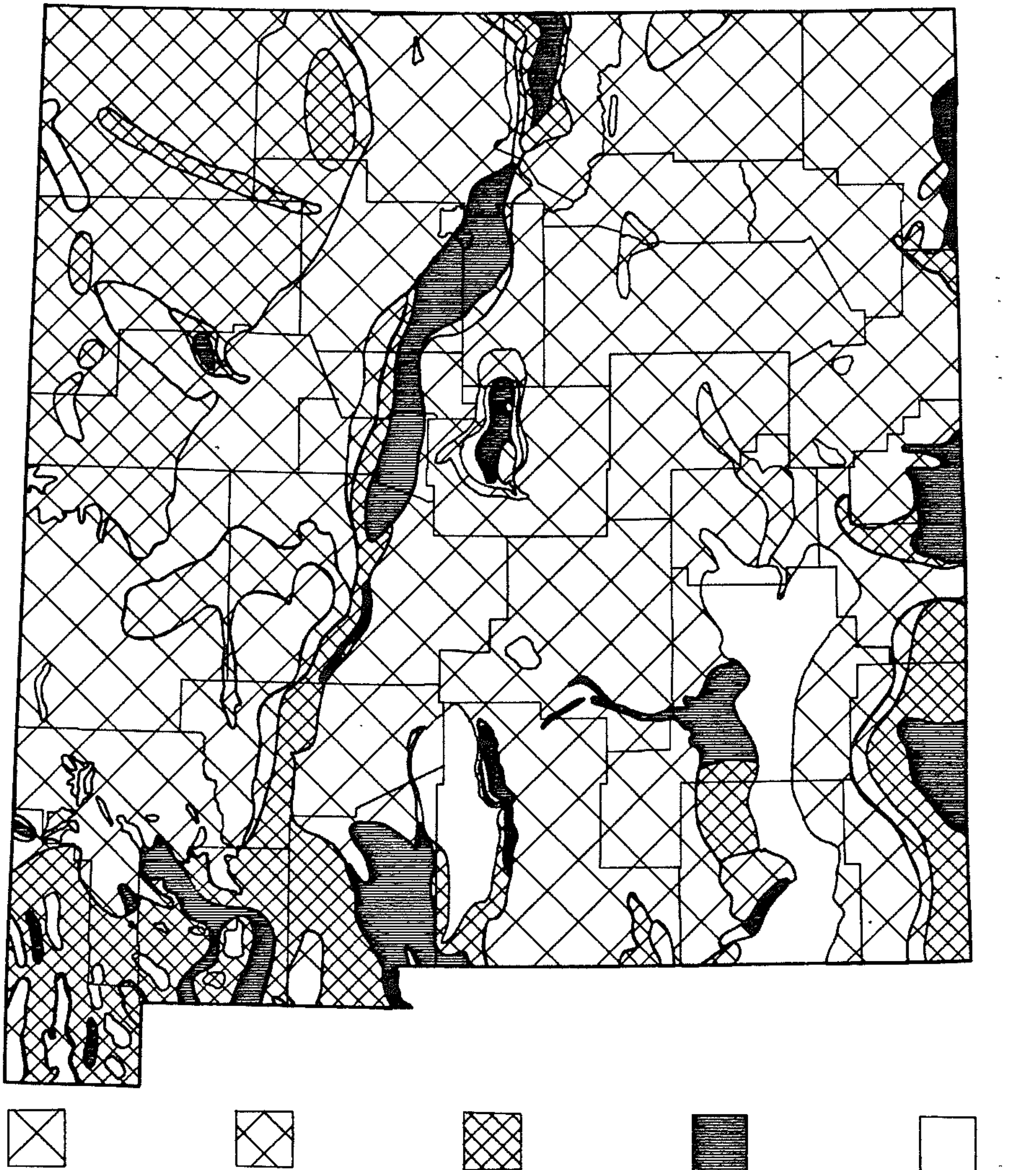
RESULTS

Production of microalgae could potentially provide a renewable source of fuel, chemicals and food, and could concurrently serve to engage the unutilized saline water resources of the state for increased economic activity.

The U.S. Bureau of Reclamation in cooperation with the New Mexico State Engineer Office (Bureau of Reclamation 1976) published general maps for potential well-yields and average aquifer thicknesses of the different classes of saline waters (figures 2, 3, 4 and 5).

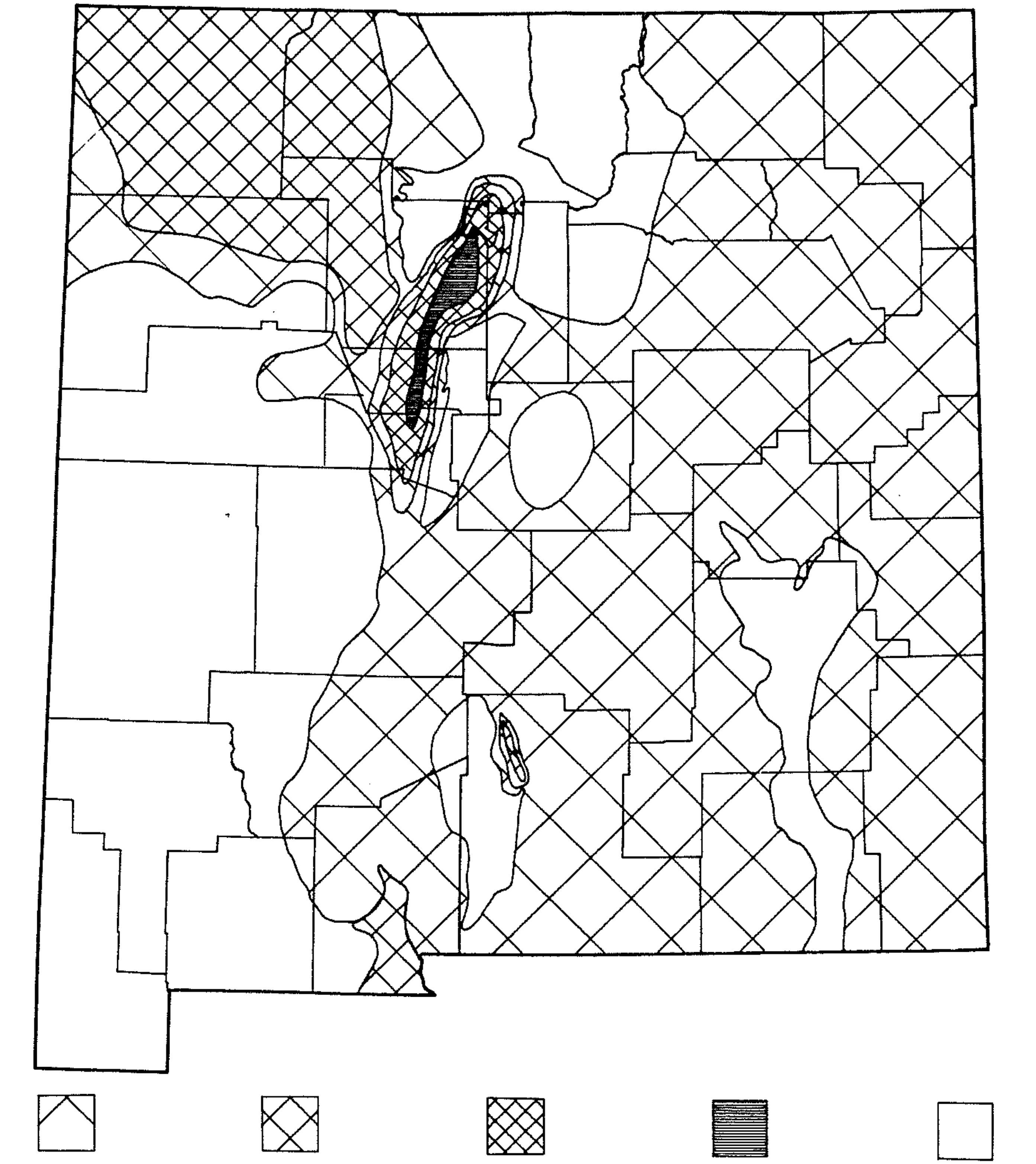
Average well-yields across the state vary from less than 25 gpm to more than 500 gpm (figure 2). The lower potential well-yields cover a large area in eastern and central New Mexico. The highest potential well-yields are typically associated with alluvial valley fills in or adjacent to river basins and can range up to 1,500 gpm.

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. The available water supply for algae production in New Mexico probably will be limited to moderately or very saline waters because of the current allocation of better quality water to existing uses. Both fresh (less than 1,000 mg/l TDS) and slightly saline waters (1,000 to 3,000 mg/l TDS) are now used for domestic, industrial and agricultural purposes. Moderately saline waters (3,000 to 10,000 mg/l) and more saline supplies are used sparingly at this time.



Units are in gallons-per-minute
Source: Bureau of Reclamation, 1976.

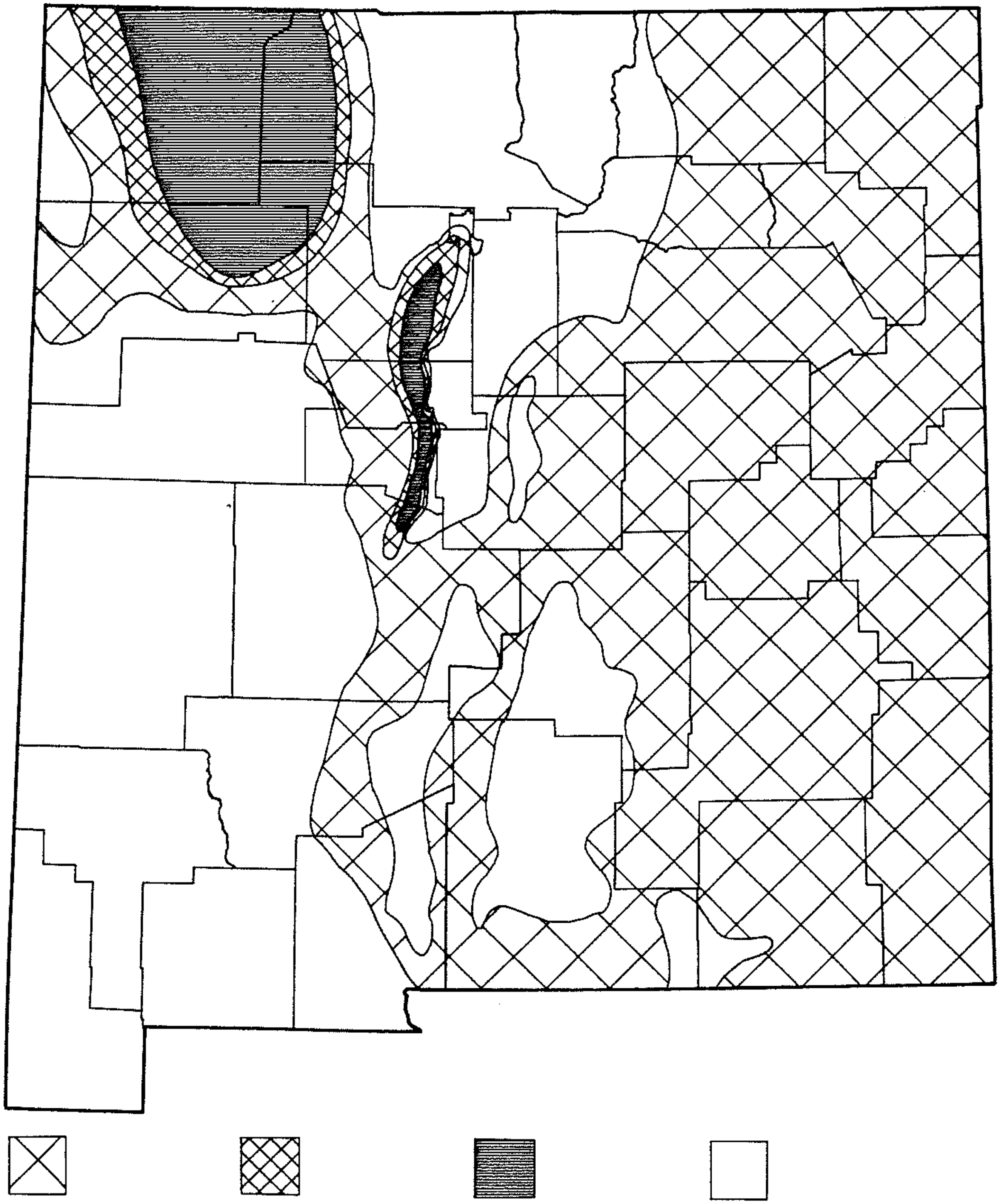
Figure 2. Estimated Potential Yield of Wells in New Mexico.



Units are in feet

Source: Bureau of Reclamation, 1976.

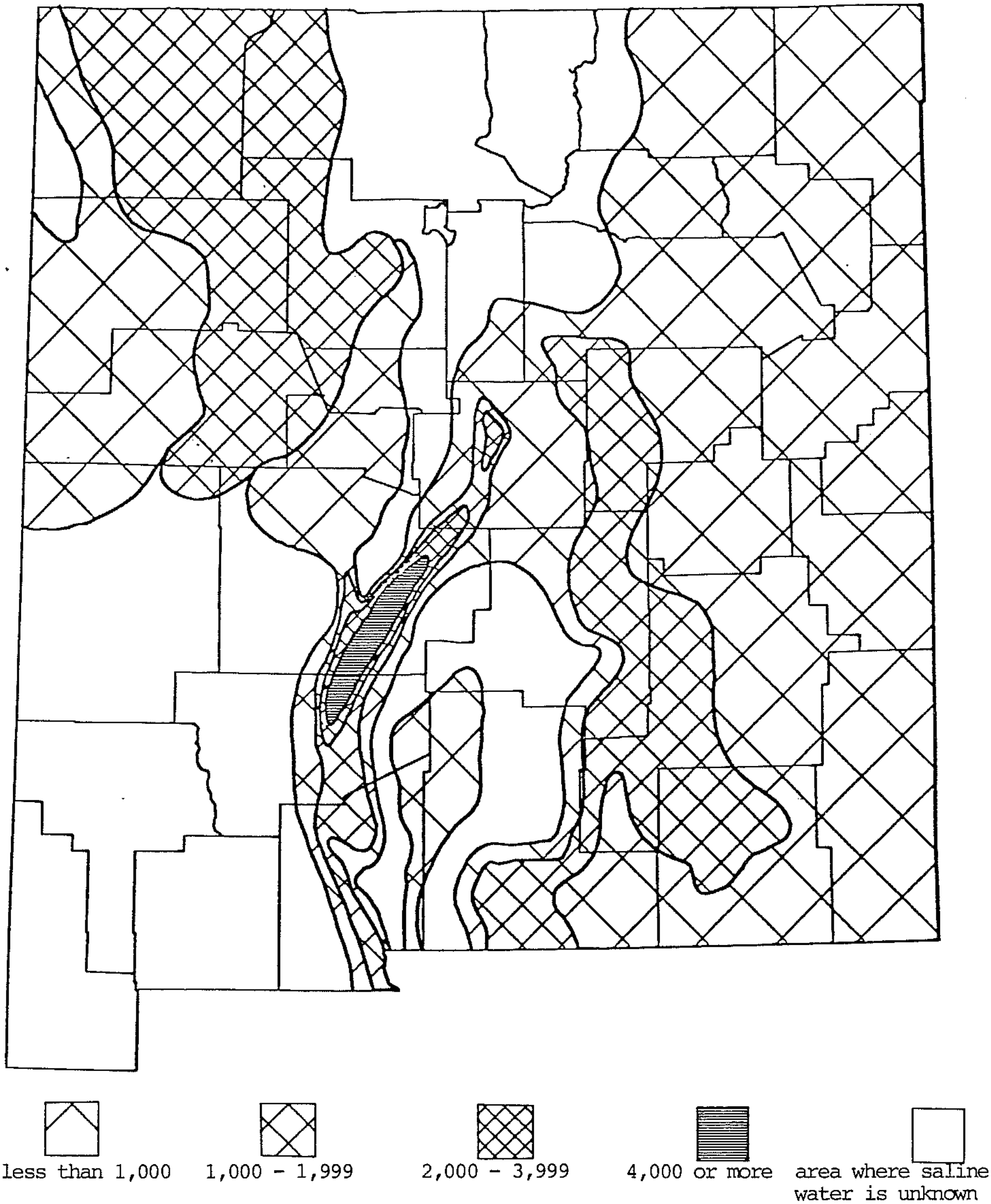
Figure 3. Estimated Thickness of Aquifers with Slightly Saline Groundwater in New Mexico.



less than 2,000 | 2,000 - 3,999 | 4,000 or more | area where moderately saline water is unknown

Units are in feet
Source: Bureau of Reclamation, 1976.

Figure 4. Estimated Thickness of Aquifers with Moderately Saline Groundwater in New Mexico.



Units are in feet
Source: Bureau of Reclamation, 1976.

Figure 5. Estimated Thickness of Aquifers with Very Saline Groundwater in New Mexico.

The New Mexico state engineer identified declared underground water basins in New Mexico with unappropriated groundwater (table 1). The research reflects the analysis of a selected group of groundwater basins within New Mexico that have known unappropriated water resources (DuMars 1986). Those basins having unappropriated groundwater were discussed with state and federal water-related agency personnel. They were asked about more precise location, availability of data on depth to the saline groundwaters, well-yields, and the quantity of water available in those basins.

Based on the discussions with the above experts, the following basins were eliminated based upon water quality considerations: Animas Basin, Lordsburg Basin, Mimbres Basin, and Nutt-Hockett Basin. Nearly all of the unappropriated groundwaters in these basins are classified as fresh or slightly saline (figure 3).

The aquifers with the greatest potential quantity of slightly saline waters (1,000 to 3,000 mg/l TDS) are located in the Middle Rio Grande Basin (figure 3). However, the saline waters lie at depths below fresh water in the area (Kelly, et al. 1970). The second largest quantity of slightly saline water is located in northwestern New Mexico with aquifer thicknesses between 2,000 and 4,000 feet. Again, these saline waters are deep, also potential well-yields are low (Stone, et al. 1983).

The moderately saline water resources (3,000 to 10,000 mg/l TDS) with the greatest aquifer thicknesses are in the same general areas as the slightly saline water resources (the Middle Rio Grande Basin and

Table 1. Water Available for New Appropriations in Declared Underground Water Basins.*

Basin	Unappropriated Groundwater
	- - million acre-feet - -
Closed Aquifers	
Animas	0.00
Estancia	2.04
Hueco	6.20
Jal	0.04
Lea County	0.77
Lordsburg	0.60
Mimbres	3.70
Nutt-Hockett	0.13
Tucumcari	0.40
Tularosa	10.70
Tributary Aquifers	
Upper Rio Grande	9.30
Middle Rio Grande	2.70
Lower Rio Grande	5.00
Pecos River	8.00
San Juan	21.50

Source: DuMars, Charles T., F. Lee Brown, Ronald G. Cummings, Robert Lansford, Ann Berkley Rodgers and Albert E. Utton. "State Appropriation of Unappropriated Groundwater: A Strategy for Insuring New Mexico a Water Future." New Mexico Water Resources Research Institute and University of New Mexico Law School, January 1986.

*Quantities do not include saline groundwaters.

northwestern New Mexico) (figure 4). The moderately saline waters generally lie at depths below the slightly saline water resources in these regions (Kelly, et al. 1970). Therefore, the Middle Rio Grande Basin and areas in northwestern New Mexico (with the exception of the San Juan Basin) were eliminated from consideration based upon the depth of saline water and saline aquifers that are overlain by fresh water.

The very saline water resources (10,000 to 35,000 mg/l TDS) are presented in figure 5. The area in Sierra and Socorro counties with largest aquifer thicknesses (more than 6,000 feet thick) are overlain with slightly and moderately saline water resources. These very saline water resources are generally over 1,000 feet deep. These areas with aquifer thickness between 4,000 and 6,000 feet generally are deep with the exception of a small area in the Estancia Valley. Other aquifers of lesser thicknesses are located in New Mexico at estimated great depths.

The Hueco Basin was eliminated because of the moderately to very saline groundwaters located near the edge of the basin overlain by fresh water. The center of the basin also includes part of Ft. Bliss Military Reservation.

Two studies were used to review the Ogallala Aquifer High Plains portion of New Mexico as an area with potential for siting large-scale microalgae production facilities. Lansford, et al. (1982) and Krothe, et al. (1982) determined depth-to-groundwater and salinity in terms of TDS, respectively. At depths that range from 10 to 325 feet, salinity in terms of total dissolved solids ranged from 500 - 1,000 mg/l as determined by Krothe (1982). Generally below 500 feet, groundwater quality deteriorates to levels that would be acceptable based on SERI criteria. However, at greater depths, the well-yields in the aquifer tend to be low as salinity increases. The Jal and Lea County basins were eliminated based on depth to moderately and very saline groundwater resources. In these basins, nearly all of the saline water is overlain by fresh water.

The following six drainage basins were identified as areas with the greatest potential for siting microalgae production facilities utilizing unappropriated saline groundwater: Tularosa Basin, Estancia Basin, Crow Flats Basin, Pecos Basin east of the Pecos River, San Juan Basin, and Tucumcari Area (figure 6). Three of the six basins were eliminated after consideration of the first two research tasks (availability of unappropriated groundwater and depth-to-groundwater of less than 500 feet). They were the Pecos Basin, the San Juan Basin and the Tucumcari Area.

The Pecos Basin east of the Pecos River in southeastern New Mexico, was removed from consideration as a potential location for microalgae production facilities because the area had poorly documented and very limited data on volume and potential well-yield of saline waters (Geohydrology Associates, 1978). One exception to this is the area between Roswell and the Pecos River. The Roswell Saline Water Test Facility about six miles east of Roswell, has a well that produces 400 to 600 gpm of very saline water (10 - 35,000 mg/l TDS) pumping from a depth of 120 feet (communications with Mr. C. Sparnon, City of Roswell, NM). This data was indicative of the water quality 10 to 15 miles both north and south of Roswell. However, size of facility (1,000 ha.), existing groundwater and land use and predominantly

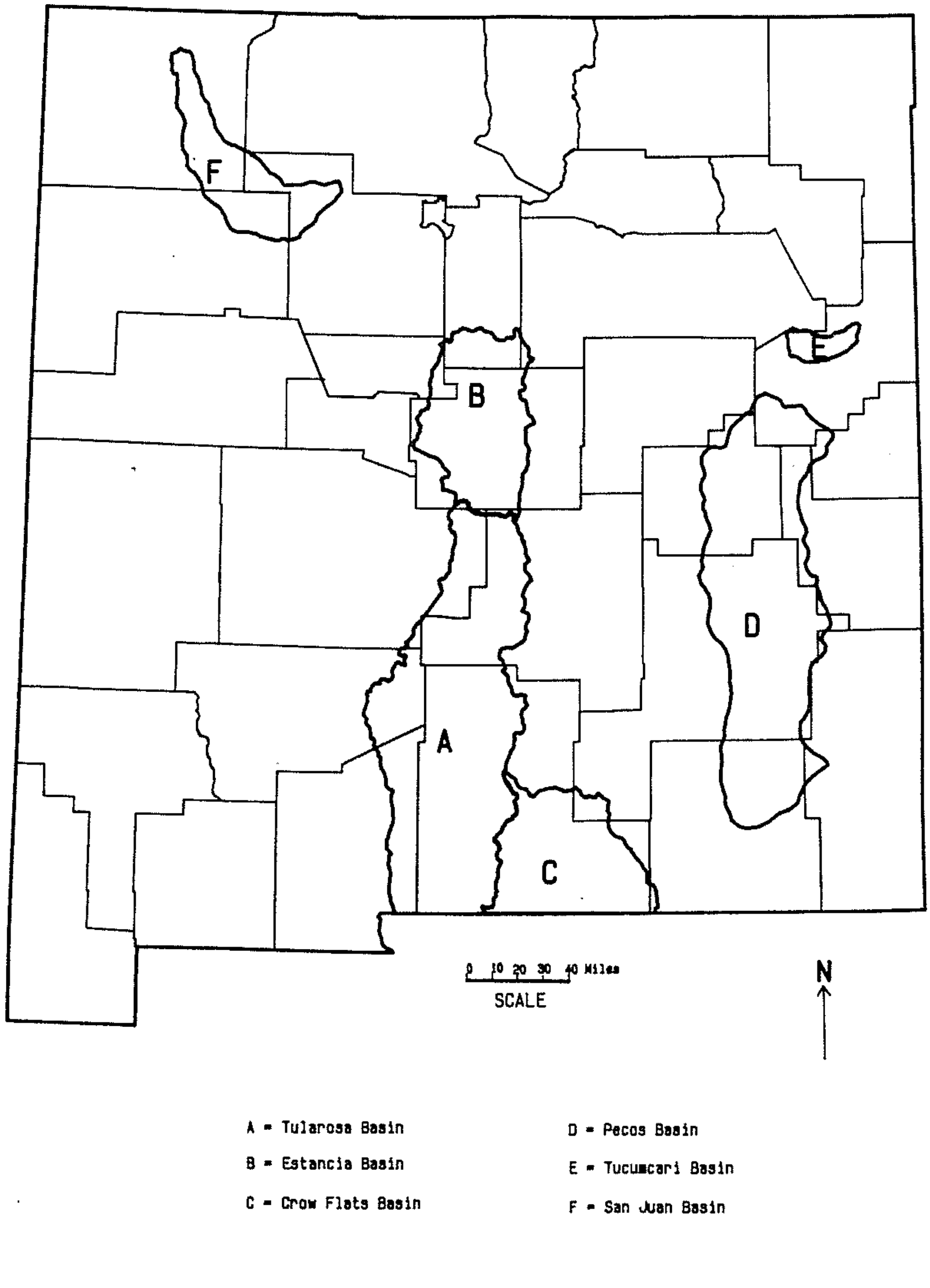


Figure 6. Areas Best Suited for Location of Microalgae Production Facilities in New Mexico.

private ownership in the area were additional factors that led to the elimination of the Roswell area west of the Pecos River as a potential site. The existing water rights structure might preclude any new appropriations of water because the Roswell Declared Basin is already considered to be over-appropriated. This matter, however, as it relates to new saline groundwater appropriations is not clear at this time. The Pecos Valley Artesian Conservancy District has a standing offer to buy and retire groundwater rights within the declared basin.

The San Juan Basin was also removed from consideration as a potential site for a production facility. The basin contains saline waters, but depths-to-water and low potential well-yields make the area unsuitable (Stone, et al. 1983). The San Juan Basin also has the disadvantage of highly complex land ownership patterns involving tribal Indian lands, federal lands, state lands and private lands.

The Tucumcari area was removed from consideration because the volume of saline water and potential well-yields in the area were too low to meet SERI criteria for consideration as a site for microalgae production. The saline waters in the area are largely a result of irrigation return flows and leakage from the canal and lateral system (Berkstresser and Mourant 1966).

The remaining three basins have areas that contain the greatest potential for siting microalgae production facilities. They are the Tularosa Basin, the Estancia Basin, and the Crow Flats Basin.

THE TULAROSA BASIN

The Tularosa Basin in south-central New Mexico was selected for analysis for the location of large-scale (1,000 hectares) microalgae production facilities (figure 7). The area of interest in the Tularosa Basin lies in Otero County on the eastside of the valley floor along the alluvial fans generated by the drainage systems from the mountains just to the east. The City of Alamogordo is within the area of interest. The area was derived using the SERI criteria.

North of this area, potential sites for microalgae production facilities are limited by slopes of greater than 2 percent and the outcrop of consolidated rock that forms the upper boundary of the alluvial valley. To the east and south of the tract, acceptable locations are limited by the Lincoln National Forest, the Mescalero Apache Indian Reservation and Fort Bliss Military Reservation (McGregor Range). Land slope is a further constraint on the eastern boundary. To the west, the availability of sites is limited by the White Sands Missile Range which occupies a majority of the western half of the Basin. White Sands National Monument is also in the valley floor to the west.

Potential Production Areas

Two possible sites that met the SERI criteria for location of large scale (1,000 hectares) microalgae production facilities were identified within the Tularosa Basin (figure 7). An area of approximately 115 square miles composed of two distinct sites was selected based on availability of moderately and very saline groundwater. The basic SERI site-selection criteria and groundwater characteristics are presented in table 2 for each of the sites.

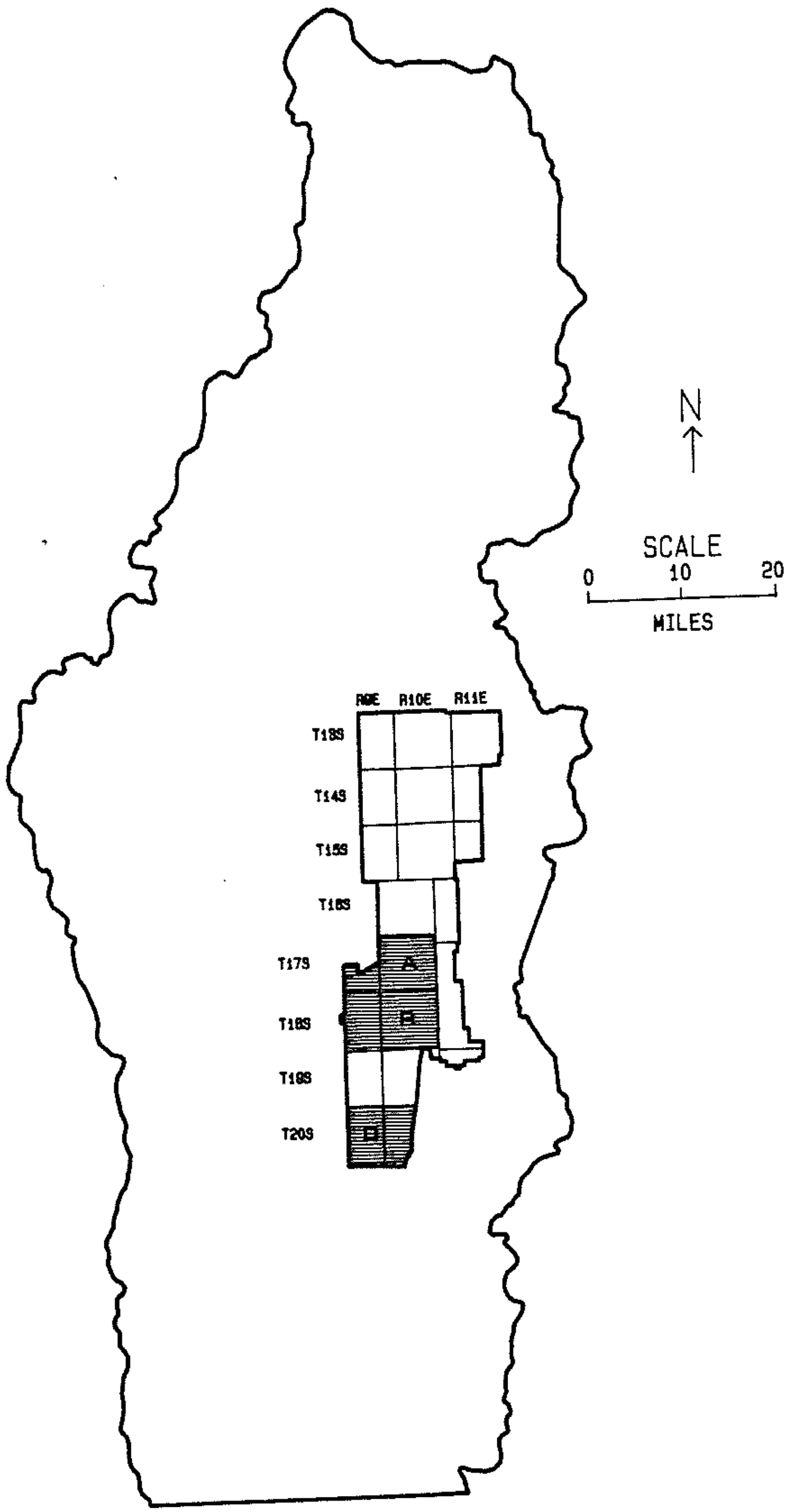


Figure 7. Potential Microalgae Production Areas in the Tularosa Basin, New Mexico.

Site A

Site A encompasses approximately 40 square miles (a little over 25,000 acres) and lies in T.17 S., R.8 and 9 E. (figure 7). This area is southwest of Alamogordo and borders on White Sands Missile Range and Holloman Air Force Base. The slope criteria (not greater than 2 percent) is met within this area (table 2). Land ownership in this area is approximately 40 percent private, 35 percent federal and 25 percent state-owned. The growing season is in excess of 200 days.

Groundwater Resources. Basic data for the groundwater resources of the Tularosa Basin were taken from McLean (1970) and Hernandez (1986). Additional well data were obtained from personal interviews with U.S. Geological Survey personnel. Groundwater quality in the site is between 10,000 and 35,000 mg/l TDS and has a range of saturated thickness of up to 2,000 feet (table 2). Potential well-yields are about 300 gpm for the entire area, but the depth-to-groundwater is less than 50 feet. In terms of an acceptable site, well-yields are marginal as it will require a minimum of ten wells to meet the SERI criteria of well production of 4 million gallons-per-day (MGD). More than 30 wells would be required to meet the SERI criteria of production of 13 MGD.

The reserves of saline water in storage were estimated for the 40 square-mile potential production area. The reserves were estimated based on a saturated thickness of 250 to 500 feet and a storage coefficient of 6 to 10 percent. The recoverable volume of water in storage would be on the order of 385,000 acre-feet to 1,248,000 acre-feet.

Table 2: Site and Groundwater Characteristics of the Tularosa Basin, NM.

	Unit of Measurement	Site A	Site B
Site Characteristics			
Area	square miles	40	75
Slope	percent	< 2	< 2
Ownership			
Federal	percent	35	15
State	percent	25	10
Private	percent	40	75
Growing Season	days	200 - 205	205 - 210
Evaporation	inches	70 - 75	75 - 80
	centimeters	178 - 191	191 - 203
Water Resources			
Depth-to-Groundwater	feet	0 - 50	0 - 50
	meters	0 - 15	0 - 15
Potential Well-Yield	gpm	up to 300	up to 300
	liters per minute	up to 1,135	up to 1,135
Average pH		7.0 - 7.6	7.0 - 7.6
Estimated Reserves	acre-feet	384,000 - 1,280,000	720,000 - 2,400,000
	cubic meters	474,000,000 - 1,580,000,000	880,000,000 - 2,960,000,000
Groundwater Quality	mg/l	10,000 - 35,000	3,000 - 10,000
Ionic Composition			
Ca	mg/l	50 - 3,100	100 - 950
Na & K	mg/l	20 - 12,600	50 - 2,100
Mg	mg/l	20 - 3,400	50 - 1,660
SO_4	mg/l	30 - 9,300	300 - 3,100
Cl	mg/l	30 - 24,000	50 - 4,200
HCO_3	mg/l	20 - 380	80 - 250

Recharge of groundwater within the basin occurs primarily from precipitation and runoff within the closed basin.

The groundwater quality in this site is classified as very saline with a range from 10,000 mg/l to 35,000 mg/l TDS (table 2). There is almost no occurrence of groundwater of less than 3,000 mg/l TDS. The pH of the groundwater ranges from 7.0 to 7.6. The ionic concentrations for the groundwater of the area are also presented in table 2. Sulfate and chloride ions have the highest concentrations.

Site B

This area encompasses approximately 75 square miles and meets all of the SERI criteria (figure 7). It is located in T.18 S., R.8 and 9 E. and T.20 S., R.8 and 9 E. The site characteristics are similar to site A with the exception of land ownership (table 2). Land ownership patterns approximate the following: 15 percent federal, 10 percent state, and 75 percent private.

Groundwater Resources. The groundwater characteristics are quite similar to those found in site A with the exception of water quality (table 2). The water quality is moderately saline (3,000 to 10,000 mg/l TDS) for site B as compared to very saline for site A. Therefore, the ionic concentrations are much lower than for waters found in site A. Well-yields for the area are below 300 gpm for the site and the depth-to-water is 50 feet or less. There is virtually no occurrence of fresh water or of water below the 3,000 mg/l TDS level in the area.

THE ESTANCIA BASIN

An area of approximately 170 square miles in the Estancia Basin was selected for analysis (figure 8). This area lies north and east of Moriarty to about 15 miles south and east of Willard. The area was derived using natural boundaries, geologic formations, political boundaries, and slope criteria. North of the area sites are limited by slope as the drainage basin merges with plateau lands. To the east and west of the basin, the Pedernal Hills and Manzano Mountains, respectively, produce slopes greater than 2 percent. The selection of the southern boundary of the area was made based on mesa lands and federal ownership in the Cibola National Forest. Surface waters from the west, north and east drain into the central valley that terminates at the southern end of the long playa lake of Laguna del Perro.

Potential Production Areas

The geology of the valley floor makes the Estancia drainage basin a prime location for microalgae facilities. A series of playas or dry alkali lake-beds on a north-south axis in the southern end of the basin would make ideal locations.

Two connecting areas within the Estancia Basin meet the SERI criteria for the location of microalgae production facilities with the possible exception of growing seasons. The average growing season of 140 to 160 days may be a major limitation for these sites (table 3). Groundwater quality, depth, potential well-yields and land slope were identified and found to meet SERI standards (table 3).

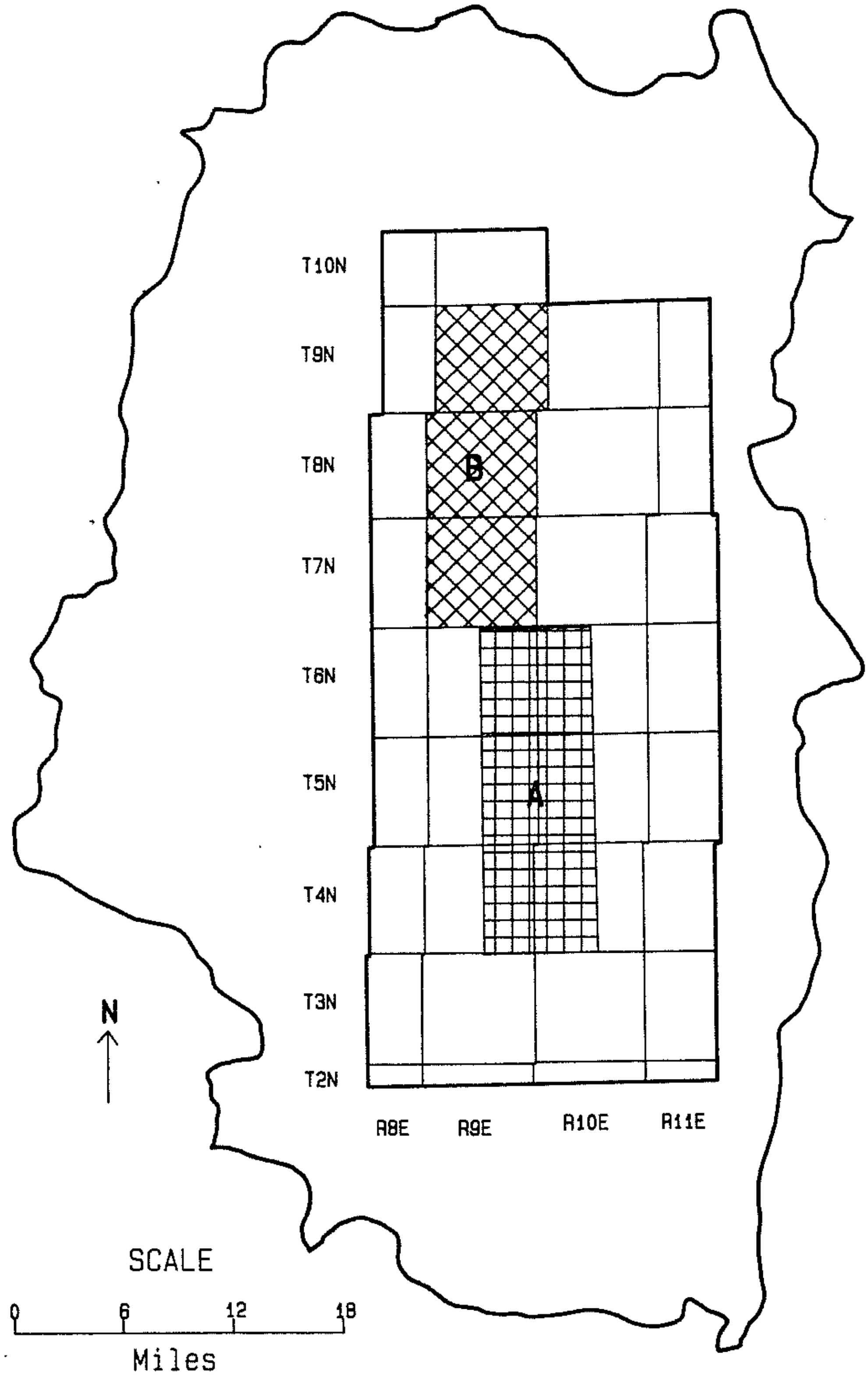


Figure 8. Potential Microalgae Production Areas in the Estancia Basin, New Mexico.

Table 3: Site and Groundwater Characteristics of the Estancia Basin, NM.

	Unit of Measurement	Site A	Site B
<u>Site Characteristics</u>			
Area	square miles	80	90
Slope	percent	< 2	< 2
Ownership			
Federal	percent	15	10
State	percent	25	30
Private	percent	60	60
Growing Season	days	150 - 160	140 - 150
Evaporation	inches	50 - 55	45 - 50
	centimeters	127 - 140	114 - 127
<u>Water Resources</u>			
Depth-to-Groundwater	feet	0 - 30	0 - 30
	meters	0 - 9	0 - 9
Potential Well-Yield	gpm	up to 1,000	up to 1,000
	liters per minute	up to 3,790	up to 3,790
Average pH		7.3 - 7.8	7.3 - 7.8
Estimated Reserves	acre-feet	155,000 - 615,000	173,000 - 692,000
	cubic meters	191,000,000 - 759,000,000	213,000,000 - 854,000,000
Groundwater Quality	mg/l	3,000 - 5,500	1,500 - 3,000
Ionic Composition			
Ca	mg/l	50 - 640	40 - 290
Na & K	mg/l	20 - 750	30 - 210
Mg	mg/l	40 - 480	20 - 180
SO_4	mg/l	120 - 3,200	60 - 1,050
Cl	mg/l	10 - 1,440	30 - 4,900
HCO_3	mg/l	65 - 900	190 - 350

Site A

The 80-square-mile area lies immediately east of Estancia on the north to about 5 miles south of Willard (figure 4). The width of the area is approximately 6 miles. The best site for the location of production facilities would be near the existing playa lakes, as the water quality is poorest and surface flows terminate at these alkali flats and provide groundwater recharge. The land ownership pattern is approximately 15 percent federal, 25 percent state and 60 percent privately-owned lands. The growing season ranges from 150 to 160 days.

Groundwater Resources. Basic data for the groundwater resources of the Estancia Basin was taken from Smith (1957) and the state engineer (1975). Additional well data was obtained from the U.S. Geological Survey. Groundwater quality in the shallow-zone is expected to have total dissolved solid of 3,000 mg/l or more (table 3). The thickness of this poor-quality alluvial zone varies from 30 to 80 feet thick in the center of the playa portion of the basin (Smith 1957). However, there is groundwater with less than 3,000 mg/l TDS below the upper zone.

Potential well-yields from this saline zone range from 700 to 1,000 gpm, but could be as high as 1,200 gpm. Depth-to-groundwater ranges from zero to 50 feet. If well-yields are at the high end of the range, a minimum of four wells would produce the SERI requirement of at least 4 MGD. Approximately 13 wells would be required to meet the SERI criteria for areas with a daily production of 13 MGD.

A range of possible reserves was estimated for the 80-square-mile surface area, a saturated thickness of 30 to 80 feet and a storage coefficient of 10 to 15 percent. The estimated recoverable volume of moderately saline water in storage would be on the order of 155,000 acre-feet to 615,000 acre-feet. Groundwater recharge occurs primarily from precipitation and runoff as there are no major surface water sources. The pH of waters in the basin were estimated to range from 7.3 to 7.8 with some outliers. The specific ions that are likely to be found in abundance in the more saline waters in the valley fill immediately below the playa are chlorides, sulfates, and bicarbonates (table 3).

Site B

A second, large area (90 square miles) appears to generally meet the criteria except for groundwater quality and the growing season of 140 to 150 days (table 3). This area is east of Highway 41 between Moriarty and Estancia (figure 8). The width of this tract is approximately 5 miles. The slope criteria of 2 percent is met in this area and ownership patterns approximate the following: 60 percent private, 10 percent federal and 30 percent state.

Groundwater Resources. The water resource characteristics in this area are almost identical to those found in site A with the exception of water quality (table 3). The total dissolved solids in the well samples runs from 1500 mg/l to 3,000 mg/l TDS which is slightly saline. Throughout this site, poorer quality water is believed to overlie better quality water. The depths-to-groundwater for poorer quality waters ranges from zero to 30 feet. The saturated thickness of the relatively poorer quality upper zone ranges from over zero to approximately 80 feet. Water quality and potential well-yields in the upper zone were marginal with respect to the SERI criteria for groundwater resources.

Because the water quality in this upper zone is likely to be classed as slightly saline and is potentially useable for irrigated agriculture, there may be legal challenges and opposition to its use for microalgae culture. The very short growing season combined with slightly saline groundwater would eliminate this site from consideration.

THE CROW FLATS AREA

The Crow Flats Area in south-central New Mexico is part of the larger Salt Basin (figure 9). The Salt Flats Basin is bordered by the Tularosa Basin on the west, the Pecos River Basin on the north and east and the state of Texas on the south and has an area of 2,370 square miles. The vast majority of the area is located within Otero County with small areas in Chaves and Eddy counties. Elevations range from 3,000 feet near the alkali flats in the southern end to approximately 4,500 feet in the surrounding hills (Bjorklund 1957).

Potential Production Area

A limited area of interest within the Crow Flats Area was identified. This area lies in the southeast portion of the Salt Basin bordering on the New Mexico-Texas state line on the south (figure 9). North and east of the area of interest, slopes greater than two percent exist near the Guadalupe Mountains. Potential sites were also limited

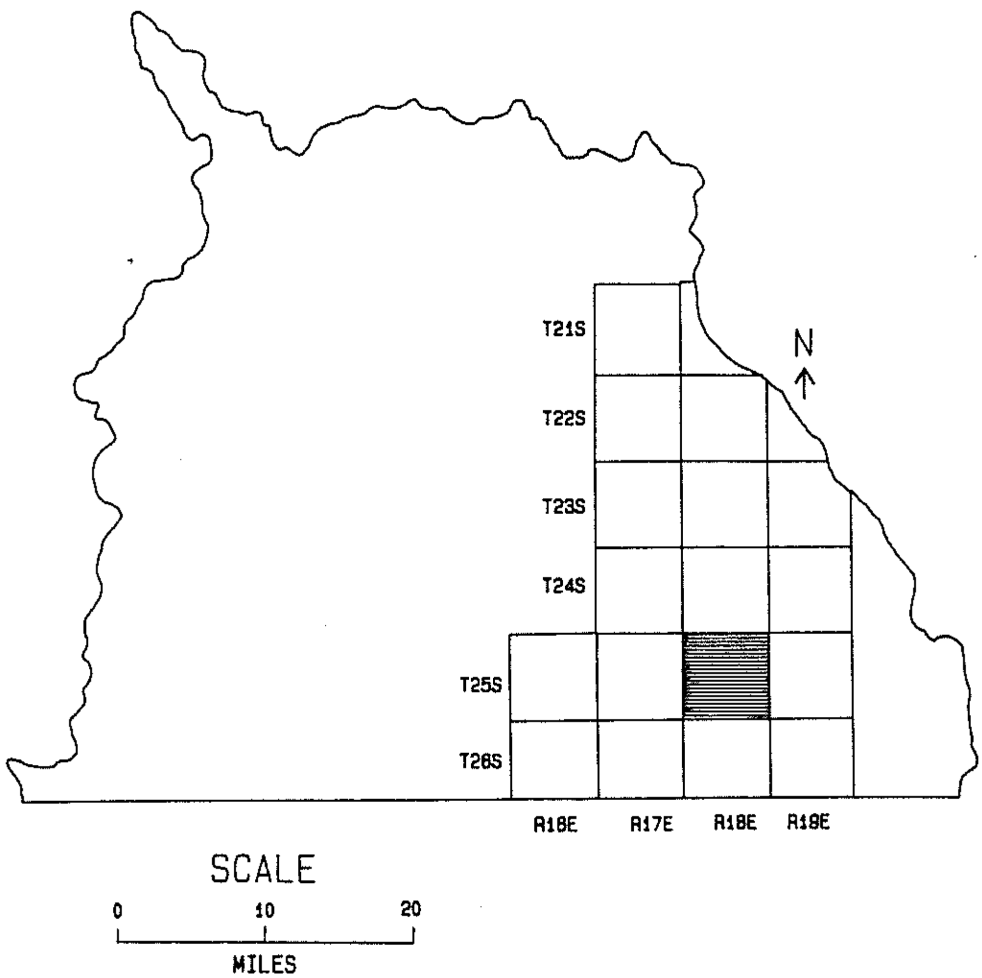


Figure 9. Potential Microalgae Production Areas in the Crow Flats Area, New Mexico.

on the north and east by outcrops of limestone rock. To the south, acceptable locations were limited by the New Mexico-Texas state line. The researchers did not have access to data for Texas, although the valley of the basin runs south into Texas and it is believed that acceptable sites can be located there. To the east of the area of interest lie the Cornudas Mountains, which produce land slopes that are greater than 2 percent. The eastern edge is also limited geologically by outcrops of limestone rocks.

One potential production area in the Crow Flats Area meets all of the SERI criteria for a facility. This area is situated on a north-south axis around T.25 S (figure 9). The average width of this area varies from 4 to 6 miles for an area of about 36 square miles. The growing season is in excess of 200 days. The approximate land-ownership pattern is 20 percent private, 70 percent federal and 10 percent state (table 4).

Groundwater Resources. Potential well-yields for the area of interest were obtained from a New Mexico State Engineer Office report by Bjorklund (1957). In the valley fill, reported well-yields ranged from 350 gpm to 840 gpm with several wells reported at over 1,000 gpm. Data from farmers in the area indicate well-yields in excess of 1,000 gpm are not uncommon. Given potential well-yields, a minimum of 4 wells would be required to meet the SERI criteria of 4 MGD. Depth-to-ground-water in the 36-square-mile area ranges from 25 to 100 feet (table 4). Depth-to-groundwater increases near the surrounding hills and increases to 400 feet in the area of limestone outcrops.

Table 4: Site and Groundwater Characteristics of the Crow Flats Basin, NM.

	Unit of Measurement	
Site Characteristics		
Area	square miles	36
Slope	percent	< 2
Ownership		
Federal	percent	70
State	percent	10
Private	percent	20
Growing Season	days	200 - 210
Evaporation	inches	70 - 75
	centimeters	178 - 191
Water Resources		
Depth-to-Groundwater	feet	50 - 110
	meters	15 - 35
Potential Well-Yield	gpm	up to 1,000
	liters per minute	up to 3,790
Average pH		6.9 - 7.3
Estimated Reserves	acre-feet	576,000 - 1,382,000
	cubic meters	710,000,000 - 1,700,000,000
Groundwater Quality	mg/l	1,000 - 3,000
Ionic Composition		
Ca	mg/l	224 - 556
Na & K	mg/l	22 - 65
Mg	mg/l	177 - 264
SO_4	mg/l	719 - 2,230
Cl	mg/l	32 - 275
HCO_3	mg/l	158 - 284

Recharge is minimal in the basin and groundwater mining is occurring. Groundwater levels declined significantly in the 1950s, but the rate of change in water levels has since stabilized because of reduced pumpage. Some decline has continued to occur and any new use of groundwater in the basin will possibly result in additional declines.

Water quality at the edges of the valley floor is on the order of 1,000 mg/l TDS. Water quality in the valley floor ranges from 1500 to 3,000 mg/l TDS (table 4). The water quality for the alkali flats would be classified as slightly saline with TDS ranging from 1,500 to 2,500 mg/l.

This water resource may not be available for use in microalgae production because of legal protests from existing water-right owners. This groundwater is currently used for irrigation, livestock, and domestic uses.

SUMMARY & CONCLUSIONS

Approximately 25 percent of the estimated 20 billion acre-feet of groundwater reserves in New Mexico is classified as fresh or slightly saline. The remaining 15 billion acre-feet of unutilized water is characterized as moderately saline, very saline and brine. The location of the state's saline groundwater reserves are relatively well known, but the magnitude of these resources and aquifer characteristics have not been rigorously assessed.

The major objective of this report was to identify potential site locations for large-scale (1,000 hectares or 2,470 acres) microalgae production facilities in New Mexico using unappropriated saline groundwater resources.

After a review of the 15 billion acre-feet of saline water resources in the state, areas that appeared to meet SERI criteria for site selection were narrowed to the following--the Tularosa Basin in south-central New Mexico, the Estancia Basin in central New Mexico, the San Juan Basin in northwestern New Mexico, the Tucumcari area on the eastside of New Mexico, the area east of the Pecos River in eastern New Mexico, and the Crow Flats area in southern New Mexico (figure 10).

A preliminary analysis was completed for the six locations. The Pecos River Basin, the Tucumcari area and the San Juan Basin were eliminated for failing to meet the preliminary SERI criteria (table 5).

A detailed analysis utilizing all of the SERI criteria for siting a microalgae production facility was then completed for the remaining three areas--Tularosa Basin, Crow Flats, and Estancia Basin. These areas possess the necessary land, site characteristics, and groundwater conditions as set forth by SERI (table 5).

Two potential sites were identified for the Tularosa Basin. Both sites (A & B) met all of the SERI criteria. One exception to this may possibly be the relatively low well-yields that are characteristic of the areas in the Tularosa Basin. For a 1,000 hectares (2,470 acres) facility, low well-yields may be offset by a larger numbers of wells.

Two potential sites were identified for the Estancia Basin. A short growing season of approximately 140 to 160 days would be a major limitation in the basin and would eliminate the basin from considera-tion for microalgae facilities. One 80-square-mile site (A) met all

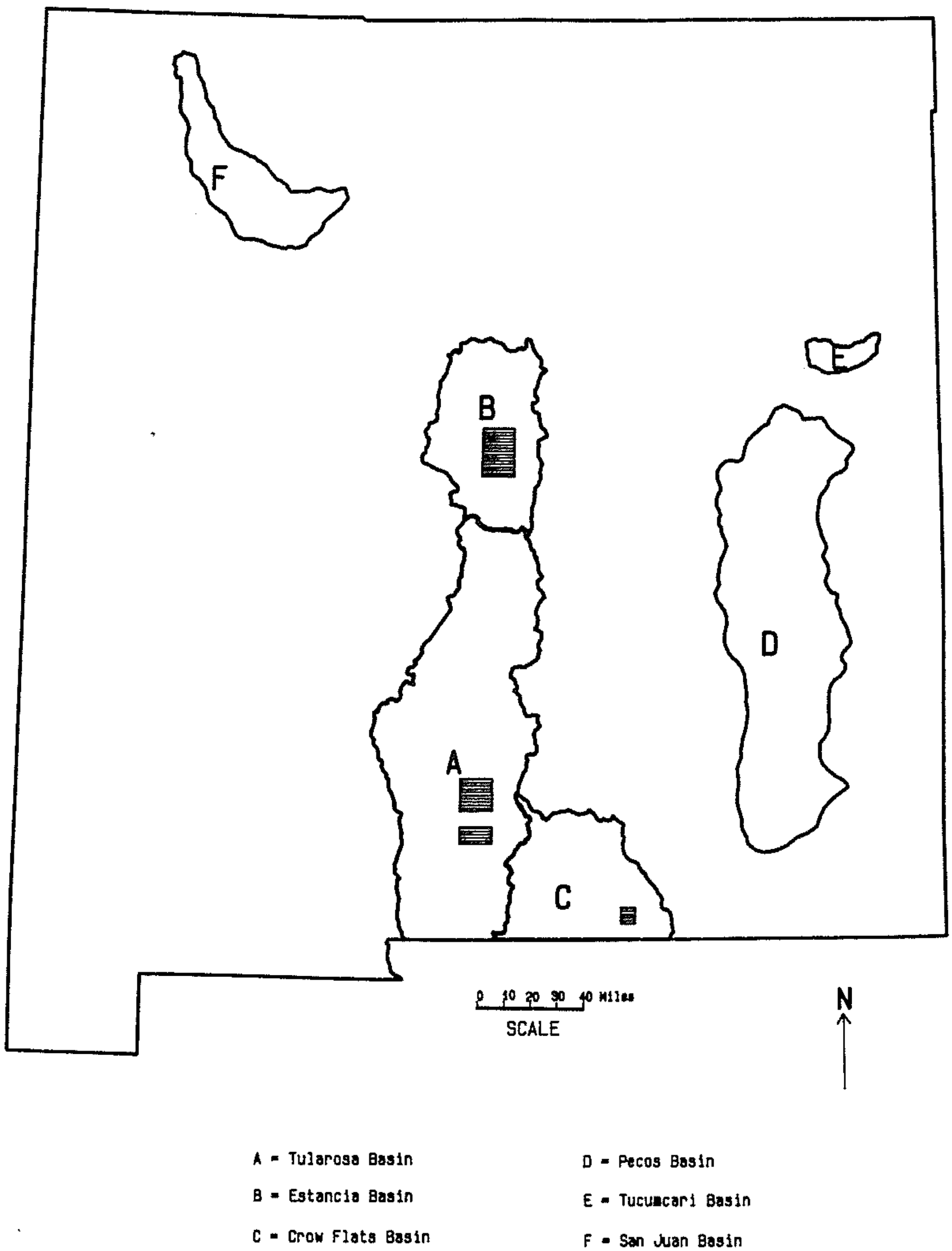


Figure 10. Potential Microalgae Production Areas in the State of New Mexico.

Table 5: Qualitative Summary of Chosen Sites and Specific Criteria Used in Selection of Areas Suitable for Microalgae Production.

Criterion	Tularosa Basin Site A	Tularosa Basin Site B	Crow Flats Basin	Estancia Basin Site A	Estancia Basin Site B	Pecos Basin	San Juan Basin	Tucumcari Basin
Supply of Unappropriated Saline Groundwater	Available	Available	Available[1]	Available	Available	Limited Availability[2]	Available	Available
Depth-to-Saline Groundwater	Satisfactory	Satisfactory	Marginal to Satisfactory	Satisfactory	Satisfactory	N/A[3]	Marginal to Satisfactory	Marginal to Satisfactory
Potential Well-Yield	Marginal to Satisfactory	Marginal to Satisfactory	Satisfactory	Satisfactory	Satisfactory	Unsatisfactory	Unsatisfactory	N/A
Water Quality (TDS)	Satisfactory	Satisfactory	Marginal	Satisfactory	Marginal	Satisfactory	Satisfactory	Marginal
Adequate Reserves of Saline Water	Yes	Yes	Yes	Yes	Yes	Uncertain	Yes	No
Growing Season	Satisfactory	Satisfactory	Satisfactory	Unsatisfactory	Unsatisfactory	Satisfactory	Unsatisfactory	Marginal to Satisfactory
Land Slope	Satisfactory	Satisfactory	Satisfactory	Satisfactory	Satisfactory	N/A	N/A	N/A
Ownership	Majority is Private	Majority is Private	Majority is Federal	Majority is Private	Majority is Private	N/A[4]	N/A	N/A
Data Base Quality	Excellent	Excellent	Poor to Good	Good	Good	Poor	Good	Good
Further Study Recommended	Yes	Yes	Yes	No	No	Yes[5]	No	No

N/A is not available.

1 While unappropriated water is available, competition from agriculture is likely because water quality is suitable for agriculture.

2 While unappropriated water is available, in the Pecos Valley, competition from existing uses may exclude microalgae production.

3 Data on depth-to-groundwater was available only for the Pecos Valley not the Pecos Basin.

4 Ownership was not described for the Pecos Basin. Ownership in the Pecos Valley was predominantly private.

5 Further study is recommended for the area around Roswell if less than a 1,000 hectare facility is considered.

other SERI criteria. The best site for the location of a facility would be near the existing playa lakes. The second site (B) met all of the criteria with the exception of groundwater quality. The groundwater is classified as slightly saline. An additional limitation for site B is that poorer quality water overlies better quality water with a potential for degradation of the higher quality water. Owners of existing water rights in the area may oppose any new appropriations of water.

One 36-square-mile area in the Crow Flats Area was identified as a potential site. The area is on the valley floor in the alkali flat portion of Crow Flats. However, the water would be classified as slightly saline and is currently being used for irrigation, livestock and domestic purposes. It is unlikely that present water right holders will readily accept requests for new appropriations of groundwater.

The Tularosa Basin was judged as best suited area for a 1,000 hectare microalgae production facility and Crow Flats the next best alternative. The Estancia Basin has the limitation of a short growing season and possible opposition from current water-right holders.

There are two potential sites where additional research on the saline water resources would be required to determine if enough saline water is available at economic depths. They are the area east of Roswell in Chaves County and the Jornada del Muerto in Sierra and Socorro counties.

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