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SOUTHWEST REGION SOLAR POND STUDY FOR THREE SITES — TULAROSA BASIN, MALAGA BEND, AND CANADIAN RIVER

August 1984

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16. ABSTRACT

In this study, the Bureau of Reclamation investigated the technical and economic feasibility of using solar salt-gradient ponds to generate power and to produce freshwater in Bureau projects at three sites – the Canadian River at Logan, New Mexico; Malaga Bend on the Pecos River near Carlsbad, New Mexico; and the Tularosa Basin in the vicinity of Alamogordo, New Mexico. The ponds would be used to generate electric power that could be integrated with the Bureau's power grid or used in combination with thermal energy from the ponds to power commercially available desalination systems to produce freshwater.

Results of the economic analysis, which concentrated primarily on the Tularosa Basin site, showed that solar-pond-generated intermediate load power would cost between 62 and 90 mills/kWh and between 52 and 83 mills/kWh for baseload power. This results in benefit-cost ratios of approximately 2.0 and 1.3 for intermediate and baseload, respectively, when compared to similar facilities powered by fossil fuels. The cost savings are even more pronounced when comparing the two (solar versus fossil fuel) as a source of power for conventional distillation and membrane-type desalination systems.

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August 1984

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Division of Design
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SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR ★ Bureau of Reclamation

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CONTENTS

APPENDIXES

TABLES

FIGURES

CONTENTS– Continued

ACRONYMS/ABBREVIATIONS

AFB	Air Force Base
$\overline{BBEC}$	bus-bar energy costs
BLM	Bureau of Land Management
DOE	Department of Energy
HAFB	Holloman Air Force Base
HTMED	horizontal tube multiple-effect distillation
JPL	Jet Propulsion Laboratory
M&I	municipal and industrial
MINTMP	analysis mode of SOLPOND
NCC	National Climatic Center
ORC	organic Rankine cycle
OWRT	Office of Water Research and Technology
RATSCAT	Radar Target Scanning Test Site
REA	Rural Electrification Administration
RO	reverse osmosis
SERI	Solar Energy Research Institute
SOLMET	solar and meteorological data base compiled by National Climatic Center
SOLPOND	SERI computer program for modeling solar ponds
TDS	total dissolved solids
TMY	typical meteorological year
USGS	U.S. Geological Survey
WSMR	White Sands Missle Range
WSNM	White Sands National Monument

SYMBOLS/DEFINITIONS

AF	=	acre-feet
Btu/ft^2	=	Btu per square foot
cm/h	=	centimeters per hour
cm/yr	=	centimeters per year
ΔC_s	=	mean concentration gradient
ft^3/s	=	cubic feet per second
g/cm^2	=	gram per square centimeter
kV	=	kilovolts, 1×10^3 volts
kW	=	kilowatts, 1×10^3 watts
kWe/kgal	=	kilowatt (electric) per 1000 gallons
kWh	=	kilowatt-hour
kWt	=	kilowatt, thermal
m	=	meter
M	=	mega (1×10^6)
m^2/kgal	=	square meter per 1000 gallons
MBtu/kgal	=	1×10^6 Btu per 1000 gallons
mg/L	=	milligrams per liter
Mgal/d	=	millions of gallons per day
Mgal/acre-d	=	millions of gallons per acre per day
MW	=	megawatt
MWh	=	mega watt-hour
MWe/km^2	=	mega watt (electric) per square kilometer
MWt/km^2	=	mega watt (thermal) per square kilometer
η_{ORC}	=	organic Rankine cycle power conversion efficiency
p/m	=	parts per million

SI METRIC CONVERSIONS

To convert from	To	Multiply by
ft	m	*3.048 000 E–01
in	m	*2.540 000 E–02
mi	km	*1.609 344
acre	ha	4.046 873 E–01
ft^2	m^2	*9.290 304 E–02
km^2	ha	*1.000 000 E+02
mi^2	km^2	2.589 988
in/yr	cm/yr	*2.540 000
ft/mi	m/km	1.893 939 E–01
kgal	m^3	3.785 412
Mgal	m^3	3.785 412 E+03
acre-ft	m^3	1.233 489 E+03
gal/min	m^3/s	6.309 020 E–05
kgal/yr	m^3/a	3.785 412
acre-ft/yr	m^3/a	1.233 489 E+03
Mgal/d	m^3/s	4.381 260 E–02
Mgal/acre	m^3/ha	9.353 918 E+03
$m^2/kgal$	m^2/m^3	2.641 720 E–01
lb/in^2	Pa	6.894 757 E+03
Btu_{IT}	J	1.055 056 E+03
Btu/ft^2	J/m^2	1.135 653 E+04
$MBtu_{IT}/yr$	MJ/a	1.055 056 E+03
$MBtu_{IT}/kgal$	MJ/m^3	2.787 163 E+02
MWe/km^2	MWe/ha	*1.000 000 E–02
MWh/mi^2	MWh/km^2	3.861 022 E–01
kWhe/kgal	$kWhe/m^3$	2.641 720 E–01
$MWh/(km^2 \cdot yr)$	$MWh/(ha \cdot a)$	*1.000 000 E–02
° F	° C	$t_{°C} = (t_{°F} - 32)/1.8$

* Exact conversion.

INTRODUCTION

Purpose and Scope

The technology of solar-powered energy systems using solar salt-gradient ponds (hereinafter referred to as "solar ponds") has been proven in Israel and is rapidly approaching readiness for power generation and process heat applications here in the United States. Experience has shown that an operational solar pond can reach temperatures as high as the boiling point of saline water, and when coupled with an ORC (organic Rankine cycle) engine, it can be used to produce electric power at costs competitive with conventional sources of power.

This report documents the results of a study to determine the technical and economic feasibility of using solar ponds to generate project power and to produce freshwater in Bureau projects at three sites – the Canadian River at Logan, New Mexico; Malaga Bend on the Pecos River near Carlsbad, New Mexico; and in the Tularosa Basin in the vicinity of Alamogordo, New Mexico. The location of each of these sites is shown in figure 1. The information presented in this report is based on an earlier Bureau study conducted for the Colorado River Basin in which the performance, operation, and cost elements of solar-pond-coupled power generation and desalination systems were investigated [1][1]

Overview of Solar Pond Technology

Briefly, a solar pond is a shallow body of saline water, generally between 2 and 5 m deep, that functions similarly to a flat-plate solar collector. It is constructed as shown on figure 2 in three distinct layers or zones:

- Surface convecting zone – a thin, top layer of low-salinity water in which there are vertical convection currents due to wind and evaporation.
- Nonconvecting or salinity-gradient zone – an intermediate layer in which the concentration of salt increases with depth to about 20 percent by weight.

[1] Numbers in brackets refer to entries in the bibliography.

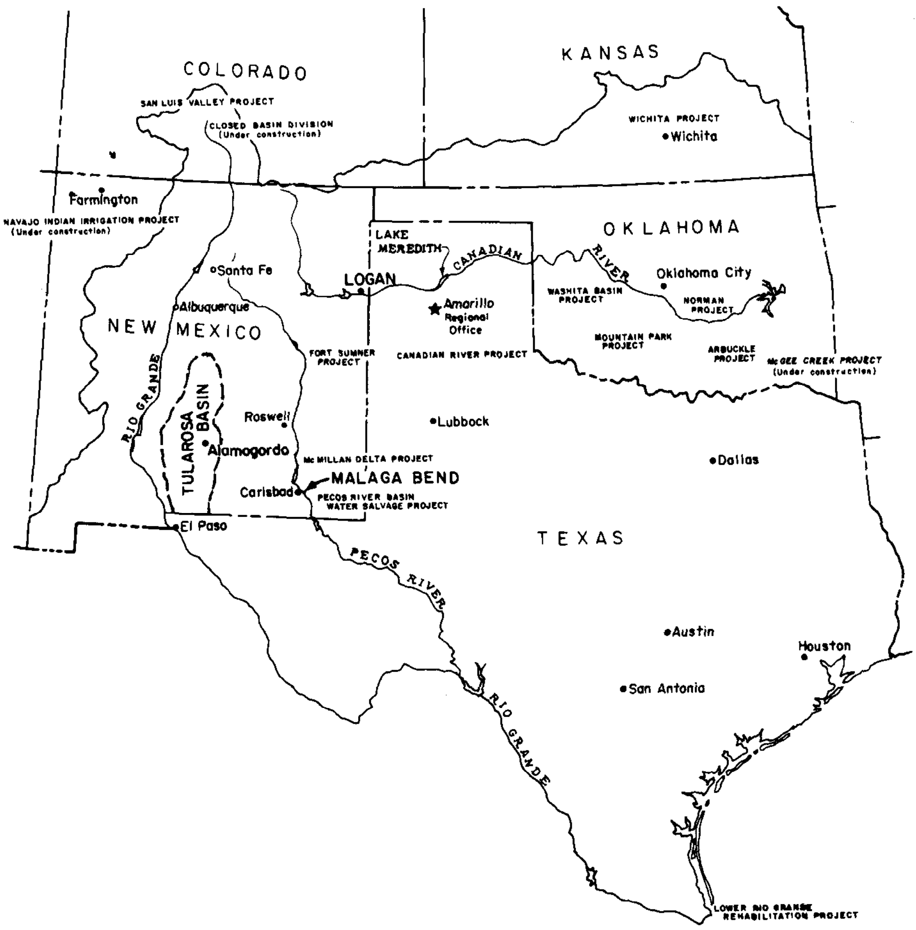


Figure 1.–Southwest Region showing the locations of the Tularosa Basin, Malaga Bend, and Canadian River sites.

Storage zone – an area of uniformly high salt concentration at the bottom which is used for heat storage.

The salinity-gradient zone acts as a thick layer of insulation by inhibiting convective heat losses from the storage zone. With these heat losses suppressed, a considerable amount of the incident solar radiation that is absorbed throughout the storage layer is trapped, enabling storage temperatures to increase substantially. Energy can then be extracted from the pond by recycling the hot storage layer brine through a heat exchanger or through an evaporator of an ORC engine for electric power generation as shown on figure 3. Surface water from the pond can be used as a source of cooling water on the condenser side of the ORC engine. Typically, pond storage temperatures range between 70 and 100 °C with pond thermal conversion efficiencies ranging from 15 to 20 percent.

For this study, pond layer depths of 0.3, 1.3, and 1.5 to 3.5 m were assumed for the dilute upper-convecting zone, intermediate nonconvecting zone, and thermal storage zone, respectively. These values are fairly representative of typical pond dimensions. Varying the thermal storage layer depth changes the pond thermal mass, thereby providing flexibility in the rate of heat extraction. This allows the pond to be operated in any mode ranging from peaking to intermediate to baseload.

Work on solar ponds began in Israel approximately 25 years ago. Since that time, the technology has developed to the point that a 150-kW solar electric powerplant was put into operation 3 years ago near Ein Bokek on the Dead Sea to demonstrate the feasibility of generating electricity from solar ponds continuously, day and night, the year round. The success of the Ein Bokek system has resulted in the construction of a 5-MW solar pond powerplant near Beit Ha'arava, Israel which went online at the end of 1983, with the ultimate plan being to construct a 2000- to 3000-MW system using the Dead Sea as the solar pond.

The first megawatt-size solar pond project in the United States is planned for Danby Dry Lake in southern California. It will be constructed by an Israeli firm, Ormat Turbines, to generate electric power for the Southern California Edison Company. The first phase of the project, a 12-MW facility, is scheduled for operation by the end of 1985 with a total of 48-MW to be on-line by 1987. Other solar pond projects

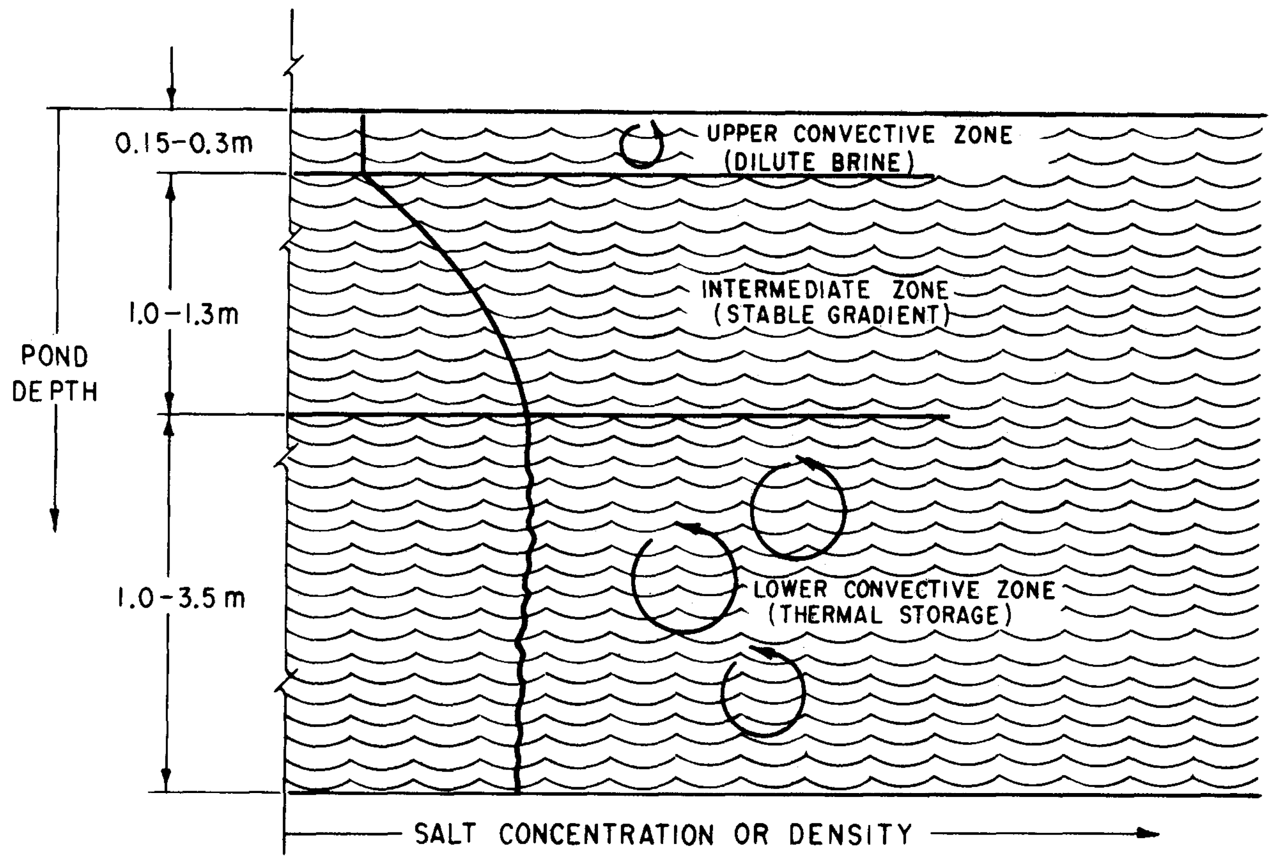


Figure 2.–Solar pond cross section.

which have been investigated for use in generating electric power include a 5-MW project at the Salton Sea in southern California and a 1.5- to 12.5-MW project at Truscott in northern Texas.

POWER AND WATER NEEDS

Electric Power Needs

An indication as to the future power needs of the Southwest Region (fig. 1) is provided by the estimates of additional generating capacity that the three power grids serving this area will be adding over the next 20 years. As shown in the chart below, each is expected to add 12 000 MW during the 1980's and approximately double that amount from 1991 to 2000 [2].

Power grid (fig. 4)	Added generating capacity (MW) 1981-1990	1991-2000
SPP (Southwest Power Pool)	12 000	25 300
ERCOT (Electrical Reliability Council of Texas)	12 000	23 100
WSCC (Western Systems Coordinating Council)	12 000	45 000-55 000

A significant portion of this additional capacity will be located in eastern New Mexico and west Texas since historically this area of the country has been an exporter of electric power. The bulk of the additional power will likely be fossil-fuel generated with a portion being generated by nuclear and renewable energy sources. Very little additional hydroelectric power will be developed since its potential in this area is virtually nonexistent. For example, in 1982, Federal hydroelectric power sales in the Southwest Region amounted to 1.2×10^6 MWh, of which more than 80 percent was generated outside the area by the Colorado River Storage Project (table 1). Of the balance, 6 percent was generated by the Rio Grande Project (Elephant Butte Dam near Truth or Consequences, New Mexico) and 11 percent by the Falcon Project (also on the Rio Grande downstream of Laredo, Texas).

The Bureau itself has considerable need for power to operate the various pumping projects located throughout the Southwest Region (table 2). These projects use electric power, all or part of which is currently generated by fossil fuels. Other planned projects in the Southwest Region that will have to rely on fossil fuels if an alternative source is not found include the Canadian River Salinity Control Project and the Eastern New Mexico Water Supply Project.

An indication as to what the average consumer in the Southwest Region is presently paying for electricity is shown in table 3. This table, which has been compiled for the principal consumers of electric power in the Tularosa Basin, shows that the military

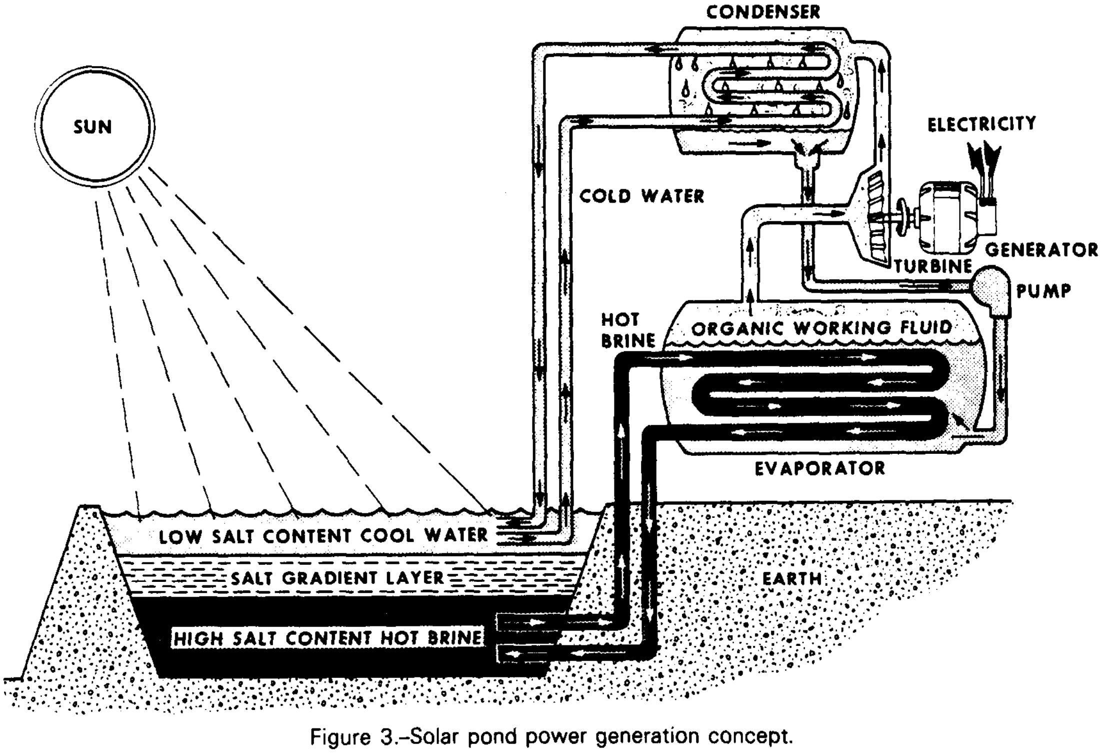


Figure 3.–Solar pond power generation concept.

bases paid approximately 55 mills/kWh in 1982, and the residential customers paid rates approaching 100 mills/kWh when one takes into account the add-on expenses for availability of energy and electrical facilities (referred to as a base charge in table 3) and for demand usage. These rates, which reflect the operations of several utilities (El Paso Electric, Texas-New Mexico Power, Public Service Company of New Mexico, and Plains Electric Generation and Transmission which services 11 REA cooperatives throughout the western two-thirds of New Mexico), demonstrate their dependence on oil and gas. El Paso Electric, for example, currently generates more than 90 percent of its power using oil or gas, and the Plains Electric cooperative produces about one-fourth of its power with these fuels [4].

Water Needs

Water needs, as applied to this study of potential solar pond sites at or in the vicinity of Tularosa Basin, Canadian River (Ute Reservoir), and Malaga Bend (Pecos River), fall into two categories – availability of freshwater [water containing less than 1000 mg/L TDS (total dissolved solids)] at all three sites and the need to control salinity in the Canadian and Pecos Rivers at the points where the bulk of the salt loading occurs. The significance of these water problems in terms of both quantity and quality increases with increased demand for freshwater, ground-water depletion (consumed so that it is no longer available as a water source), and the potential for saltwater intrusion into the ground-water supplies which occurs when the water table is drawn down.

Table 4 lists the present and projected demands for freshwater for urban and other users in the vicinity of the three candidate sites. These demands are having a significant effect on ground-water supplies. For example, the cumulative ground-water depletion for the Tularosa Basin and Eddy County (Carlsbad, New Mexico) currently stands at 60 to 65 percent and approximately 50 percent in Quay County (Logan, New Mexico). By the year 2005, it is estimated that more than 70 percent of the high-quality ground-water supply (< 1000 TDS) will have been depleted in all three areas [6]. Further recognition of future shortages of freshwater is evidenced by the fact that most surface waters in these areas are already fully allocated and by the declaration that the underground water basins in which the candidate sites are situated cannot be tapped further without State approval.

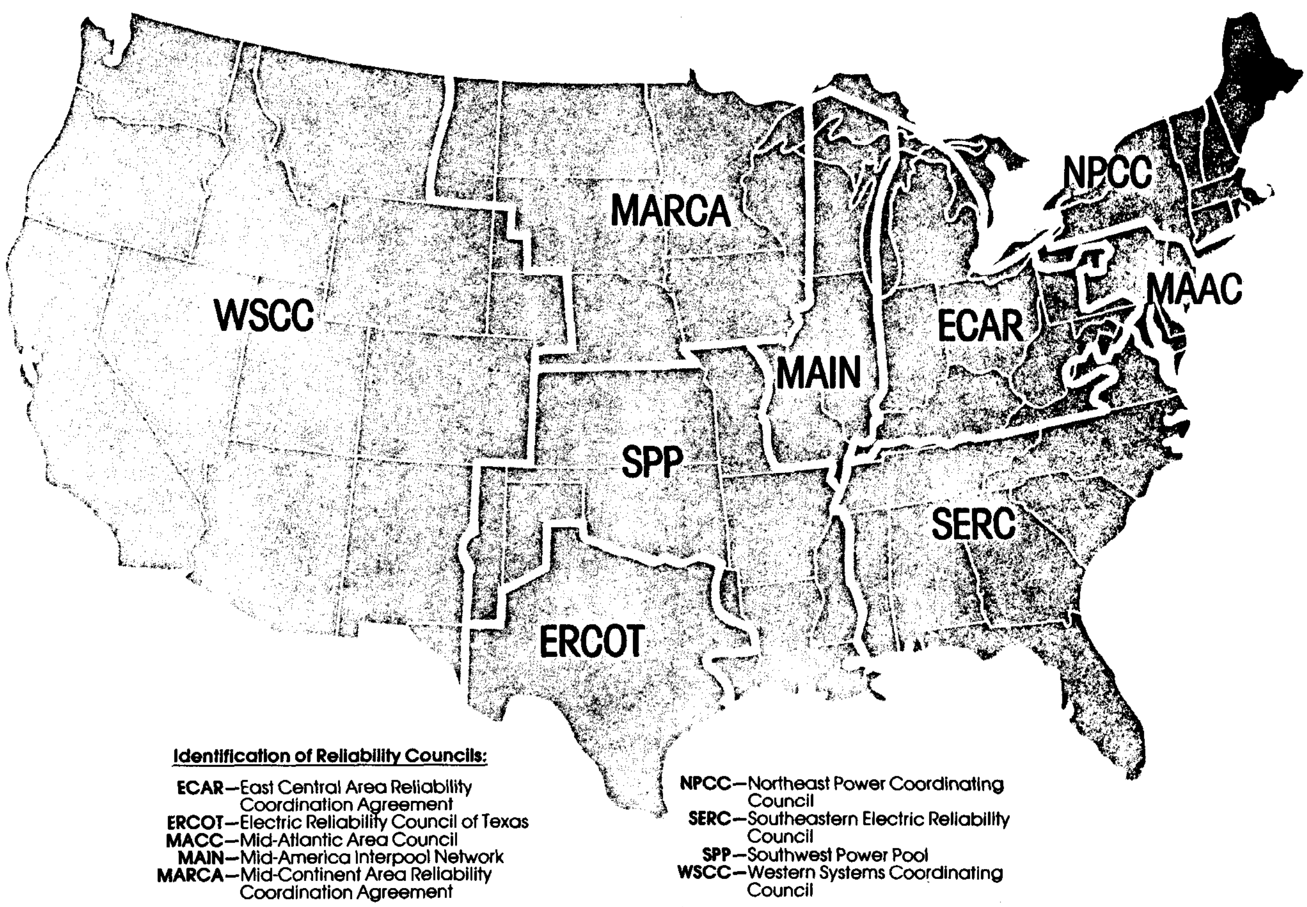


Figure 4.–National electric regional reliability councils.

Table 1.—*1982 Federal electric power sales in the Southwest Region* *

Customer	Source	Annual energy (kWh x 10^6)	Unit cost (mills/kWh)**
Municipalities			
Aztec, New Mexico	Colorado River Storage Project	16.9	19.7
Farmington, New Mexico	Colorado River Storage Project	116.6	16.8
Truth or Consequences, New Mexico	Colorado River Storage Project	22.6	9.3
	Rio Grande Project	6.3	15.8
Rural Electric Cooperatives			
Plains Electric Generation and Transmission	Colorado River Storage Project	628.3	8.8
	Rio Grande Project	73.9	17.7
Federal Agencies			
Department of Energy	Colorado River Storage Project	74.9	12.9
Navajo Agricultural Product	Colorado River Storage Project	24.9	13.8
Navajo Tribal Utility Authority	Colorado River Storage Project	101.6	9.0
Private Utilities			
Public Service Company of New Mexico	Colorado River Storage Project	6.2	36.4
Central Power and Light	Falcon Project	139.6	14.0
	Total	1211.8	

* Compiled from data presented in reference [3].

** Rate increases are projected to occur as follows:

- Colorado River Storage Project—April 1983.
- Falcon Project—May 1983 when the Amistad Powerplant is expected to become operational.
- Rio Grande Project—The first step of a rate increase designed to meet project payoff went into effect on September 1, 1982, at 21.44 mills/kWh at 58.2 percent load factor; the second step at 27.0 mills/kWh and 58.2 percent load factor becomes effective on September 1, 1983.

Freshwater supplies in the Tularosa Basin are particularly limited. The city of Alamogordo presently obtains its water from Bonito Lake, Alamo Canyon, Fresnal Canyon, and La Luz and from nearby wells; Holloman AFB (Air Force Base) obtains the majority of its water from well fields with the remaining portion coming from Bonito Lake by way of the city of Alamogordo; and White Sands Missile Range obtains its freshwater from well fields located in the alluvial fans at the base of the mountain range on the west side of the basin [7]. In general, the surface water available to the city of Alamogordo and Holloman does not require extensive treatment to make it potable. However, this is not the case with the basin's ground-water supplies which typically range between 1000 and 3000 mg/L TDS with the freshest water found at shallow depths near the base of the mountains [7, 8]. In other words, the salinity of the ground water generally increases with distance from the mountain base and with depth. Additionally, further drawdown of these ground-water supplies will lead to saltwater intrusion from adjacent brine aquifers.

Water users in and around Quay County, New Mexico, are also faced with future water shortages. Their main source of freshwater, the Ogallala aquifer, has been depleted to the point where it now contains only 100 to 130 million acre-feet of physically pumpable water and that is being extracted at a rate of approximately 5 million acre-feet per year [9]. This depletion, coupled with anticipated increases in demand by certain users and the potential diversion of 40 300 acre-feet per year of Ute Reservoir water to nine communities along the proposed Eastern New Mexico Water Supply Project, contribute to

Table 2.—*Bureau pumping projects (existing or planned) in the Southwest Region which use power, all or part of which is generated by fossil fuels**

Project	Load (application)	Power required (horsepower)
Arbuckle Project	1 pumping plant for M&I water	500 (4 units)
Canadian River Project	10 pumping plants for M&I water (units range from 30 to 1750 hp)	25 350
Fort Sumner Project	1 pumping plant for irrigation	70
Lower Rio Grande Rehabilitation Project	6 pumping plants for irrigation	6 430
McGee Creek Project	3 pumping units	2 400
Mountain Park Project	2 pumping plants for M&I water	1 000
Navajo Indian Irrigation Project	3 pumping plants for irrigation	30 850
Pecos River Basin Water Salvage Project (including McMillan Delta)	Pumping power for water salvage and salinity control	N/A
Norman Project	2 pumping plants for M&I water	2 730
San Luis Valley Project, Closed Basin Division	95-160 pumps for water salvage	2 500 (estimated)
Washita Basin Project	3 pumping plants for M&I water	420
Wichita Project	Pumping power for M&I water	N/A

* See figure 1 for the location of each of these projects.
M&I—Municipal and industrial.

uncertain water supplies in this area of the Southwest Region.

Of more immediate concern with respect to the Canadian River is the identified need to reduce salt loading in the river downstream of Ute Reservoir. The salt comes primarily from a brine aquifer which produces 30 000 mg/L brine at a rate of approximately 0.6 ft^3/s. This combines with other sources of salt loading in the river to raise the salinity at Lake Meredith to about 1250 mg/L. To eliminate this problem would require intercepting a minimum of 1.0 ft^3/s of brine at the source [10].

Communities and water users in Eddy County, New Mexico, are experiencing problems similar to those of Quay County, i.e., rapid depletion of the high-quality ground water and salt loading of the Pecos River. Ground-water reservoirs in this area are being depleted at a rate of 100 000 to 125 000 acre-feet per year faster than they are being recharged [9]. The salt-loading problem results from saturated brine being introduced to the river in the vicinity of Malaga Bend at a rate of about 0.5 ft^3/s [11].

SITE SELECTION

Factors that would be used to evaluate sites for possible solar pond development are listed in table 5. The list is not complete, but it does show the type of information that would be considered in the site selection process. Most of the data would be available from existing reports and records, but some would have to be obtained from site-specific field tests.

Due to the preliminary nature of this study, and also to time and budget constraints, the remainder of this section deals with potential solar pond sites in the Tularosa Basin as measured in terms of only selected criteria listed in table 5. Comparisons are based principally on resource availability; general soil characteristics; ground-water conditions; and proximity to surface transportation, electrical transmission, and water conveyance facilities. Climatic and meteorological conditions do not vary significantly throughout the Basin and, therefore, were assumed constant. Other factors, such as environmental acceptability, were not addressed.

Resource Availability

The Tularosa Basin is filled with unconsolidated and semiconsolidated bolson deposits of alternating layers of clay and sand and some gravel. The thickness of this fill varies from less than 300 feet at the base of the mountains enclosing the Basin to more than 6000 feet at the valley floor. Most of these bolson deposits are saturated with saline water, consisting predominantly of NaCl (sodium chloride) salts.

Table 3.—*1982 electric power requirements for the Tularosa Basin* *

Load	Avg. daily electrical energy consumption (kWh)	Peak power requirement (kW)	Energy cost (mills/kWh)	Estimated change over next 10-15 years (percent/yr)	Supplier
Urban Centers (Residential)					
Alamogordo, New Mexico	294 000	24 800	85.9 plus $4.70 base charge	2	Texas-New Mexico Power Company with power purchased from El Paso Electric
Carrizozo, New Mexico	13 200	1 100	**97.0	N/A	Otero County Electric Cooperative with power purchased from Plains Electric Generation and Transmission
Tularosa, New Mexico	32 500	2 600	85.9 plus $4.70 base charge	N/A	Texas-New Mexico Power Company with power purchased from Public Service Company of New Mexico
Military Bases					
Fort Bliss, Texas	377 000	27 700	56.4	1-2	El Paso Electric Company
Holloman Air Force Base	166 300	12 700	55.6	1.6	El Paso Electric Company
White Sands Missile Range	198 300	20 000	55.0	5	El Paso Electric Company

* Data provided by representatives of the respective cities and military bases [5].

** Includes energy at 58.0 mills/kWh plus a $10.00 base charge for availability of energy and electrical facilities and a fee of $6.00/kW for demand usage greater than 10 kilowatts.

Table 4.—*Present and projected requirements for freshwater in the vicinity of Tularosa Basin, Canadian River (Ute Reservoir), and Malaga Bend (Pecos River)*[1]

Location	Population 1980	Population 2005	Water demand—acre-ft/yr 1980	Water demand—acre-ft/yr 2005
Tularosa Basin				
City of Alamogordo, New Mexico	24 000	26 744	4 033	4 831
Holloman Air Force Base	6 750	6 750	2 639	2 730
White Sands Missile Range	2 600	2 600	2 113	2 113
Total (all municipalities)	[40 025]	[43 667]	[10 217]	[10 281]
Other users within Basin (Otero, Lincoln, and Dona Ana Counties)	—	—	[2] 58 300	[2] 150 000
Users outside Basin:				
Fort Bliss Military Reservation	32 000	39 500	7922	9765
City of El Paso, Texas	424 114	670 440	104 515	176 367
Canadian River (Ute Reservoir)				
Quay County surrounding Logan, New Mexico				
Urban	8 300	11 000	1800	2500
Other users	—	—	[2] 148 000	[2] 148 000
Downstream users	—	—	[3] 64 000	[4]
Malaga Bend (Pecos River)				
Eddy County surrounding Carlsbad, New Mexico				
Urban	34 500	44 750	10 100	13 000
Other users	—	—	[2] 272 000	[2] 274 000
Downstream users	—	—	[4]	[4]

[1] Compiled from data presented in references [2, 6].
[2] Does not include surface water used for irrigation.
[3] Represents that portion diverted from Lake Meredith.
[4] Information not available.

Concentrations vary from between about 500 and 1500 mg/L TDS in alluvial fans which extend from the mountains to well over 35 000 mg/L toward the center of the Basin.

Figures 5 through 8 present four diagrammatic sections which show salinity intervals at three locations along the west side of the Basin and one on the east (refer to map on fig. 9 for section locations). These diagrams show graphically the transition in salt concentration toward the center of the Basin. They also show the extent and contour of the bolson fill and the relative volume containing brines in excess of 35 000 mg/L. It has been estimated that approximately 98 percent of the saturated deposits in the Basin contain saline water in this concentration range [12].

Well yields in the bolson fill are variable and range from about 1400 gal/min high on the alluvial fans where deposits are relatively coarse (high transmittance) to 100 gal/min or less at the base of the fans [13]. There is very little information available concerning the productivity of the predominantly fine-grained deposits in the central part of the Basin; however, one estimate for an existing well designated RATSCAT (acronym for Radar Target Scanning Test Site) in the alkali flats area shows a yield of approximately 70 gal/min [14]. In this area, yields are variable depending on whether silt and clay, fine sand, or bedded gypsum is encountered in drilling. For example, in the Rhodes Canyon area, north of the alkali flats, well yields are reported to be as low as 10 gal/min due to high-clay soil conditions.

Table 5.–*Evaluation factors for candidate site selection*

Resource Availability:

a. Concentrated brine
  (1) Well productivity
  (2) Concentration (mg/L)
  (3) Composition
b. Dilute saline water
  (1) Well productivity
  (2) Concentration (mg/L)
  (3) Composition
c. Land
  (1) Area
  (2) Terrain/slope
  (3) Ownership
  (4) Potential use
d. Construction materials

Climatic and Meteorological Conditions:

a. Insolation
b. Ambient temperature
c. Wind (airborne particulates)
d. Evaporation
e. Precipitation

Hydrogeologic Conditions:

a. Soil properties
  (1) Permeability
  (2) Organic content
  (3) Thermal conductivity
b. Ground-water conditions
  (1) Water table
  (2) Ground-water movement
c. Seismic risk
d. Subsidence susceptibility

Distance to:

a. Transmission lines
b. Water conveyance facilities
c. Transportation facilities (roads and railroads)

Environmental Acceptability:

a. Vegetation
b. Wildlife
c. Archeology
d. Historical
e. Ground-water contamination (potential for)

Well log data obtained from open file reports located at the USGS (U.S. Geological Survey) office in Las Cruces, New Mexico, were used to identify sources of both highly concentrated brine and dilute saline

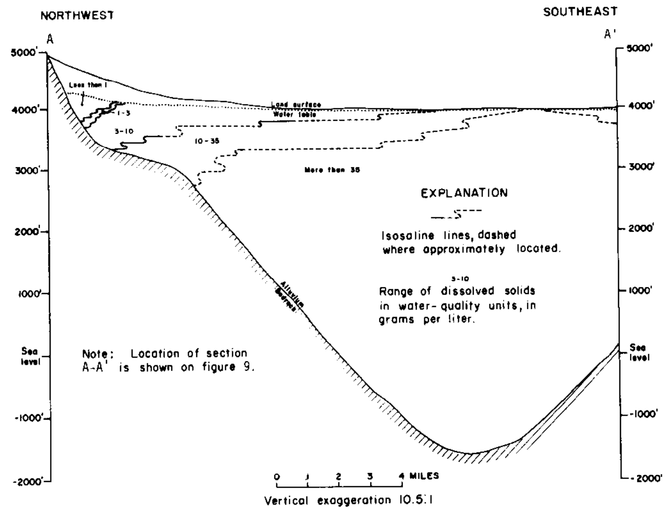


Figure 5.–Diagrammatic section A-A' at Rhodes Canyon showing water-quality units.

water which could be used for solar pond construction and maintenance. Particular attention was given to locating sources of saturated or near-saturated brine, containing predominantly salts of relatively high solubility, [e.g., NaCl, $MgCl_2$ (magnesium chloride), and others], which could be used directly for pond construction with little or no need for further concentration. Only limited data were available on brines of this quality. Most published well logs generally result from attempts to locate high-quality water for domestic and/or industrial (military) use and, consequently, high-salinity data are not widely available or reported in the literature.

Table 6 presents a summary of composition data for 12 brine sources identified as having in excess of 10 000 mg/L TDS at some depth.[2] The location of these wells are indicated on figure 10. All but four are located along the west side of the Basin. One well (RATSCAT) is in the alkali flats area, and the remaining three are located toward the east, two of which

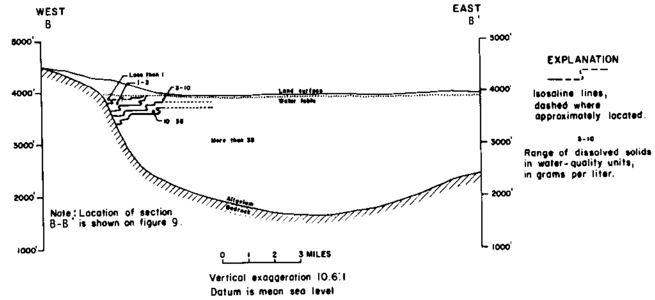


Figure 6.–Diagrammatic section B-B' at the south edge of T. 16 S. showing water-quality units.

[2] The analyses appear just as they do in the source documents. In several instances, there are marked imbalances between the concentrations (equivalents) of cations and anions as noted in the footnotes to table 6.

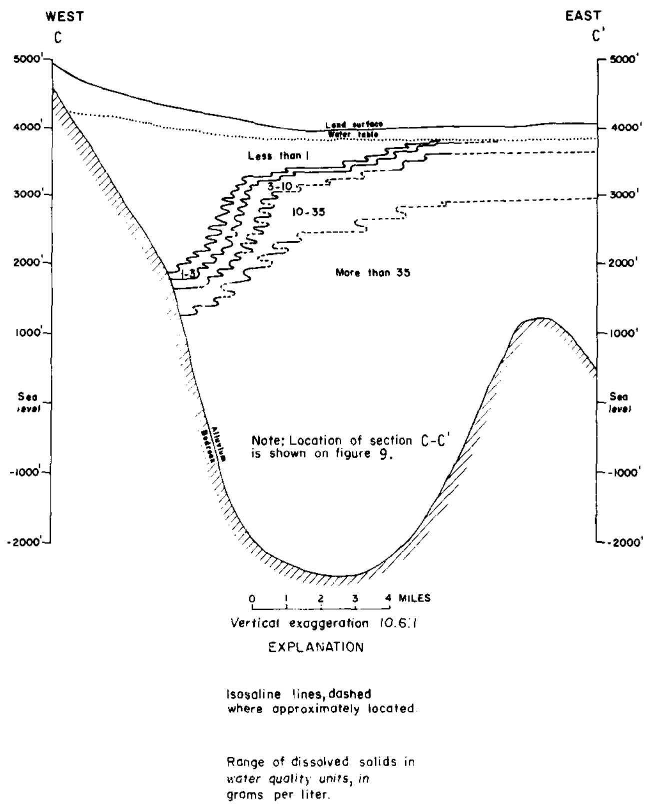


Figure 7.–Diagrammatic section C-C' at White Sands Missile Range headquarters showing water-quality units.

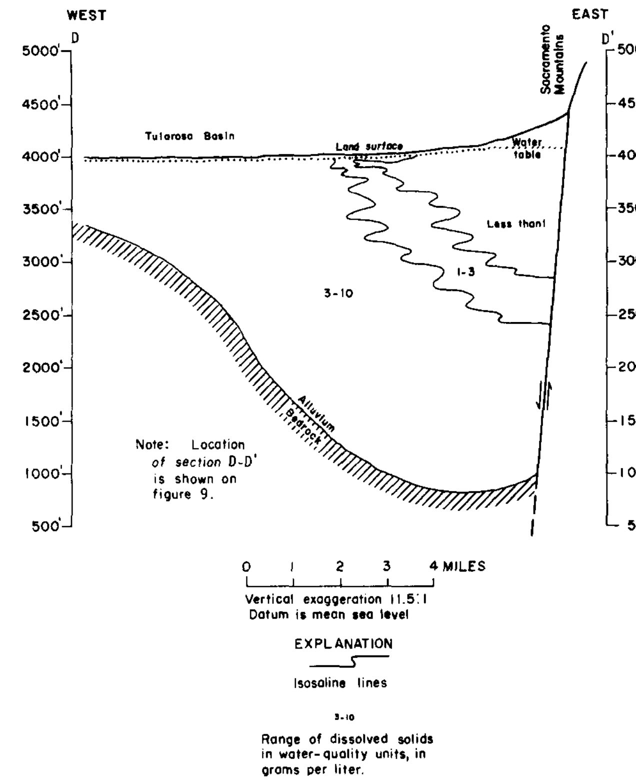


Figure 8.–Diagrammatic section D-D' in the vicinity of San Andreas Canyon south of Alamogordo showing water-quality units.

are at HAFB (Holloman Air Force Base). It can be seen from table 6 that all wells are stratified in salinity, becoming more concentrated with depth. Some increase in concentration to a certain depth and then become more dilute. Well T-14 was reported to have penetrated a halite bed at approximately 2800 feet which would account for the rather large increase in salinity and relative NaCl content at that depth [12].

Most of the deeper brine compositions shown in table 6 would be suitable for use in solar ponds. The only obviously detrimental salt present would be $CaSO_4$ (calcium sulfate) because of its poor solubility characteristics. Calcium sulfate has a solubility that is both low and inversely proportional to temperature. Both are undesirable characteristics for solar ponds; however, the percentage of $CaSO_4$ in the brines shown is relatively small compared to other salts present, particularly at greater depths.

Figure 11 presents two salinity profiles, the first extending roughly north-south along the west side of the Basin through eight of the concentrated brine sources listed in table 6, and the second along an approximate east-west line passing through three sources. The two axes meet at well NW-30-1. These diagrams show that the most concentrated brines and those closest to the surface are generally in the center of the Basin in the alkali flats area where the RATSCAT well is located. Extending to the east and west of RATSCAT, brines become less concentrated, and usable brines are at progressively greater depths. On the north-south axis, brines of equal concentration seem to be available at shallower depths towards the north end of the Basin.

Dilute saline water sources, somewhat above potable quality, are also required for pond construction and maintenance (surface flushing). Saline waters of this concentration are generally available at shallow depths throughout large portions of the Basin. Much of it, though, contains excessive quantities of $CaSO_4$ which, as previously mentioned, is not desirable for solar pond use. Very dilute saline water and potable water are present as ground water in the alluvial fans which extend from the mountains enclosing the Basin. The most abundant supplies of this quality water are found in the vicinity of the WSMR (White Sands Missile Range) headquarters and the Alamogordo area (refer to the less than 1000 mg/L interval on figures 7 and 8).

Several geophysical considerations are involved in selecting an appropriate land site for a solar pond. Some of the more important factors include: (1) Relative slope and roughness of the terrain which affect the amount, as well as cost, of excavation required during construction; (2) the depth to and

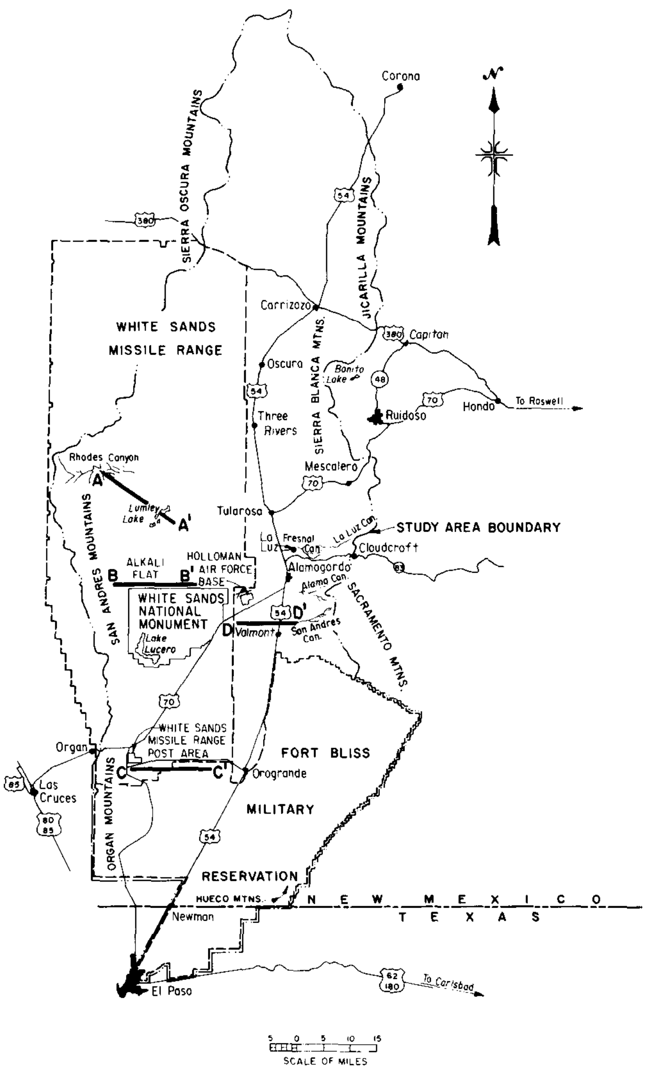


Figure 9.–Location of diagrammatic sections.

movement of ground water which potentially could cause thermal losses or structural problems for a pond or create difficulties during excavation; and (3) accessibility to suitable earth materials for construction of the pond liner and diking. Addressing the first consideration, the topography of much of the land area within the Basin is fairly flat (slope less than 1 to 2 percent) and smooth, i.e., free of sand dunes or gullies. In addition, numerous land depressions and playas (dry or intermittent lakebeds) exist throughout the Basin which might make suitable pond sites. Both land features would require a minimum of excavation, and playas, generally formed by layers of fine-grained sediments (silt and clay) and recrystallized salts, are fairly impervious. Depending on the clay and silt content, these playas may be usable as is with minimal liner preparation.

Although not preferable, it is possible to build solar ponds in areas with shallow ground-water tables, as is the case with most of the playas in the Basin, using

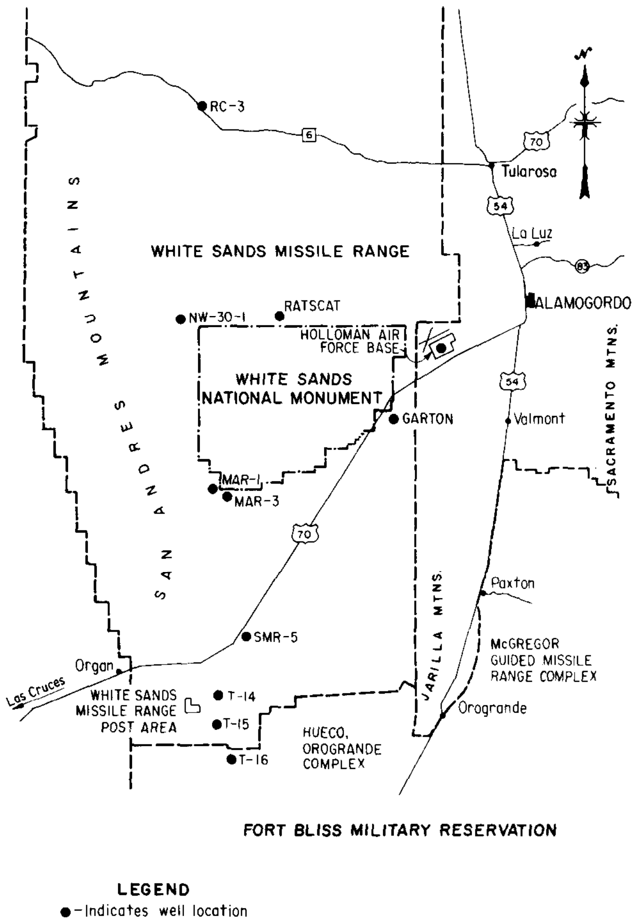


Figure 10.–Location of identified brine sources.

above-ground diking with a minimum amount of excavation. A reasonable distance should be maintained between the pond bottom and the ground-water table to prevent flowing water from convecting heat away from the pond or hydraulic pressures from causing damage to compacted liner material. This could possibly preclude the use of those areas of the Basin where ground-water levels are within a few feet of the surface [15].

The suitability of specific soils for use in pond liner and dike construction is generally determined by the soil's composition (unified classification) and size distribution of the commonly available soils within the Basin. Those with a classification of lean clay or sandy clay would likely be considered good materials for lining from the standpoint of permeability and erosion resistance [16]. Local sources of silt, silty sand, and silty gravel are also relatively impervious where there is an abundance of soil fines (significant percentages passing the No. 200 sieve) to fill voids between the larger particles. However, some of these soils would lack cohesion and, depending on the amount of sand and gravel present, are subject to erosion and would need protection from flowing water or wave action.

Table 6.—*Stratified well-log data for selected concentrated brine sources*

Ref. No.	Well identification	Depth (ft)	Brine composition (mg/L except as noted) Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	Cl^{-}	SO_4^{-2}	CO_3^{-2}	HCO_3^{-}	TDS	pH
1	RC-3[1]	257-269	950	421	[14]8 440		11 950	5 280	0	98	27 100	7.6
		390-412	1950	1420	64 800		103 000	5 920	0	54	177 000	7.1
		490-512	2000	1270	53 100		84 500	6 120	0	60	147 000	7.1
2	NW-30-1[2]	352	–	–	–	–	156	613	–	–	–	–
		490	940	730	7 300	64	15 000	1 000		[3]10	25 000	8.1
		620-735	–	–	–	–	24 200	2 330	–	–	–	–
		[4]	418	264	3 040		5 520	744	0	203	10 100	7.7
3	RATSCAT[5]	50	2837	2030	8 520	–	8 947	18 499	–	175	41 008	7.2
		60	2853	2100	9 480	–	15 495	24 532	–	164	56 624	7.9
		80	1215	2590	86 000	–	79 975	148 930	–	170	318 880	7.5
		105	1120	2640	85 900	–	164 950	155 880	–	128	410 620	6.7
		160	1073	2630	85 200	–	194 940	106 520	–	110	390 470	6.8
		270	1203	2640	85 700	–	204 940	103 100	–	110	397 690	7.2
4	HAFB[6]	110	965	3360	12 600		24 000	9 280	–	208	50 300	6.7
5	HAFB	160	3070	1715	9 900		15 000	1 940	–	–	32 000	7.6
6	Garton well[7]	889-892	808	1662	2 100		4 218	2 150	32	78	10 240	7.1
7	MAR-1 (test)[8]	250-350	–	–	–		42	234	–	–	–	–
		650	81	36	42		42	162	–	254	520	7.4
		582-718	–	–	–		42	93	–	–	–	–
		820-1000	–	–	–		27 200	2 460	–	–	–	–
8	MAR-3[9]	290	53	38	94		45	258	–	212	617	7.8
		670-749	–	–	–		18 100	1 890	–	–	–	–
9	SMR-5[10]	109-249	195	81	207		104	922	0	194	1 670	7.5
		615-666	575	685	2 500		1 930	6 450	0	278	12 300	7.5
10	T-14[11]	200	2.1	0.1	300	6.2	340	85		[3]140	822	10.3
		300	1.8	0.2	300	6.2	330	81		140	807	10.2
		210-360	32	1.9	146	–	82	161	9	133	543	8.6
		2590-3700	1660	792	41 400	–	66 800	1 061	0	112	112 000	6.7
		3700-4100	1260	62	17 600	–	28 500	1 450	0	71	48 900	6.1
		4140-4900	2120	27	15 100	–	25 900	1 240	0	71	44 500	6.3
		4865-5900	2170	8.8	15 000	–	25 700	1 230	0	94	44 300	6.9
		5890-6000	1300	72	19 000	–	30 800	1 500	0	166	52 800	6.9
11	T-15[12]	400	31	0.9	99.5		130	99	0	24	375	8.5
		714-736	47	4.7	63		54	112	0	93	357	7.7
		1620-1642	1700	379	10 200		17 100	3 600	0	43	33 000	6.9
12	T-16[13]	310-700	34	5.6	33		16	48	0	127	240	8.1
		628-650	27	1.8	47		20	59	0	104	239	8.2
		1360-1382	1280	683	1 450		13 300	3 360	0	102	26 000	7.5

[1] Water sampling indicated 10 gal/min (257-269 ft); lower zones 1-2 gal/min.
[2] 248 gal/min for 8 hours with 30.5-ft drawdown; penetrated bolson and fan deposits.
[3] Alkalinity as $CaCO_3$.
[4] Cased well—depth not reported.
[5] Values reported in p/m; projected yield greater than 70 gal/min above 136 ft with less than 50-ft drawdown. Ion concentrations do not balance, particularly for last three analyses.
[6] 100 gal/min or less to the west of the 4200-ft contour line in the vicinity of Holloman Air Force Base.
[7] Ion concentrations do not balance.
[8] 165 gal/min for 12 hours with 39.4-ft drawdown.
[9] Not pump tested—bailed at 1.6 gal/min.
[10] Not pump tested—bailed at 20 gal/min.
[11] Not pump tested—bailed at 10 gal/min for 7 hours.
[12] Not pump tested.
[13] 175 gal/min for 8 hours with 16.2-ft drawdown; ion concentrations do not balance for bottom interval.
[14] In some instances, combined sodium-potassium concentrations were determined.

Site Evaluation

For the purposes of this study, the Basin was arbitrarily divided into five areas to facilitate the discussion of potential solar pond sites. These areas, shown on figure 12, are designated as follows:

I. (White Sands north) – bounded on the south by military road 6, on the east by the eastern boundary of WSMR, and on the north and west by the 5000-foot contour interval.

II. (White Sands central) – bounded on the north by military road 6, on the west by the 5000-foot contour interval, on the south by the southern WSNM (White Sands National Monument) boundary, and the east by U.S. Highway No. 70 and the eastern boundaries of WSMR and HAFB.

III. (White Sands south) – bounded by the southern WSNM boundary on the north, WSMR boundaries on the east and south, and the 5000-foot contour interval to the west.

IV. (Fort Bliss) – Fort Bliss boundaries.

V. (Eastern Basin) – bounded on the west by WSMR, WSNM, and HAFB boundaries, to the south by Fort Bliss, and to the north and east by the 5000-foot contour interval.

Area I. – Well RC-3, located along military road 6 (refer to fig. 10), is the only high-salinity brine source identified in this area. The well provides predominantly NaCl water at fairly high concentrations and at a relatively shallow depth (177 000 mg/L at a depth of approximately 400 feet). The yield, however, is reported to be less than 10 gal/min which is low compared to the other brine sources discussed. The well was drilled to a depth of 750 feet and penetrated only fine-grained materials with poor water-bearing properties. This is reported to be typical of the Rhodes Canyon area [17]. Another well (RC-2), located about 6 miles north of RC-3 along the foothills, produces saline water at approximately 3300 mg/L TDS (predominantly NaCl with about 14 percent $CaSO_4$). This source might be adequate for use as dilute makeup to a solar pond or as feed to a solar-pond-coupled desalination process. No data are available on the expected yield from this well.

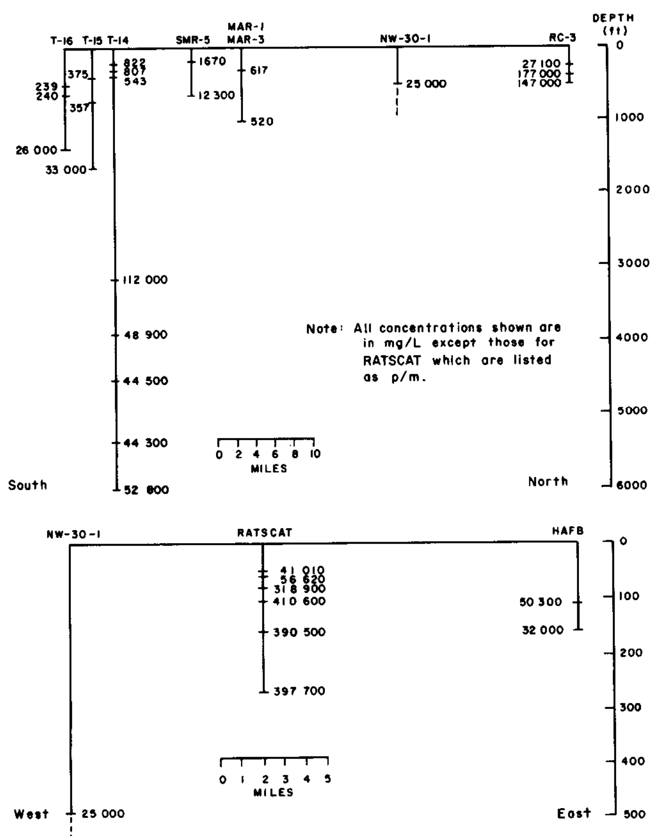


Figure 11.–Salinity profiles on north-south and east-west axes through concentrated brine sources.

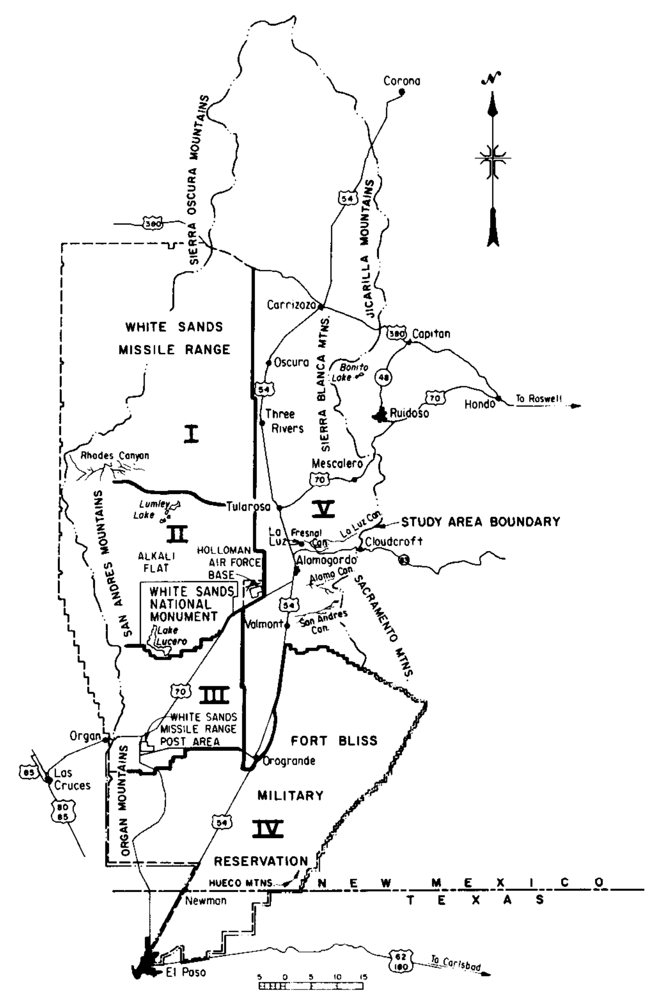


Figure 12.–Solar pond study areas in the Tularosa Basin.

The terrain is fairly flat (generally less than 1 percent slope) and smooth to the east of well RC-3. Three playas, varying in size from about 0.3 to 0.8 km^2, are located approximately 2 miles to the southeast. In addition, several similarly sized shallow depressions are located within a 6-mile radius to the southeast and northeast. Potential construction soils with lean clay, silty clay, and silty clay loam are available in large areas immediately surrounding well RC-3 [18].

Surface access to area I is limited to military roads which are frequently blocked during missile firings. In addition, personnel working in this area are subject to evacuations during these military operations. No major electrical transmission or water pipelines were noted.

Area II. – Four high-salinity sources were identified in this area: NW-30-1, RATSCAT, and two at HAFB. The HAFB wells produce brine concentrations of 50 300 and 32 000 mg/L, both at expected yields of about 100 gal/min. Two complete analyses (major ions) are available for well NW-30-1, one showing a TDS of 25 000 mg/L; however, another partial analysis for the 620- to 735-foot-depth interval indicates a Cl^- (chloride) level of 24 200 mg/L which infers a significantly higher total salt concentration, possibly close to 40 000 mg/L. Well NW-30-1 has been pump tested for 8 hours at 248 gal/min with a maximum drawdown of 30.5 feet.

The concentrated brine source that appears to have the greatest potential for solar pond applications within the Basin is from a 270-foot well at the RATSCAT site, located approximately 13 miles to the west of HAFB in the alkali flats. The stratified analyses for this well (refer to table 6) indicate that the brine contains high concentrations of both Na_2SO_4 (sodium sulfate) and NaCl (at or near saturation below 80 feet).[3] In addition, $CaSO_4$ levels are relatively low, generally below 2 percent at or below a depth of 80 feet. Shallower brines contain a higher concentraction of $CaSO_4$, up to about 20 percent. Limited pump test data suggest that this well could produce in excess of 70 gal/min with less than 50 feet of drawdown. A distinct advantage associated with the RATSCAT brine, compared to the other sources discussed, is that it is concentrated enough to be used directly for solar pond construction and maintenance. This, of course, eliminates any need for further brine concentration by evaporation ponds or other means, which affects pond construction costs appreciably.

The alkali flats, situated in the lowest part of the Basin, are comprised of a series of playas which contain fine-grained silt, sand, and clay with evaporites in the form of recrystallized sulfates and NaCl. The playas are extremely flat with a shallow water table nominally between 3 and 7 feet from the surface, which would preclude excavation to any significant depth in this area. During periods of heavy rain or runoff, the ground-water level rises even closer to the surface.

To the east of the alkali flats are the gypsum dunes of WSNM. Further to the east toward HAFB is some fairly flat, smooth terrain that might be suitable for solar ponds. There are also a few small dry lakebeds (between 0.03 and 0.35 km^2 in size) immediately to the south of HAFB which might be usable. These areas are close to two principal potable water and energy use centers (HAFB and Alamogordo) and appear to be less restrictive to access than the alkali flats. Concentrated brines similar to those found at RATSCAT might be available farther east toward the eastern fringe of the dunes, most likely at a greater depth, which could be used for a solar pond near HAFB. Alternatively, RATSCAT brine could conceivably be transported by pipeline to a pond site in this area. Moderately saline waters of a concentration suitable for dilute makeup and pond construction are available generally to the north and southeast of HAFB. Slightly saline sources that could be used as feed water to a solar-pond-coupled desalination process have been identified in the Alamogordo area [19]. In addition, clay-bearing soils appropriate for pond construction are available to the west, just within WSMR boundary. No data were available to substantiate materials farther to the east.

Surface access to area II, west of the dunes, appears to be more restricted than area I, particularly in the vicinity of the RATSCAT site. No major electrical transmission or water pipelines were noted.

Area III. – Six brine sources were identified in this area: Garton well, MAR-1 (test), MAR-3, SMR-5, T-14, and T-15. Brines from Garton well and SMR-5, at the depths penetrated, would not be too useful for solar ponds because of their limited maximum concentration (refer to table 6). Only partial analyses [Cl^- and SO_4^{-2} (sulfate)] were available for the MAR-1 and -3 wells at the lower, more concentrated intervals. It appears, however, that the TDS for these sources could be as high as 50 000 and 30 000 mg/L, respectively [based on a matching equivalence of Na^+ (sodium)]. The

[3] It should be noted that ion concentrations do not balance (equivalents of anions far exceed cations) in most of the RATSCAT analyses, particularly at the deeper levels.

brine analysis that shows the greatest potential is from well T-14, located about 4 miles east of the WSMR post area. At depths of between 2590 and 3700 feet, this well yields a brine concentration of 112 000 mg/L with a very high percentage NaCl as well as a low $CaSO_4$ content (as stated earlier, it is suspected that the well penetrates a halite bed within this interval). Well T-14 has not been pump tested, but it is estimated that the yield would exceed 700 gal/min. Well T-15, just to the south of T-14, might produce similar brines if it had been drilled to a greater depth.

Referring to figure 7, it can be seen that moderately saline water (3000 to 10 000 mg/L), adequate for a solar pond dilute source, is available within a narrow interval a few hundred feet below the surface in the vicinity of well T-14. This figure, when compared to the other diagrammatic sections presented, also shows the relative magnitude of the freshwater zone (less than 1000 mg/L) existing in this area. The freshest water in the Basin (salinities down to 300 mg/L), and the most abundant supply, is located adjacent to the mountains near WSMR headquarters. Based on this and the relative population densities, the potential for a potable water shortage in the WSMR area is not nearly as great as would be expected for the HAFB/Alamogordo area.

There were no playas identified near well T-14; however, many large depressions just to the east, some about 2 km^2 in size, might be good pond sites. Both silty clay and clay loam deposits are available in this area. Three playas, averaging approximately 0.6 to 0.7 km^2, are located in the northeast corner of area III immediately south of U.S. Highway No. 70 near Garton well.

Access to much of this area is controlled; however, the specific regions and degree of restriction are unknown. Surface transportation includes U.S. Highway No. 70 which traverses diagonally across the area from northeast to southwest and several adjoining and other military roads. Two 115-kV transmission lines cross this area – one an El Paso Electric line passing north along the eastern boundary of WSMR with branches terminating at HAFB and WSMR headquarters, and the second, a Plains Electric Generation and Transmission line which parallels U.S. Highway No. 70. This line, which until recently was owned by the Bureau of Reclamation, provides power to the military installations on an emergency basis only [20]. El Paso Electric is the largest supplier of power in the region, serving WSMR and some of Fort Bliss and southern fringe areas. One major water pipeline was noted between the WSMR post area and the vicinity of Orogrande on U.S. Highway No. 54.

Area IV. – Well T-16 is the only highly saline source identified in this area. The usefulness of the analysis for the bottom interval of this well shown in table 6 is limited, however, because of a severe ion imbalance (the anion equivalence greatly exceeds that for cations), i.e., the maximum expected concentration is unknown. Since the well is located relatively close to well T-14 (area III), one might expect somewhat higher salinities at a greater depth. There are probably sources of brine further south in the Hueco Range; however, no data were available for this area. The most concentrated sources identified east of U.S. Highway No. 54 in the McGregor Range were from wells located 12 to 15 miles east and northeast of Newman which contain 8740 and 9130 mg/L TDS, respectively.

Fresh to slightly saline water supplies are located in the southwest corner of Fort Bliss in the vicinity of Biggs Army Airfield from sand and gravel strata (40 to 400 feet) and, to a lesser extent, from poorly fractured consolidated rock along the base of the Sacramento and Organ Mountains.

Most of the land area within Fort Bliss is relatively flat (0 to 3 percent slope) with extensive regions of small sand dunes and mesa. Surfaces are rough in the dune areas and generally smooth elsewhere. Several playas and shallow depressions are located in the McGregor Range, and to a lesser extent in Hueco Range, mostly interspersed with flood plains and broad drainageways. The predominantly silty soils associated with these land features reportedly have permeabilities ranging from 0.5 to 1.5 cm/h [21].

Most of Fort Bliss, particularly that portion within New Mexico, is used as a missile impact area or for firing ranges and is, therefore, restricted or limited in access. Both U.S. Highway No. 54 and New Mexico Highway No. 506 penetrate the reservation – the former dissecting the range area parallel to a Southern Pacific rail line on roughly a north-south axis, and the latter traversing east to west across the northern edge of McGregor Range. Numerous secondary unpaved military roads also crisscross the area. The El Paso Electric 115-kV transmission line discussed in the previous section in area III traverses south to north, adjacent to U.S. Highway No. 54 to the south, and diverging west from the highway to the north. Water transport pipelines noted include a 12-inch line extending from Newman northeast 11 miles into McGregor Range, a 4- to 10-inch line (generally in poor condition) extending from the Sacramento River 20 miles to Orogrande, and an 84-mile, 1.5- to 6-inch line connecting the Sacramento River with various sites on the Otero Mesa.

Area V. – This area includes State, private, and BLM (Bureau of Land Management) administered public lands along the east side of the Basin which are used principally as rangeland. Unlike the previous areas discussed, there appears to be no potential for conflict with military land use.

No high-salinity well waters were identified in this area; however, an analysis was found for a shallow pool, located approximately 12 miles north of HAFB and just east of WSMR boundary, which contains brine at a concentration of nearly 260 000 mg/L, comprised predominantly of $MgSO_4$ (magnesium sulfate) [22]. No information was presented regarding the source of the brine. According to data presented by McLean [12], the only saline ground-water sources in this area with a TDS greater than 10 000 mg/L would be located immediately to the southeast of HAFB. Any solar pond development would, therefore, most likely depend on the import of concentrated brine from WSMR.

Land to the north of HAFB and Alamogordo slopes westward roughly 50 ft/mi (approximately 1 percent), while that to the south is relatively flat down to the Jarilla Mountains. Several playas and depression areas exist from HAFB extending south 15 to 20 miles along WSMR boundary. Concentrated brines from the alkali flats area, or possibly farther east, could be used to support pond construction in these land features. Moderately saline ground water (3000 to 10 000 mg/L), adequate for a solar pond dilute source, is available within a very sizable interval in this area (refer to fig. 8). In addition, slightly saline or brackish waters in the vicinity of HAFB and Alamogordo have been identified in several reports which could be used as feed water for a solar-pond-coupled desalination process [19, 23, 24].

Both U.S. Highway No. 54 and a line of the Southern Pacific railroad traverse north to south through this area, along with several connecting east-west highways. The Plains Electric 115-kV transmission line coming from Elephant Butte Reservoir parallels U.S. Highway No. 70 to Alamogordo then heads northeast where it terminates at the town of Hollywood. The principal water transport pipeline in this area is the 14- to 20-inch line supplying potable water from Bonita Lake (north of Ruidosa) in the Sacramento Mountains to Carrizozo, Tularosa, Alamogordo, HAFB, and other smaller communities. The average diversion of water from Bonita Lake is reported to be 2.76 Mgal/d [19].

As a result of this preliminary site evaluation, it appears that two of the most promising locations for solar ponds would be an area immediately west of HAFB using brine either transported by pipeline from the RATSCAT site or possibly from a similar source to the east of RATSCAT, and an area within a few miles east or south of WSMR headquarters using brine from well T-14. The HAFB site offers the advantages of being close both to an excellent concentrated brine source and to principal energy and potable water-use (need) centers. Feasibility studies on the desalination potential of this area have already been completed which could be used to support a solar-pond-coupled desalination proposal or design effort [19]. This site also seems to be well outside any impact or highly restricted areas and is relatively close to primary surface transportation routes and to the 115-kV transmission line paralleling U.S. Highway No. 70. Clay bearing soils (containing lean clay and silty clay) suitable for pond construction are available just to the west of HAFB.

The area to the east of WSMR headquarters contains several large depressions which could be used as pond sites with a minimum of excavation. In addition, both silty clay and clay loam construction soils are available locally. The projected energy need for WSMR has been fairly well documented; however, the future need for alternate potable water supplies (other than those obtained from local well fields) appears not to be nearly as acute. This general area is not in an impact or otherwise hazardous area and is also near U.S. Highway No. 70 and an existing 115-kV transmission line. As was previously mentioned, the use of T-14 brine as a concentrated source would require some means of further concentration, i.e., solar evaporation, brine concentrator, which would affect construction and operating costs.

Other potential locations include an area to the south of Garton well using existing playas or possibly playas around Lumley Lake, depending on groundwater levels. The latter would be preferable to sites on the alkali flats because of the higher clay and silt content in the playa deposits.

PERFORMANCE ANALYSIS

Solar Pond Performance

The monthly and annual thermal performance of solar ponds in the Tularosa Basin, as well as at Canadian River and Malaga Bend, were determined using a computer program called SOLPOND developed by SERI (Solar Energy Research Institute). SOLPOND uses a finite difference technique to model solar ponds with a one-dimensional thermal network used for large ponds and a three-dimensional network for small ponds [25, 26]. Large solar ponds have lateral dimensions much greater than pond depth so the

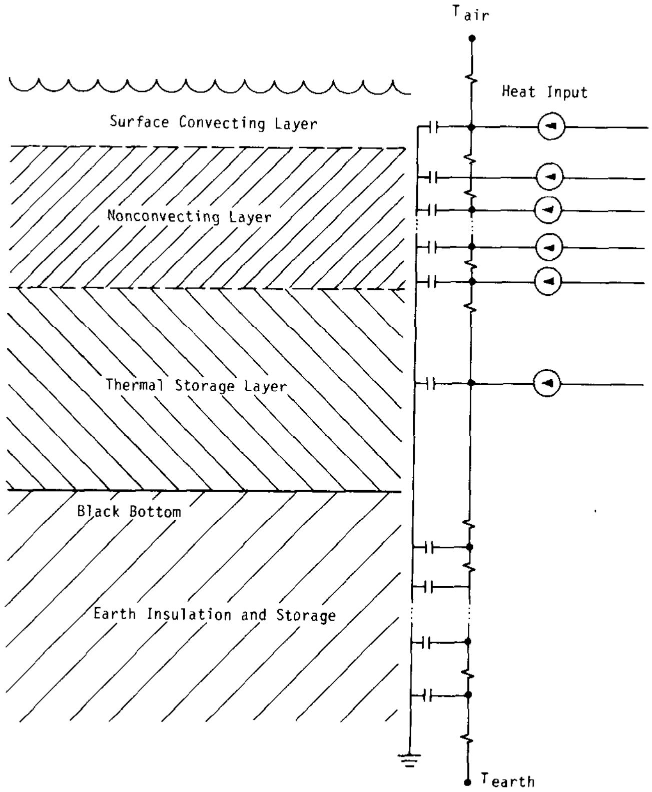


Figure 13.–One-dimensional solar pond thermal network (electrical analogy).

perimeter edge losses become very small compared to collected energy. Figure 13 shows the thermal network for SOLPOND.

SOLPOND has the flexibility to analyze pond performance for a wide range of input parameter values and load profiles in arriving at temperature distributions and energy extraction rates for transient and steady-state operation. Three types of analyses can be selected including (1) a transient mode to determine temperatures and energy extraction during warmup, (2) an analysis mode referred to as MINTMP which uses a user-specified minimum storage temperature and tracks an imposed load profile over the year, and (3) a constant energy extraction mode (i.e., constant load over the year). The transient analysis mode is used to determine the warmup period characteristics, including temperatures and heat extraction rates during startup. After a sufficient length of time, typically 1 to 4 years depending on storage layer depth and other conditions, the resulting energy extraction profile approaches a steady-state pattern which is periodic but repeats each year. This profile is typically used as the input load for MINTMP. As an additional check on the annual energy delivery predicted by MINTMP, the constant load mode of analysis is performed, usually resulting in close agreement with MINTMP for ponds having storage layer depths corresponding to baseload operation (i.e., 3 to 3.5 m).

Detailed computer simulations used to predict pond performance depend on several variables including the following:

- Solar radiation and meteorological conditions
- Optical transmission to the storage zone
- Zone thicknesses
- Thermal properties of the brine and soil

A list of SOLPOND input parameters is presented in appendix A. The values listed in the "default" and "limits" columns were provided by SERI; those listed in the "assumed" column were used in simulations of the present study.

The solar and meteorological data used in this study were obtained from the SOLMET data base maintained by the NCC (National Climatic Center) in Asheville, North Carolina. The data base contains hourly data for 248 United States stations with the period of record for each station being about 20 years [27, 28]. The SOLMET data for each location have been synthesized by months into a TMY (typical meteorological year). Each TMY contains hourly solar radiation and surface meteorological data representative of an average or "typical" year at a particular station. Reference [29] contains a discussion of the procedure used in generating the TMY data base.

A TMY station was chosen to represent each of the pond sites being investigated. Selection was based on proximity to the site and on geographic and meteorologic similarity. The location of each solar pond site is compared with that of its respective TMY station in the following chart:

Solar Pond Site	TMY Site
Tularosa Basin (Alamogordo, New Mexico) Latitude = 32°53'N. Elevation = 1323 m (4341 ft)	Truth or Consequences, New Mexico Latitude = 33°14'N. Elevation = 1481 m (4858 ft) 21 108 kJ/m² per day (1860 Btu/ft² per day)
Malaga Bend, New Mexico Latitude = 32°12'N. Elevation = 882 m (2895 ft)	El Paso, Texas Latitude = 31°48'N. Elevation = 1194 m (3916 ft) 21 559 kJ/m² per day (1899 Btu/ft² per day)
Canadian River (Logan, New Mexico) Latitude = 35°22'N.	Tucumcari, New Mexico Latitude = 35°11'N.

Solar Pond Site	TMY Site
Elevation = 1122 m (3680 ft)	Elevation = 1231 m (4038 ft) 19 573 kJ/m² per day (1724 Btu/ft² per day)

The average daily insolation at the three TMY sites is among the highest in the United States. Needles, California, and Tucson, Arizona, for example, average 1861 and 1872 Btu/ft², respectively. The TMY temperatures were used in the analysis since they are virtually identical to those measured at the solar pond sites.

Other variables which have a significant effect on pond performance include optical transmission of solar radiation through the salt solution, pond zone thicknesses, and thermal properties of the brine and soil. Optical transmission in this study corresponds to the clear brine solutions described in references 25, 30. Several factors determining optical transmission are discussed in detail in references 31, 32, 33, 34. Solar pond zone thicknesses (shown in fig. 2) were set at 0.3, 1.3, and 1.75 m for intermediate load operation and 0.3, 1.3, and 3.5 m for baseload operation of the pond. Typical values were used for the thermal properties of the brine and soil. For large ponds, the soil conductance has a small effect on output after the warmup period and the heat loss from the bottom of the pond is typically 2 percent or less of the incident solar energy [35, 36].

Variables which are not treated as input parameters in SOLPOND include gradient stability, wind/wave action, mud/brine interactions, and diffusion and evaporation rates. These factors are not directly used in the model but do influence the selection of input values for variables such as optical transmission (or extinction) coefficients and zone thicknesses. References 15, 32, 33, 34 discuss these design variables and methods for their control.

Computer programs that predict solar pond performance have been developed by several institutions and organizations in the United States and Israel. In addition to SOLPOND, other solar pond performance models have been developed by JPL (Jet Propulsion Laboratory), Ormat Turbines, and others. References 15, 32, 34, 35, 36 discuss these models and the variables that affect their accuracy.

Performance predictions made using SOLPOND and the JPL and Ormat models are generally in good agreement for locations in the southwestern United States which experience similar meteorological conditions [1, 33]. An example of the capabilities of the Ormat model is shown on figure 14 which

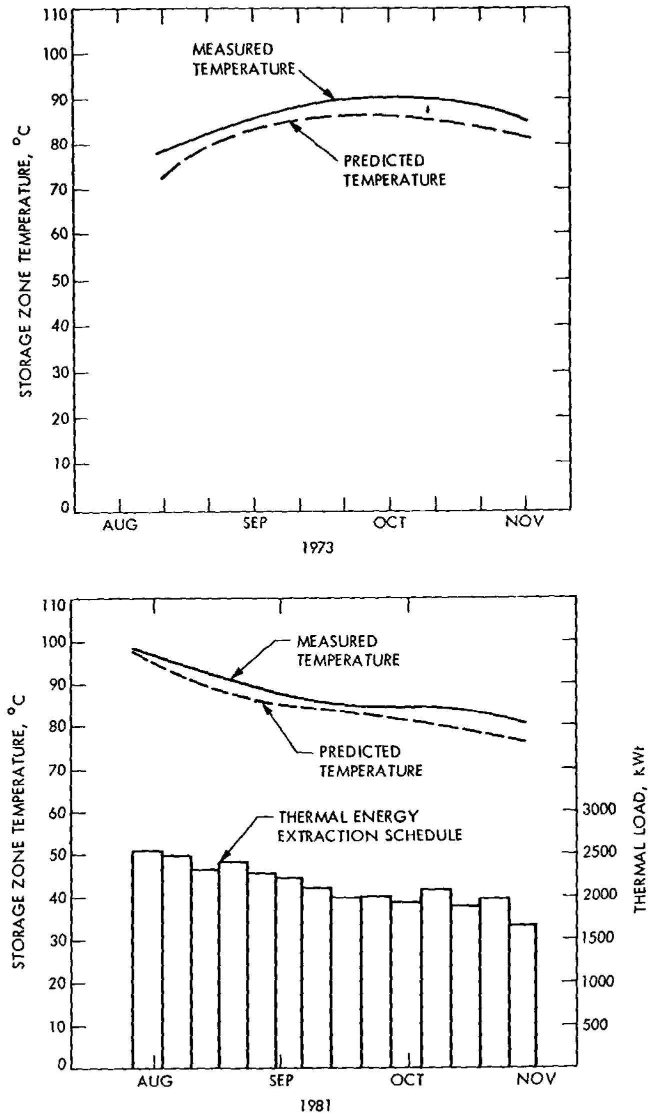


Figure 14.–Comparison of Ormat model simulations to measured performance for the Ein Bokek, Israel solar pond [33].

compares predicted performance with measured data for a 7500-m² solar pond located near Ein Bokek, Israel. This model, which is reported in reference 37 to now be validated using more extensive data for the Ein Bokek pond, has been used to simulate solar ponds at the Salton Sea and Danby Dry Lake in California. A similar comparison of actual versus predicted performance for SOLPOND is shown on figure 15 for a 2020-m² solar pond at Miamisburg, Ohio.

Power Generation

Performance results from the SOLPOND analysis for solar ponds in the Tularosa Basin are presented in table 7 and figure 16 in terms of the thermal and electrical power output as a function of time of year. These results represent the power extraction profiles

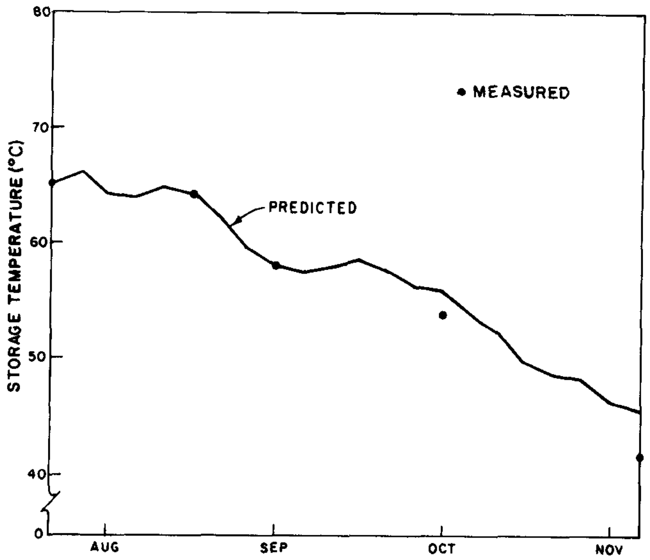


Figure 15.–Comparison of SOLPOND model simulations to measured performance for the Miamisburg, Ohio, solar pond [25].

for optimized electric power conversion under baseload operation (3.5-m storage layer depth) using an ORC engine since this represents developed technology. It should be noted that these profiles, if optimized for thermal power, would peak at a different time of the year. The thermal-to-electric conversion efficiencies (η_{ORC}) used in the power generation analysis are tabulated in table 7. The temperature profiles plotted on figure 16 for the pond storage layer and cooling water (solar pond surface water) show a phase shift between peak temperatures and power extraction rates. The power extraction rates are based on the SOLPOND output shown in table B-1 in appendix B and the following performance characteristics for the power system:

- Gross-to-net thermal power efficiency of 90 percent to account for parasitic power consumed in extracting heat from the pond.
- Thermal-to-electric (gross) power conversion efficiencies (η_{ORC}) equal to 64 percent of Carnot cycle efficiency. In making this calculation, it is assumed that the temperature drop across the heat exchangers will reduce the available ΔT (storage layer temperature minus ambient air temperature) by 12 °C.
- Gross-to-net electric power efficiency of 77 percent to account for parasitic losses associated with the ORC boiler feed pump and cooling water circulation pump.

The results of SOLPOND analyses for the Malaga Bend and Canadian River sites are presented in tables B-2 and B-3, respectively, in appendix B. Table 8 shows the annual energy production values for the Tularosa Basin, Malaga Bend, and Canadian River sites.

Since solar ponds may be operated in several modes (peaking, intermediate, or baseload), the study also included an analysis to determine the effect of each on the power generation capabilities of the pond. This was done using storage layer depths of 0.5, 1.75, and 3.5 m to simulate peaking, intermediate, and baseload operation, respectively.

The analysis showed that solar pond expansion (rate of development) can be accelerated by starting with peaking load operation and then converting to intermediate and baseload operation as more concentrated brine becomes available. It also showed that reduced storage layer depths result in a relatively small reduction in the amount of energy produced;

Table 7.–*Continuous thermal and electric power output at Tularosa Basin*

Month of year	Thermal power (MWt/km^2) Gross	Net	Conversion efficiency η_{ORC}	Electric power (MWe/km^2) Gross	Net
January	40.18	36.16	0.1154	4.639	3.572
February	37.47	33.72	.1051	3.936	3.031
March	35.42	31.88	.1011	3.579	2.756
April	34.95	31.46	.0986	3.447	2.654
May	36.22	32.60	.1004	3.638	2.801
June	38.72	34.85	.0996	3.857	2.970
July	41.54	37.39	.1039	4.316	3.320
August	44.36	39.92	.1082	4.800	3.696
September	46.49	41.84	.1105	5.136	3.955
October	47.06	42.35	.1171	5.508	4.240
November	45.95	41.36	.1204	5.534	4.261
December	43.52	39.17	.1194	5.196	4.001
Average	40.99	36.89	.1083	4.465	3.438

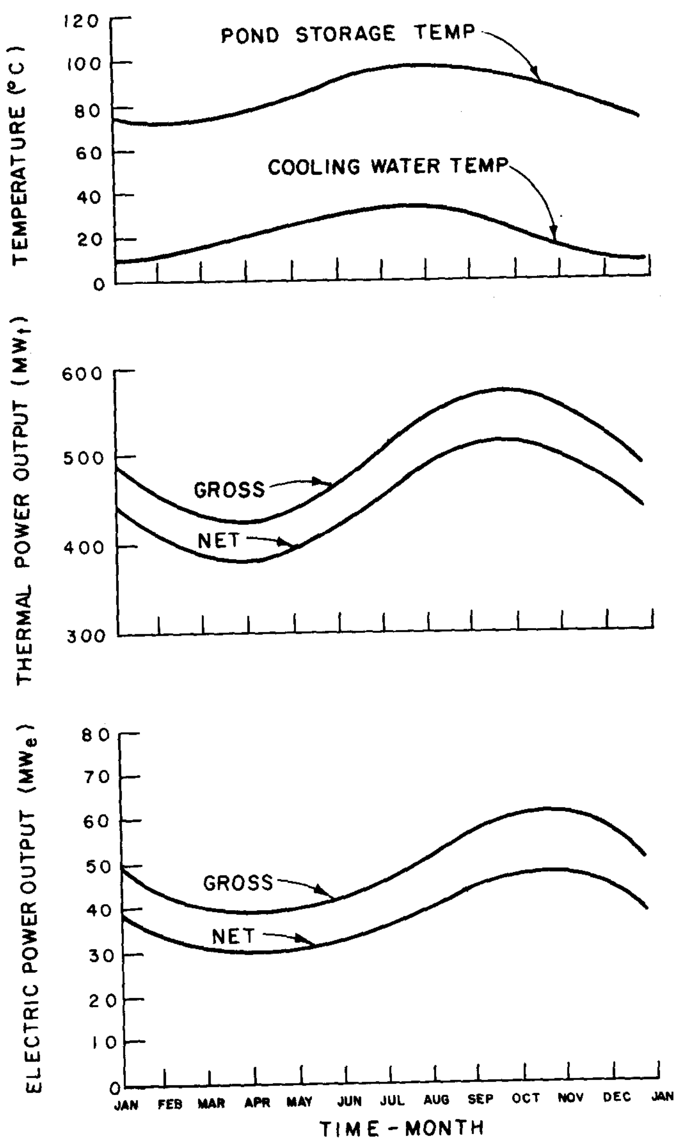


Figure 16.–Temperature and continuous power profiles for the Tularosa Basin (10-km² solar pond with 50-MWe baseload power module).

e.g., under baseload conditions, operating at a storage layer thickness that is only half of what is considered optimum reduces the annual production of electrical energy by less than 10 percent.

Further improvement in pond performance can be achieved through the use of enhanced heat exchangers. For example, using a direct-contact boiler in place of a conventional shell-and-tube unit can reduce the size of the power generation equipment needed in a given installation by as much as 25 percent [34, 38, 39, 40].

Solar-Pond-Coupled Desalination

Desalination is another beneficial application of solar ponds. Coupling solar ponds to desalination/salinity control projects allows:

- Brine reject from the desalting plant to be used for solar pond construction and maintenance.
- Energy produced by the ponds to be used to power the desalting process and for associated pumping needs.
- Intercepted brine from a salinity control project to be used beneficially to construct and support solar ponds thereby displacing significant portions of a disposal pond system.

The net results of coupling solar ponds to desalting plants is that the brine reject provides all or part of the surface flush for the solar ponds and, upon further concentration, serves as makeup brine for the storage layer. This can have a significant effect on desalination costs since it allows a portion of the brine disposal pond area to be displaced by solar ponds. The coupled system also takes advantage of the relatively inexpensive thermal and electric energy available from the solar ponds as well as the integral thermal storage feature which allows for continuous energy production and thereby maximum use of the desalting plant equipment. The availability of both thermal and electric energy in any

Table 8.–*Solar pond energy production for Tularosa Basin, Malaga Bend, and Canadian River*

	Annual energy production, $\frac{\text{MWh}}{\text{km}^2\text{-yr}} \times 10^4$		
	Tularosa Basin	Malaga Bend	Canadian River
Thermal Energy:			
Gross	35.9	39.2	30.4
Net	32.3	35.3	27.4
Electrical Energy:			
Gross	3.91	4.14	3.36
Net	3.01	3.19	2.59

combination of the two provides flexibility in selecting the appropriate desalination process for the application.

A schematic of a typical solar-pond-coupled desalination system is shown on figure 17. The principal components of this system are the desalting plant, the solar pond (with associated power generation equipment), and a brine makeup and final disposal pond. The desalting plant converts saline feed water into product water (with concentrations typically less than 500 mg/L for membrane processes and less than 50 mg/L for distillation processes) and brine reject, which when used as surface flush for the solar pond reduces the size of the disposal pond.

For this study, two of the more promising state-of-the-art desalination processes were considered, namely RO and HTMED (horizontal-tube, multiple-effect distillation). Other processes which may be suitable for solar-pond-coupled desalination are electrodialysis and other energy-efficient distillation processes.

RO is a desalination process that can be readily coupled to solar ponds. In a solar-pond-coupled RO system, pond thermal energy is converted in a Rankine cycle to mechanical energy for use in driving the high-pressure RO feed pumps. The salinity of the feed water strongly influences the amount of power required by an RO plant because the osmotic pressure in an RO membrane element increases directly with the salinity gradient across the membrane. Feed pressure must be great enough to overcome osmotic pressure and to provide sufficient driving force for the desalting process. System pressures for RO desalination are typically 400 to 600 lb/in^2 for brackish waters and 800 to 1000 lb/in^2 for seawater.

Another commercially available desalination process that provides a good load match with solar ponds is a low-temperature distillation process known as HTMED. By coupling the two together, the HTMED process can utilize the medium- to low-grade thermal

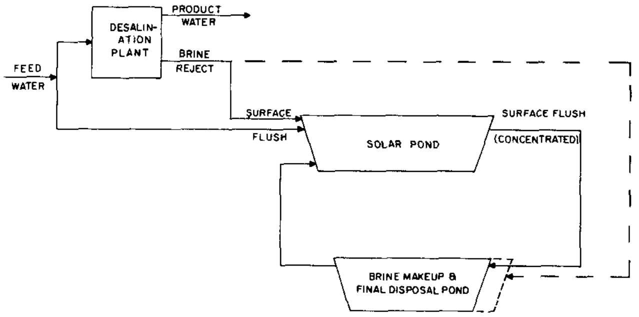


Figure 17.–Schematic of a typical solar-pond-coupled desalination system.

energy produced by the ponds (at temperatures ranging between 160 and 200 °F) to generate 160 to 180 °F steam for use in driving a series of distillation effects. The HTMED process is able to operate with relatively small temperature differences between effects which allows the thermal energy to be reused many times, thereby increasing the amount of product water produced per unit of heat input. Operation at these low temperatures also contributes to reliable operation in terms of low scale and corrosion rates. In addition, solar ponds in this system can, through the use of an ORC engine, provide the energy (either mechanical or electrical) needed for pumping power.

Performance data for both an RO and HTMED plant coupled to a solar pond are presented in table 9 in terms of energy, water, and solar pond area requirements and water production capabilities for a feed salinity of 1780 mg/L and 70 percent recovery.

MASS BALANCES

Mass balance analyses were performed for two separate operational scenerios: power generation only and solar-pond-coupled desalination, each at selected ultimate solar pond areas, storage layer depths, construction periods, and desalination plant capacities as shown in table 10. In each of the eight cases, the variable levels indicated were imposed on the analysis to determine their combined effect with time on system support requirements, system losses due to evaporation and salt precipitation, and solar pond expansion rates.

Power Generation Only

Two influent brine conditions were considered in calculating mass balances for the power generation only scenario. The first assumed the use of brine from well T-14 at a concentration of 112 000 mg/L, and the second, concentrated brine at 260 000 mg/L available in the vicinity of RATSCAT. Representative mass balance diagrams for these two conditions are shown on figure 18. The flow rates and pond areas presented in both diagrams relate to the fourth mass balance case indicated in table 10. Complete mass balance solutions associated with figures 18a and b are presented in appendix C on pages C-1 and 3, respectively.

Calculations were performed at solar pond area increments equivalent to 10 percent of the ultimate pond size; e.g., 1, 2, 3, . . ., 10 km^2 for the fourth case presented in table 10. The flowrates, evaporative losses, and production/makeup pond area shown on figure 18 relate to the 5-km^2 solution for this particular analysis.

Table 9.—*Solar-pond-coupled desalination performance characteristics for Tularosa Basin*[1]

	RO	HTMED
Feed pressure, lb/in^2 (gage)	400	–
Energy required:		
◦ Thermal, MBtu/kgal of product[4]	–	[2]0.756
◦ Electrical, kWhe/kgal of product	[3]9.5	5
Pond area required for:		
• Thermal energy, m^2/kgal per day	–	248
• Electrical energy, m^2/kgal per day	115	61
Water ratio[4]	7.5	12.6
Productivity, Mgal/acre per day	0.035	0.016

[1] Based on 1780-mg/L feed salinity and 70 percent recovery, operating at a desalination plant factor of 0.9 with product salinities of 500 mg/L for the RO plant and 50 mg/L for the HTMED plant.

[2] Assumes 10 percent of the thermal energy will be needed for pumping power to extract the thermal energy.

[3] Accounts for auxiliary power but no energy recovery and a combined motor and pump efficiency of 72 percent.

[4] Quantity of saline feed water needed for the desalting plant and for cooling water for the powerplant and final condenser of the HTMED process per unit of product water.

Table 10.—*Mass balance cases investigated*

Solar electric powerplant				Desalination plant	
Capacity, rated gross (MWe)	Storage layer depth* (m)	Solar pond area (km^2)	Const. period (yr)	Rated capacity (Mgal/d)	Capacity, net cont.** (Mgal/d)
5	1.75	0.5	0.5	–	–
5	3.5	1	1	–	–
50	1.75	5	5	–	–
50	3.5	10	10	–	–
5	1.75	0.5	0.5	5	4.5
5	3.5	1	1	5	4.5
50	1.75	5	5	50	45
50	3.5	10	10	50	45

* 1.75- and 3.5-m storage layer depths are associated with intermediate-load and baseload operation, respectively.

** Based on a desalination plant factor of 0.9.

The upper-convecting and nonconvecting layer depths were assumed constant at 0.3 and 1.3 m, respectively. The dilute makeup shown on both figures 18a and b is required for periodic flushing of surface (upper convecting) layer brines that have been concentrated by evaporation and salt transport (migration from the more concentrated lower layers). Surface flushing also serves to remove accumulated dirt and other debris from the pond surface. The brine makeup shown replenishes salt to the storage zone which has been depleted by this transport mechanism. For these analyses, it was assumed that salt concentration in the upper convecting zone will fluctuate during the flushing cycle between 3000 mg/L (dilute source concentration assumed for the four power generation only cases) and 50 000 mg/L, yielding an average concentration of 26 500 mg/L (26 020 p/m) which, when compared to the storage layer salinity of 260 000 mg/L (222 500 p/m), results in a mean concentration gradient (ΔC_s) of approximately 196 500 p/m or 19.7 percent, by weight. The flushing cycle [time (days) required for combined processes of evaporation and salt transport to concentrate the surface layer to 50 000 mg/L][4] and annual flushing volume for the power generation only analyses were calculated to be 154 days and 7.45 acre-ft/acre per year, respectively.

Average net annual evaporation and salt transport rates were assumed to equal 1.68 m/yr (5.5 ft/yr)[5] and 0.0086 g/cm^2 per day, respectively. This salt transport coefficient (about 1.5 times that attributable to molecular diffusion)[6] will require approximately 0.4 acre-ft of brine makeup at 260 000 mg/L per year per acre of solar pond to maintain the salinity gradient. This brine makeup is supplied from the production/makeup pond for the system shown on figure 18a, and from the externally available concentrated brine source on figure 18b.

Flushing water blowdown from the solar pond in figure 18a is combined with influent brine at 112 000 mg/L in production/makeup ponds for further concentration by evaporation to the 260 000 mg/L required for solar pond expansion/maintenance. The proportion of dilute and concentrated production pond effluent used for solar pond expansion is a function of the various pond layer depths required. Flushing water blowdown on

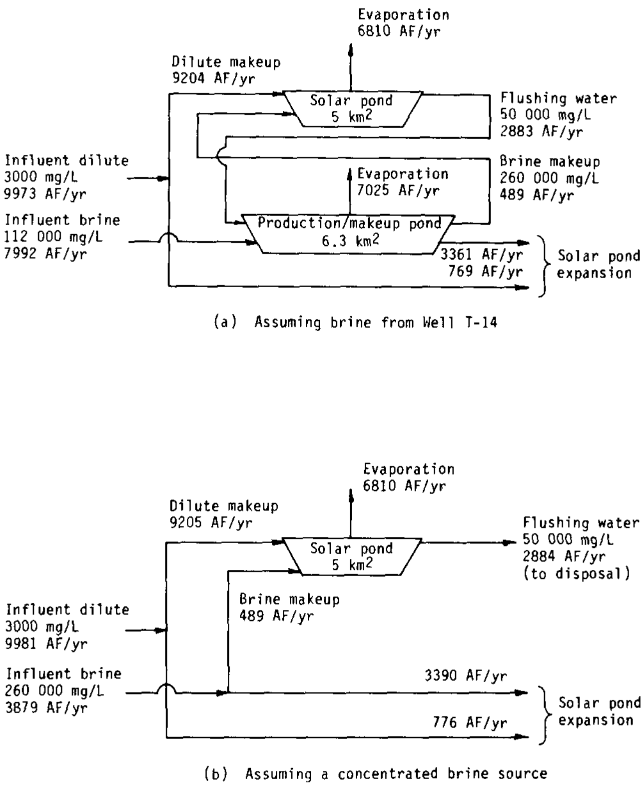


Figure 18.–Representative solar pond mass balances (power only scenario – 50-MWe baseload).

figure 18b is wasted from the system, most probable to evaporate in unlined depressions or playa where salt contamination does not pose a problem.

As brines concentrate, both in the evaporation ponds and within the surface layer of the solar pond, salts of limited solubility will reach saturation and precipitate from solution. One such salt, predominant in many shallow ground-water sources in the Tularosa Basin, is $CaSO_4$ (calcium sulfate). The $CaSO_4$ represents only about 1.3 percent of the total salt content in T-14 brine and, therefore, would not cause much precipitation in the production/makeup pond. The dilute source, however, would likely contain as much as 30 to 40 percent $CaSO_4$, based on analyses of shallow brackish water sources in the vicinity of HAFB. Precipitate formed from this salt above the storage layer would absorb or scatter penetrating solar radiation and would thus reduce the pond's thermal efficiency. The precipitate is dense, however, and would settle rapidly.

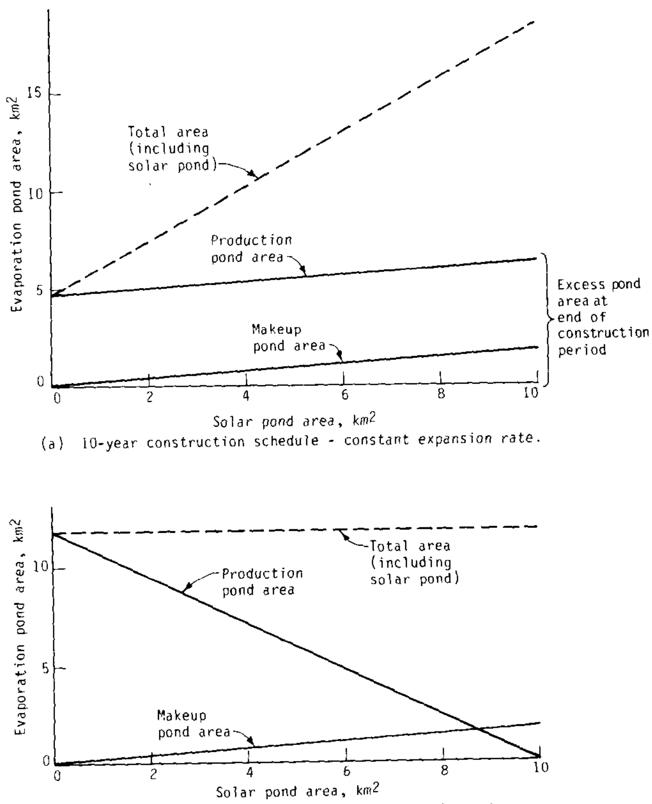
The dilute source assumed for this analysis contained 42.7 percent $CaSO_4$ (same percentage as contained in the desalination feed water discussed in the next section). It is estimated that 90 percent of this salt will precipitate in the solar pond leaving an accumulation at the pond bottom of approximately 0.5 cm/yr.

[4] Dilute makeup is continuously fed to the surface convecting zone to maintain a layer depth of 0.3 m.

[5] Based on data presented in reference [41] which show that the average net annual evaporation rate for freshwater in the Tularosa Basin ranges from 4.5 to 5.5 ft/yr depending on location.

[6] Higher transport coefficients have been reported but are associated with small ponds where edge effects are significant [42].

Comparing the two systems presented in figure 18, it can be seen that the use of T-14 brine requires some means of concentration to bring the dissolved solids content up to the 260 000 mg/L required for pond construction/maintenance. In this case, solar evaporation is assumed. Other possible methods include spray-enhanced evaporation, solution mining of existing salts at or near the pond site, and the use of a brine concentrator. The main drawback to using evaporation ponds for brine concentration, in conjunction with a reasonably short solar pond construction period, is the large evaporation area required. An extensive, costly (particularly if sealed with an elastomeric liner) evaporation pond area remains at the completion of solar pond construction. A relatively small portion of this area is required for production of makeup brine for injection to the storage layer; however, most of the area will remain unused, except possibly for brine disposal area. Figure 19a presents evaporation pond area data as a function of solar pond size for the analysis represented by figure 18a. It can be seen that, at the end of the 10-year construction schedule, approximately 6.5 km² of production pond remains. The production pond area during solar pond expansion was sized to provide a fairly constant expansion rate of 1.0 km²/yr (refer to page C-2 of appendix C).



(a) 10-year construction schedule - constant expansion rate.

(b) Constant total pond area - declining expansion rate.

Figure 19.–Evaporation pond area needed to support solar pond expansion and maintenance (assuming T-14 brine and 50-MWe baseload construction).

An alternate method of employing evaporation ponds for brine concentration is shown on figure 19b. Here the beginning production pond area is equivalent to the combined area of the final solar and makeup ponds. As the solar and makeup ponds expand, they consume existing production pond area until, at the completion of the construction period, production area is totally converted and no excess remains. The initial rate of solar pond expansion using this method of brine concentration is considerably greater than 1.0 km²/yr; however, towards the end of construction, the rate approaches zero along with production pond area. The result is a construction schedule (for the full 10-km² solar pond) significantly greater than 10 years. If one were interested in bringing 60 to 70 percent of the solar pond online fairly rapidly, for example, to drive a desalination plant, and accept the remaining pond area at a reduced pace, then this method may be appropriate.

Another alternative to limit excess evaporation pond area would be to build solar ponds initially with a shallower storage depth (during the same construction period), which would require less concentrated brine per unit area of pond. In so doing, the pond would initially be used for peaking load operation and would be converted to intermediate or baseload operation as more concentrated brine becomes available.

Obviously, the most advantageous situation would be to have saturated or near-saturated brines of an appropriate composition at or near the pond site which would support the system shown in figure 18b, in which no evaporation ponds or other means of concentration are required. Brines of this quality are available at RATSCAT and are presumed to exist elsewhere in the alkali flats and possibly to the east towards HAFB [43] (refer to table 6 and discussions in the Site Evaluation section). Low well yields in this area would make it necessary to pump from several wells to produce the quantity of brine required (1210 to 2405 gal/min) for the construction cases presented in table 10; however, depths at which brines would have to be pumped are relatively shallow. Considering the above information, it was decided that a concentrated brine source would be assumed for the remaining analyses (refer to figure 18b).

Mass balance solutions for the remaining three power generation only cases are presented on pages C-5 through 10 of appendix C. A summary of the more important information from these results is presented in table 11. The concentrated and dilute brine flowrates shown represent the maximum resources required during solar pond expansion. Upon completion of pond construction, both requirements will

Table 11.–*Mass balance summary for the power-only scenario*

	Intermediate load		Baseload	
MWe, rated gross	5	50	5	50
Solar pond area, km^2	0.5	5	1	10
Total construction time, yr	0.5	5	1	10
Maximum concentrated brine required, Mgal/d	1.7	2.0	3.0	3.5
Maximum dilute required, Mgal/d	1.5	8.8	2.3	17.0
MWe, net continuous	1.7	17.2	3.4	34.4

decrease, the concentrated brine by 75 to 97 percent and the dilute by 3 to 45 percent depending on the case. The net continuous power outputs shown are based on a per unit value of 3.44 MWe/km^2 obtained from earlier SOLPOND predictions (table 7).

Solar-Pond-Coupled Desalination

The solar-pond-coupled desalination cases (last four listed in table 8) were computed using the same solar plant assumptions and construction periods as were used in the power generation only analyses. A representative mass balance diagram for the 50-MWe baseload case is shown on figure 20. The desalination plant calculations assume a 70 percent product recovery, 500 mg/L product water, and an electrical energy consumption of 9.5 kWhe/kgal of product (reverse osmosis) [1]. The feed water quality is the same as that assumed by Kaiser Engineers in the Alamogordo desalination feasibility study for the OWRT (Office of Water Research and Technology) [19]. This analysis is presented on page C-11 of appendix C.

On figure 20, desalination plant reject brine at a concentration of 5930 mg/L is used as a source of

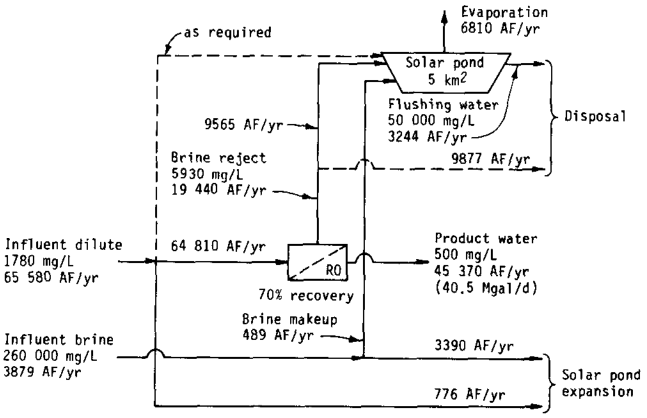


Figure 20.–Representative solar pond mass balance (solar-pond-coupled desalination scenario – 50-MWe baseload).

dilute makeup to the solar pond. Excess reject is wasted from the system. Conversely, influent dilute is used to augment the pond's requirements should the brine reject flow prove insufficient. The consequences of using a more concentrated dilute makeup for pond support are that the flushing cycle decreases to 137 days and the annual flushing volume increases to 7.74 acre-ft/acre per year, respectively.

Mass balance solutions for the four solar-pond-coupled desalination cases are presented on pages C-12 through 19 of appendix C with a summary of the more pertinent information shown in table 12. Two changes can be noted when comparing these results with those in table 11. First, the quantity of dilute brine or brackish water used is considerably greater, which reflects the RO plant feed requirement. At the completion of pond construction, the dilute flowrate needed will drop by between about 1 and 10 percent of the maximum shown. Secondly, a slight adjustment was made in pond area for the intermediate load cases to ensure adequate energy production for the desalination plant capacities indicated. The baseload cases show additional power available, after the needs of the desalination plant are satisfied, of 1.66 and 16.59 MWe for the 1 and 10 km^2 ponds, respectively. This power would be available for other Bureau projects or for integration into the grid.

ECONOMIC ANALYSIS

During this portion of the study, the economics of using solar ponds to generate electricity and to desalt water were evaluated. In the case of electric power generation, this was done on an economic justification basis by comparing the levelized BBEC (bus bar energy costs) of solar-generated electricity with the BBEC of electricity generated by the most likely alternative source, namely, an oil-fired combined-cycle plant for intermediate load power (35 percent plant factor) and a coal-fired steam plant for baseload power (70 percent plant factor). These

Table 12.–*Mass balance summary for the solar-pond-coupled desalination scenario*

	Intermediate load		Baseload	
MWe, rated gross	5	50	5	50
Solar pond area, km^2	0.5	5.2	1	10
Total construction time, yr	0.5	5	1	10
Maximum concentrated brine required, Mgal/d	1.8	2.0	3.0	3.5
Maximum dilute required, Mgal/d	7.1	64.9	7.1	64.9
Product water, Mgal/d	4.5	45	4.5	45
MWe, net continuous	1.8	17.9	3.4	34.4
MWe, net continuous required for desalination	1.8	17.8	1.8	17.8
MWe remaining, net continuous	0.0	0.1	1.6	16.6

energy costs were subsequently used in the desalination analysis to compare the economics of solar-pond-coupled desalination with that of conventional, fossil-fueled plants for two types of desalting processes, RO and HTMED.

Consistent with the mass balance analysis discussed in the previous section, this analysis was based on the assumption that the solar ponds would be constructed as shown on figure 21, with the powerplants brought online in 5 MW increments until a capacity of 50 MWe is reached, at which time it is assumed Nth plant costs would be achieved. During startup (staged construction), the plants would be operated as a peaking load facility with a 10-percent plant factor leading to intermediate load operation or 20 percent leading to baseload operation. Using this approach, it will take approximately 5 years to bring 50 MW of intermediate load power online or 10 years for 50 MW of baseload power.

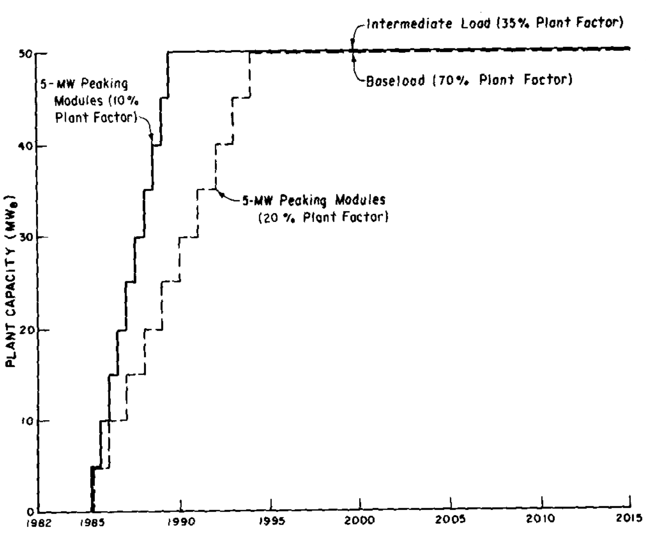


Figure 21.–Solar pond construction profiles.

Costs were compiled for the range of conditions listed in table 13. This was done in accordance with the planning guidelines established by the Water Resources Council for Federal water resource development projects [44] which specify in the case of power generation that costs be calculated using a Federal discount rate of 7-7/8 percent and projected values (in real terms) for the cost of fuel. This procedure recognizes the trend of recent years in the escalation of fossil-fuel costs and allows the real effect of that trend to be reflected in benefit/costs.

Electric Power Generation

Costs of installing and operating the solar pond and conventional fossil-fuel powerplants assumed for this anaylsis are presented on figure 22 and in table 14, respectively. The solar plant costs on figure 22 are based on cost data obtained from the JPL [37, 45] and Barber-Nichols Engineering [46], which assume that Nth plant costs will be achieved following construction of the 10th 5-MW module (figs. 23 and 24). The \$5.00/m^2 cost represents an unlined pond and the \$7.50-\$12.50/m^2 range represents a lined pond where the low value is compacted earth and the high value is the upper limit for an elastomeric liner.

The alternative plant costs were obtained from electric utilities serving the southwest United States and from the Electric Power Research Institute [47]. Fuel for the alternative plants was assumed to escalate 0 to 4 percent in price above the general rate of projected inflation. As shown in the graphs on figure 25, the 4 percent rate approximates DOE (Department of Energy) estimates for both oil and coal prices over the next 12 years (through 1995). Beyond 1995, DOE estimates that oil prices will exceed 4 percent escalation, whereas, coal prices will remain fairly constant.

Table 13.—*Economic assumptions*

Parameter	Value
Federal discount rate	7-7/8 percent
Fuel cost escalation rate	0 and 4 percent
Solar pond:	
Type	Unlined and lined
Size	$\leqslant$ 10 km²
Service life	90 years
Powerplant:	
Type	Solar, oil combined-cycle, and coal steam
Size	5 to 50 MWe
Plant factor:*	
Intermediate load	35 percent
Baseload	70 percent
Service life	30 years
Desalination plant:	
Type	RO and HTMED
Size	5 and 50 Mgal/d
Plant factor	90 percent
Service life	30 years
Operating conditions:	
Feed salinity	1780 mg/L
Recovery	70 percent
Product water salinity	500 mg/L for RO and 50 mg/L for HTMED
Surface flush salinity	5930 mg/L

* During startup, the powerplant will be operated as a peaking load facility with a 10 percent plant factor leading to intermediate load operation or 20 percent leading to baseload operation.

Results of the power generation economic analysis are presented on figures 26 and 27 in the form of $\overline{BBEC}$ bar graphs. Figure 26 is for staged construction (the assumed construction scenario), and figure 27 represents Nth plant conditions, i.e., without the learning curve shown in figures 23 and 24. These graphs show the benefits of utilizing solar ponds (as opposed to fossil fuels) to generate electricity in the Tularosa Basin. For staged construction under intermediate load conditions, the solar $\overline{BBEC}$ ranges between 62 mills/kWh for an unlined (\$5.00/m²) pond and 90 mills/kWh for a lined pond costing \$12.50/m². The oil-fired plant $\overline{BBEC}$, on the other hand, ranges from 123 mills/kWh assuming no fuel cost escalation to 179 mills/kWh for 4 percent fuel escalation. Comparable costs under baseload operations are 52 to 83 mills/kWh for the solar plant and 79 to 99 mills/kWh for a coal-fired steam plant.

Desalination

The desalination economic analysis also involved a comparison of solar ponds with conventional fossil fuels, where oil was assumed to be the fuel source for intermediate load power and coal for baseload power. As noted in table 13, two types of single-purpose desalting systems were evaluated: RO and HTMED, each at 5- and 50-Mgal/d capacity. The desalting plant operating conditions assumed for the analysis were similar to those used for the proposed

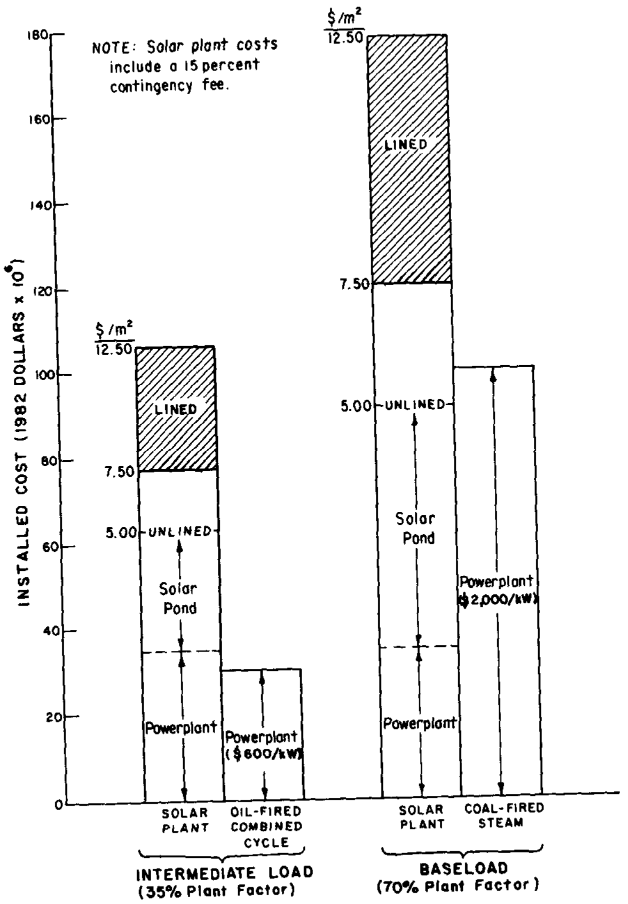


Figure 22.–Solar and conventional powerplant installed costs (Nth 50-MW plant).

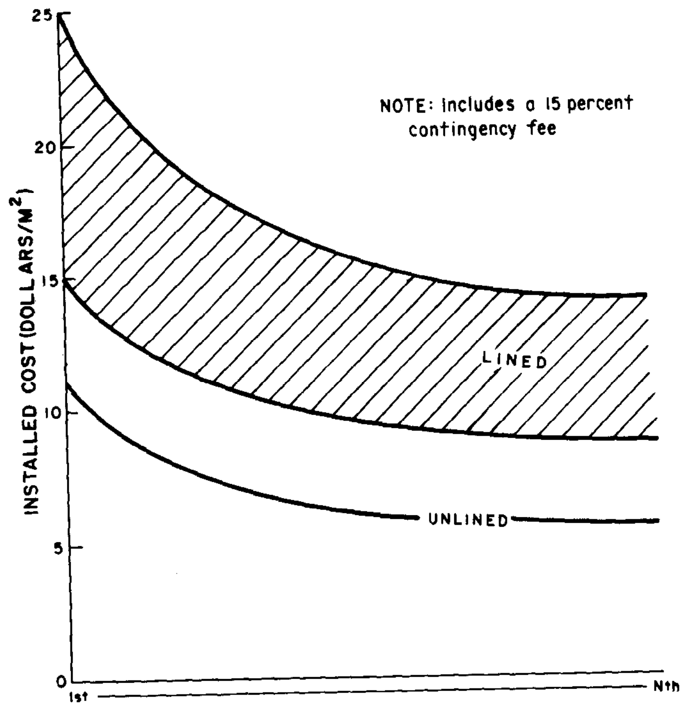


Figure 23.–Startup solar pond costs.

2-Mgal/d demonstration plant at Alamogordo [19], i.e., 1780 mg/L feed salinity and 70 percent recovery.

A component breakdown of the desalination costs (capital, annual, and energy) used in the analysis is presented in tables 15 and 16 for each of the desalting scenarios considered. The energy costs shown in table 16 are based on the energy requirements listed in table 9 and the BBEC calculated earlier for the staged construction scenario.

Results of the desalination analysis are summarized in table 17 in terms of product water costs ($/kgal) and plotted as bar graphs on figures 28 and 29. Note: The fossil-fuel HTMED costs have not been plotted, because the high cost of oil and coal make the task of providing the low-grade thermal energy needed for this process prohibitively expensive (with product water costs ranging from $6 to $22 per kgal) when operated in a single-purpose mode. For this reason, fossil-fuel powered HTMED plants are

Table 14.–*Powerplant operational costs*

	Intermediate load (35 percent plant factor)	Baseload (70 percent plant factor)
Solar plant–O&M costs only	2-1/2 mills/kWh	2-1/2 mills/kWh
Conventional plant:*		
Current fuel prices	$9.50 per MBtu	$2.50 per MBtu
Future fuel prices	See fig. 25	See fig. 25
Net heat rate	8500 Btu/kWh	10 860 Btu/kWh
Fuel inventory	90 days	90 days
O&M costs	3 mills/kWh	3 mills/kWh

* Based on the use of an oil-fired, combined-cycle plant for intermediate load power and coal-fired steam for baseload power.

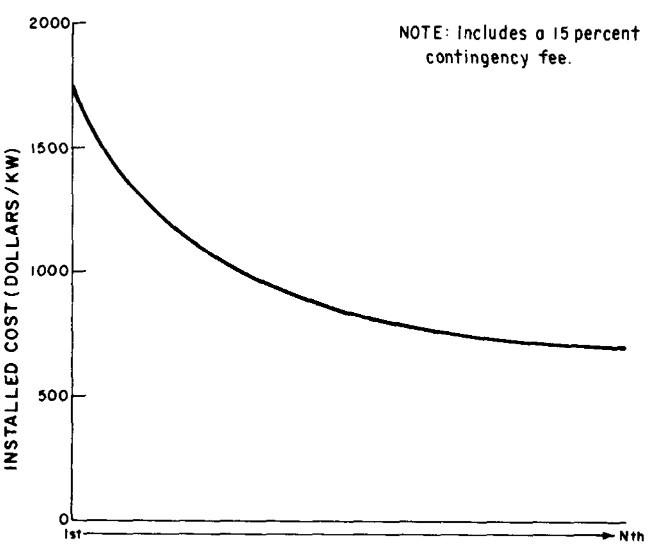


Figure 24.–Startup solar powerplant costs (constructed in 5-MW modules).

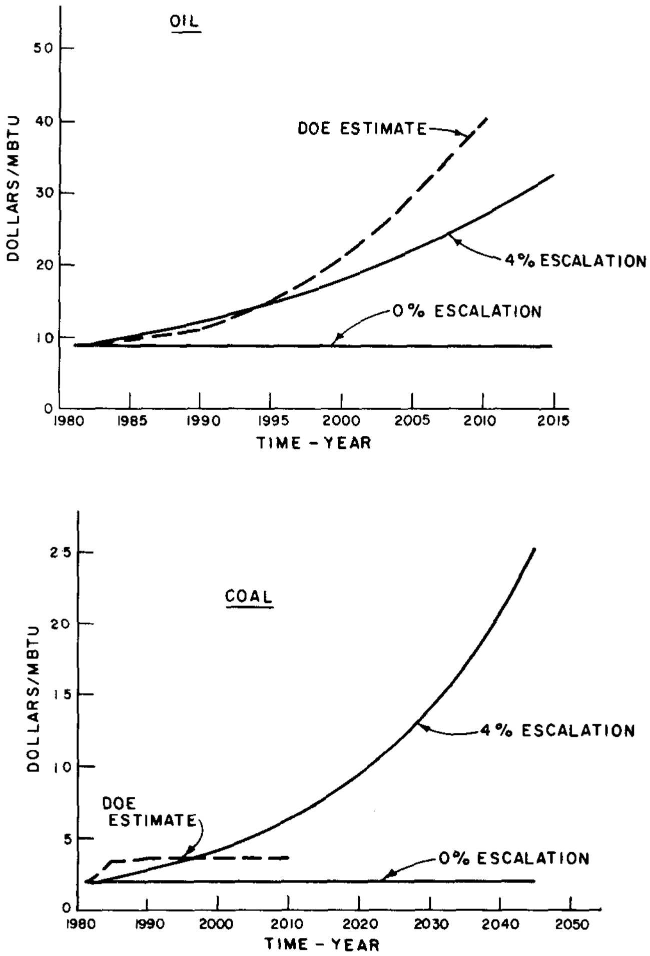


Figure 25.–Future fuel prices (Note: The DOE price projections starting in November 1981 update data published in the January 23, 1980, issue of the *Federal Register*[48]).

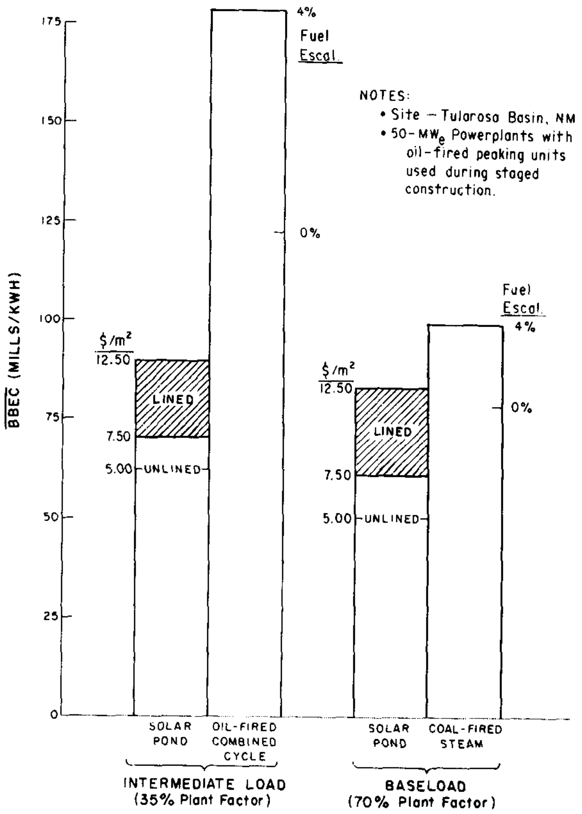


Figure 26.–Levelized bus bar energy costs for assumed construction profile (staged).

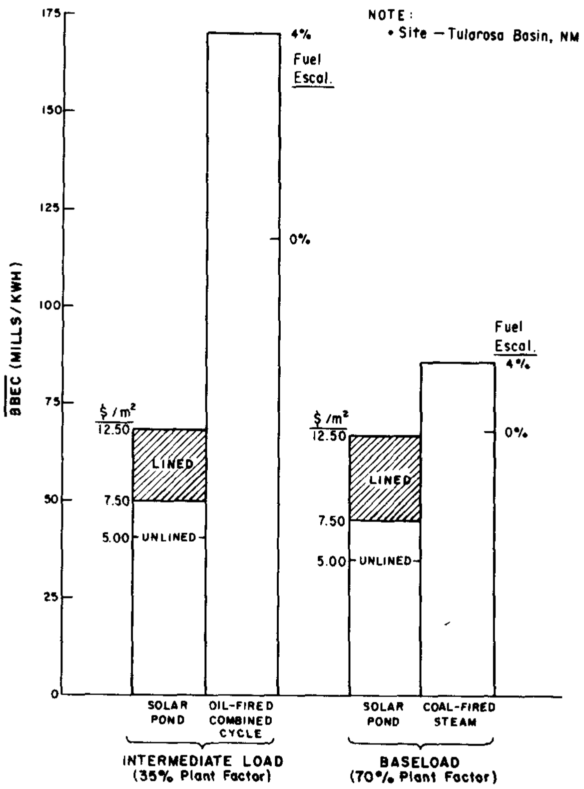


Figure 27.–Levelized bus bar energy costs for Nth 50-MW plant.

Table 15.—*Capital and annual costs (excluding energy) for single-purpose desalination plants**

Cost component	Cost of product water ($/kgal)			
	5 Mgal/d		50 Mgal/d	
	Solar plant	Conventional plant	Solar plant	Conventional plant
Reverse osmosis				
Capital costs:				
Desalting and pretreatment equipment**	$0.356	$0.356	$0.294	$0.294
Brine disposal	0.223	0.348	0.223	0.348
Annual costs:				
Membrane replacement	0.321	0.321	0.321	0.321
O&M (labor, chemicals, supplies, and general administrative)	0.536	0.536	0.436	0.436
Total	$1.436	$1.561	$1.274	$1.399
Horizontal-tube multiple-effect distillation				
Capital costs:				
Desalting and pretreatment equipment**	$1.151	$1.151	$0.774	$0.774
Brine disposal	0.144	0.348	0.144	0.348
Annual costs:				
Interim replacement at 2 percent	0.267	0.267	0.169	0.169
O&M (labor, chemicals, supplies, and general administrative)	0.413	0.413	0.260	0.260
Total	$1.975	$2.179	$1.347	$1.551

* Based on information presented in reference [1] adjusted for 1780-mg/L feed salinity and 70 percent recovery and a desalination plant factor of 0.9 with product salinities of 500 mg/L for the RO plant and 50 mg/L for the HTMED plant.

** Includes interest during construction at 7-7/8 percent.

normally operated in a dual-purpose (cogeneration) mode.

The results presented on figures 28 and 29 and in table 18, which lists the land areas required for the solar ponds and final disposal ponds, show that:

- Solar desalination is more cost effective than using fossil fuel.
- RO is better than HTMED for the conditions considered; i.e., 1780-mg/L feed salinity and 70 percent recovery. It should be noted that higher feed salinities and recovery ratios would be more favorable to HTMED, since RO costs increase under these conditions, and HTMED costs are relatively insensitive to feed salinity and recovery ratio.
- Solar desalination costs are not affected significantly by pond construction costs, particularly when RO is the process used, whereas fuel escalation rate has a significant effect on fossil-fueled desalination costs. For example, an

Table 16.—*Energy costs for single-purpose desalination plants**

Desalination plant size	Thermal energy ($/Btu x 10^6)					Electric energy (mills/kWh)				
	Solar pond			Fossil fuel		Solar pond			Fossil fuel	
	Unlined	Lined		0 percent escal.	4 percent escal.	Unlined	Lined		0 percent escal.	4 percent escal.
	$5.00/m^2	$7.50/m^2	$12.50/m^2			$5.00/m^2	$7.50/m^2	$12.50/m^2		
Intermediate load power (35 percent plant factor)				Oil					Oil	
5 Mgal/d	1.24	1.40	1.79	17.13	24.93	62.0	70.3	89.6	122.6	178.5
50 Mgal/d	1.24	1.40	1.79	14.65	21.32	62.0	70.3	89.6	122.6	178.5
Baseload power (70 percent plant factor)				Coal					Coal	
5 Mgal/d	1.14	1.34	1.66	6.13	7.74	52.0	61.3	83.1	78.7	99.4
50 Mgal/d	1.14	1.34	1.66	5.23	6.61	52.0	61.3	83.1	78.7	99.4

*Based on the use of packaged boilers in the 5-Mgal/d plants and field-erected boilers in the 50-Mgal/d plants.

Table 17.—*Cost summary for single-purpose desalination plants**

Desalination plant size	Cost of product water ($/kgal)									
	Intermediate load power (35 percent plant factor)					Baseload power (70 percent plant factor)				
	Solar pond			Oil		Solar pond			Coal	
	Unlined	Lined		0 percent	4 percent	Unlined	Lined		0 percent	4 percent
	$5.00/m²	$7.50/m²	$12.50/m²	escal.	escal.	$5.00/m²	$7.50/m²	$12.50/m²	escal.	escal.
(a) Reverse osmosis										
5 Mgal/d										
Desalting system	$1.436	$1.436	$1.436	$1.561	$1.561	$1.436	$1.436	$1.436	$1.561	$1.561
Power generation-electric only	0.589	0.667	0.851	1.165	1.696	0.494	0.584	0.789	0.750	0.947
Total	$2.03	$2.10	$2.29	$2.73	$3.26	$1.93	$2.02	$2.23	$2.31	$2.51
50 Mgal/d										
Desalting system	$1.274	$1.274	$1.274	$1.399	$1.399	$1.274	$1.274	$1.274	$1.399	$1.399
Power generation-electric only	0.589	0.667	0.851	1.165	1.696	0.494	0.584	0.789	0.750	0.947
Total	$1.86	$1.94	$2.13	$2.56	$3.10	$1.77	$1.86	$2.06	$2.15	$2.35
(b) Horizontal-tube, multiple-effect distillation										
5 Mgal/d										
Desalting system	$1.975	$1.975	$1.975	$2.179	$2.179	$1.975	$1.975	$1.975	$2.179	$2.179
Power generation-										
Thermal	0.935	1.062	1.353	12.941	18.834	0.862	1.013	1.254	4.635	5.852
Electric	0.310	0.351	0.448	0.613	0.893	0.260	0.307	0.416	0.395	0.499
Total	$3.22	$3.39	$3.78	$15.73	$21.91	$3.10	$3.30	$3.65	$7.21	$8.53
50 Mgal/d										
Desalting system	$1.347	$1.347	$1.347	$1.551	$1.551	$1.347	$1.347	$1.347	$1.551	$1.551
Power generation-										
Thermal	0.935	1.062	1.353	11.066	16.104	0.862	1.013	1.254	3.954	4.997
Electric	0.310	0.351	0.448	0.613	0.893	0.260	0.307	0.416	0.395	0.499
Total	$2.59	$2.76	$3.15	$13.23	$18.55	$2.47	$2.67	$3.02	$5.90	$7.05

* Based on 1780-mg/L feed salinity and 70 percent recovery, operating at a desalination plant factor of 0.9 with product salinities of 500 mg/L for the RO plant and 50 mg/L for the HTMED plant.

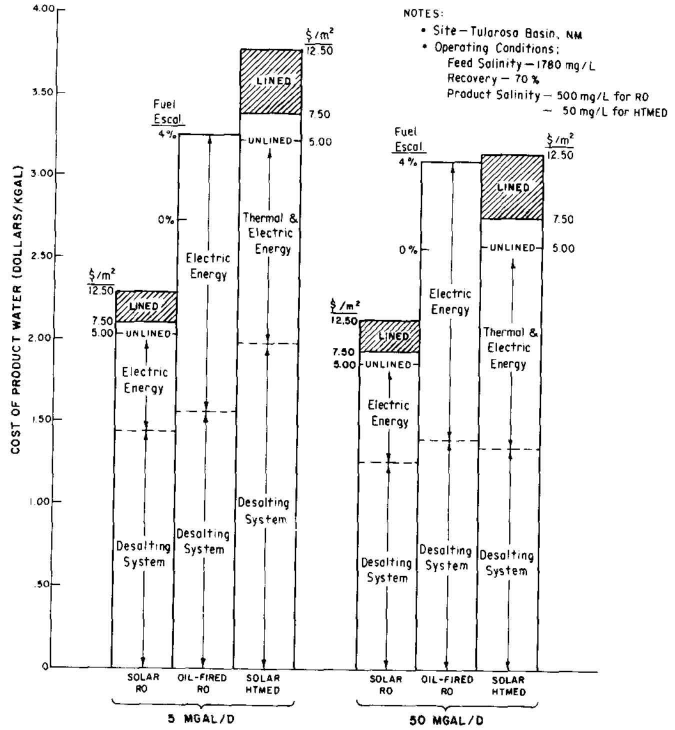


Figure 28.–Cost of desalting water with intermediate load power.

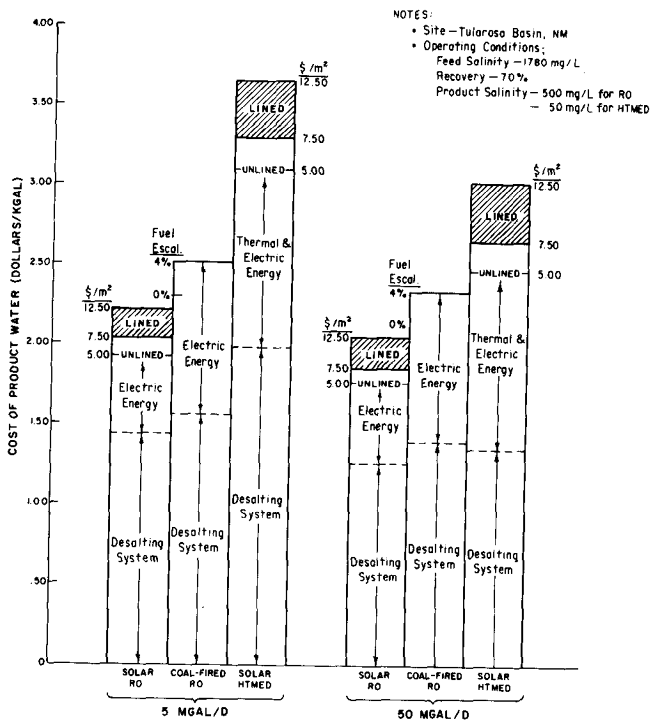


Figure 29.–Cost of desalting water with baseload power.

increase of 2 percent in fuel escalation rate increases product water costs about the same amount as does doubling pond cost from \$5.00 to \$10.00/m².

- The amount of land required for an RO plant is approximately the same whether it is solar powered or fossil-fueled powered. An HTMED plant, on the other hand, requires approximately 40 percent more land area if powered by solar.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The most significant conclusions drawn from this study are:

- All three candidate sites (Canadian River, Malaga Bend, and Tularosa Basin) have critical water and power needs, which appear to be getting worse as demand increases and resources diminish. Oil and gas are the primary sources of fuel for electric power generation, and freshwater supplies are extremely limited, resulting in the use of more and more ground water which does not meet State and Federal drinking water quality standards.
- The Tularosa Basin in particular appears to offer great potential for solar pond development, considering the physical resources (land area, topography, concentrated brine, and construction soils) and high solar radiation levels available.
- The results of the site evaluation suggest that the most promising locations for solar ponds in the Tularosa Basin would be an area immediately west of HAFB using brine either transported by pipeline from the RATSCAT site or possibly from a similar source to the east of RATSCAT, and an area within a few miles east or south of the WSMR headquarters using brine from well T-14.
- The most cost-effective method of constructing solar ponds in the Tularosa Basin would be to use saturated or near-saturated brines similar to those found at the RATSCAT site, which would eliminate the need for evaporation ponds or other means of concentration. Brines of this quality are presumed to exist elsewhere in the alkali flats and possibly to the east towards HAFB.
- Due to average daily insolation values that are among the highest in the United States, solar ponds located at Tularosa Basin, Malaga Bend, and Canadian River would produce 3.0, 3.2, and 2.6 x 10^4 MWh/km², respectively, of net electrical energy annually.
- A solar pond can be brought online (made operational) prior to achieving the optimum storage layer depth. For example, operating a solar pond at a storage layer thickness that is only half of what is considered optimum reduces the

Table 18.—*Pond areas associated with single-purpose desalination plants (membrane and low temperature distillation processes)* *

	Pond area (acres)	
	5 Mgal/d	50 Mgal/d
RO (reverse osmosis)		
Solar plant:		
Solar pond supported by brine reject	129	1290
Solar pond supported by dilute brine feed	–	–
Brine disposal for surface flush	61	610
Disposal of unused brine reject	212	2120
Total	402	4020
Conventional plant–disposal of brine reject	392	3920
HTMED (horizontal-tube, multiple-effect distillation)		
Solar plant:		
Solar pond supported by brine reject	252	2520
Solar pond supported by dilute brine feed	94	940
Brine disposal for surface flush	212	2120
Disposal of unused brine reject	–	–
Total	558	5580
Conventional plant–disposal of brine reject	392	3920

* Based on 1780-mg/L feed salinity and 70 percent recovery, operating at a desalination plant factor of 0.9 with product salinities of 500 mg/L for the RO plant and 50 mg/L for the HTMED plant.

annual production of electrical energy by less than 10 percent under baseload conditions.

- Solar ponds can be used in the Tularosa Basin to generate intermediate-load electricity for 60 to 90 mills/kWh (in terms of levelized BBEC over a period of 30 years), whereas it would cost 120 to 180 mills using oil, assuming a fuel cost escalation rate of 2 percent. Under similar conditions, baseload power would cost 50 to 80 mills using solar ponds as compared to 80 to 100 mills if coal were used.
- For the desalination conditions considered (1780-mg/L feed salinity and 70 percent recovery), RO is a more cost-effective process than low-temperature distillation.
- Solar-pond-coupled desalination is more economical than using fossil fuel.
- Solar pond construction costs do not have a significant effect on desalination costs, particularly if RO is the process used. For example, doubling the pond cost from $5/m² to $10/m² increases RO-desalted water costs by less than 10 percent, since the bulk of the costs are attributable to the desalting system including operation and maintenance costs.

Recommendations

Because of the encouraging results from this study, it is recommended that the Bureau:

- complete the Tularosa Basin studies by compiling the following site specific data for the HAFB and RATSCAT sites:

  brine characteristics including composition, optical properties, solubility-temperature relationships, salt diffusivities, and potential chemical reactions

  soil properties including permeability, thermal conductivity, organic content, and availability of suitable clay materials for liner construction

- climate and meteorological phenomena (solar, wind)
- ground-water conditions (level, flow velocities)

Note: This effort will require fieldwork (to gather soil and brine samples and possibly meteorological data), laboratory investigations (to study diffusivity, sediment characteristics, and methods of pretreatment), and some computer analysis (to calculate pond thermal performance and mass balances).

- perform similar detailed analyses of the Canadian River and Malaga Bend sites, with major emphasis placed on determining the benefits of using solar ponds to control salinity at these two sites.

BIBLIOGRAPHY

[1] Boegli, W. J., M. M. Dahl, and H. E. Remmers, *Preliminary Study of Solar Ponds for Salinity Control in the Colorado River Basin*, REC-ERC-82-19, Bureau of Reclamation, Denver, CO, December 1982.

[2] *Tularosa Basin Water and Energy Study – Problems and Opportunities*, Bureau of Reclamation, Southwest Region, Amarillo, TX, November 1982.

[3] *Annual Report for Fiscal Year 1982*, Western Area Power Administration, Golden, CO, 1982.

[4] *Small Power Systems Study Technical Summary Report*, Aerospace Corporation Report ATR-78(7693-05)-1, vol. 1, Los Angeles, CA, May 31, 1978.

[5] Correspondence between Bureau of Reclamation's Southwest Regional Planning Office and major consumers of electric power in the Tularosa Basin.

[6] *New Mexico Water Resources Assessment for Planning Purposes*, Bureau of Reclamation, U.S. Department of the Interior, November 1976.

[7] *A Preliminary Economic Feasibility Study for the Establishment of an Energy-Water Complex in the Tularosa Basin*, New Mexico Water Resources Research Institute Report No. 068, New Mexico State University, Las Cruces, NM, February 1976.

[8] *Use of Brackish Ground Water Resources for Regional Energy Center Development, Tularosa Basin, New Mexico: Preliminary Evaluation*, Los Alamos Scientific Laboratory Report prepared for the Federal Energy Administration under ERDA-FEA Memorandum of Understanding No. E(29-2)-3574, June 17, 1975.

[9] Grant, Philip R., *Energytic New Mexico . . . The Power State*, Second Edition, Albuquerque Industrial Development Service, Inc., Albuquerque, NM, November 1977.

[10] *Lake Meredith Salinity Study, Canadian River, Texas-New Mexico*, Bureau of Reclamation, Southwest Region, Amarillo, TX, October 1979.

[11] Kunkler, J. L., *Evaluation of the Malaga Bend Salinity Alleviation Project, Eddy County, New Mexico*, U.S. Geological Survey Open-file Report No. 80-1111, September 1980.

[12] McLean, J. S., *Saline Ground Water Resources of the Tularosa Basin, New Mexico*, Progress Report No. 561, Office of Saline Water, July 1970.

[13] McLean, J. S., "Saline Ground Water in the Tularosa Basin, New Mexico," *New Mexico Geological Society Guidebook*, 26th Field Conference, 1975.

[14] Corps of Engineers District study, Fort Worth, TX (unpublished).

[15] Lin, E.I.H., *A Review of the Salt-Gradient Solar Pond Technology*, Jet Propulsion Laboratory Publication 81-116, DOE/SF-11552-1, January 1982.

[16] *Earth Manual*, U.S. Department of Interior, Bureau of Reclamation, Denver, CO, 2nd edition, 1974.

[17] Lyford, F. P., *Test Wells T-15, T-16, T-17, T-18, and RC-3, White Sands Missile Range, Dona Ana and Sierra Counties, New Mexico*, U.S. Geological Survey Open-file Report, February 1970.

[18] Neher, R. E., and O. F. Bailey, *Soil Survey of White Sands Missile Range, New Mexico*, U.S. Department of Agriculture, Soil Conservation Service, January 1976.

[19] *Desalting Demonstration Plant Feasibility Study – Alamogordo, New Mexico*, Kaiser Engineers for the Office of Water Research and Technology, Report No. 79-29-R, September 1979.

[20] *Seafarer Site Survey, New Mexico Region – Book 3*, EDAW, Inc., San Francisco, CA, for U.S. Navy Electronic Systems Command, Washington, DC.

[21] *Fort Bliss, Texas Terrain Analysis*, Soil Systems, Inc., Marietta, GA, Contract No. DACA87-77-C0061, September 1978.

[22] "Geological and Water Resources of Tularosa Basin," U.S. Geological Survey *Water Supply Paper 343*, 1915.

[23] Stucky, H. R., and W. C. Arnwind, *Potential for Desalting in the Tularosa Basin, New Mexico – A Case Study*, Progress Report No. 776, Office of Saline Water, August 1971.

[24] Ballance, W. C., *Ground-water Resources of the Holloman Air Force Base Well Field Area, 1976, New Mexico*, U.S. Geological Survey Open-file Report No. 76-807, November 1976.

[25] Henderson, J., and Cecile M. Leboeuf, *SOLPOND – A Simulation Program for Salinity Gradient Solar Ponds*, Solar Energy Research Institute, SERI/TP-351-559, Golden, CO, January 1980.

[26] SERI Truscott Brine Lake Task Force, *Conceptual Design of the Truscott Brine Lake Solar Pond System, vol. 1*, SERI/TR-731-1202, June 1981.

[27] *SOLMET, Volume 1: User's Manual, TD-9724, Hourly Solar Radiation-Surface Meteorological Observations*, National Oceanic and Atmospheric Administration, Asheville, NC, August 1978.

[28] *SOLMET, Volume 2: Final Report, TD-9724, Hourly Solar Radiation-Surface Meteorological Observations*, National Oceanic and Atmospheric Administration, Asheville, NC, February 1979.

[29] Hall, I., R. Prairie, H. Anderson, and E. Boes, *Generation of Typical Meteorological Years for 26 SOLMET Stations*, SAND78-1601, Sandia Laboratories, 1978.

[30] Rabl, A., and C. Nielsen, "Solar Ponds for Space Heating," *Solar Energy*, vol. 17, pp. 1-12, 1975.

[31] Webb, John D., *Optical Transparency of Inexpensive Salt Solutions for Construction of Density-Gradient Ponds*, Solar Energy Research Institute, SERI/RR-641-615, July 1981.

[32] Peelgren, M. L., *Salton Sea Project, Phase 1*, Jet Propulsion Laboratory, DOE/JPL-1060-44, January 1982.

[33] Lin, E.I.H., R. L. French, M. J. Singer, Y. C. Wu, J. C. McMurrin, R. H. Barbieri, A. L. Walton, S. C. Jones, M. G. Hurick, N. Levine, and P. H. Richter, *Regional Applicability and Potential of Salt-Gradient Solar Ponds in the United States, Volume II, Detailed Study*, Jet Propulsion Laboratory, DOE/JPL-1060-50, vol. 2, March 1982.

[34] Ormat Turbines report prepared for Southern California Edison Company, *A Study of the Feasibility of a Solar Salt Pond Generating Facility in the State of California*, vols. 1 and 2, May 1981.

[35] Sayigh, A.A.M., *Solar Energy Engineering*, Academic Press, 1977.

[36] Kreider, Jan F., and Frank Kreith, *Solar Energy Handbook*, McGraw-Hill, New York, NY, 1981.

[37] Personal communication with R. French, Jet Propulsion Laboratory, February 1983.

[38] Wright, John D., *An Organic Rankine Cycle Coupled to a Solar Pond by Direct-Contact Heat Exchange – Selection of a Working Fluid*, Solar Energy Research Institute, SERI/TR-631-1122, June 1981.

[39] *The Technical and Economic Feasibility of Salt-Gradient Solar Ponds at the Truscott Brine Lake of the Red River Chloride Control Project*, Joint Publication of the Tulsa District, U.S. Army Corps of Engineers and Battelle Pacific Northwest Laboratory, PNL-4396, September 1982.

[40] Bonn, M. S., *Heat Exchanger Effectiveness and Thermoelectric Power Generation*, Solar Energy Research Institute, SERI/TP-641-757, 1981.

[41] *Weather Atlas of the United States*, U.S. Environmental Data Service, June 1968.

[42] Lin, E.I.H., Jet Propulsion Laboratory Interoffice Memorandum, "Salton Sea Brine Concentration and Recirculation," November 1980.

[43] Personal communication with L. Buescher, White Sands Missile Range headquarters, November 1982.

[44] *Federal Register*, "Water Resources Council," vol. 44, No. 242, Friday, December 14, 1979.

[45] Ormat Turbine Cost Data obtained from Jet Propulsion Laboratory, Pasadena, CA, February 1981.

[46] Telecon with Daryl Prigmore, Barber-Nichols Engineering Company, Arvada, CO, February 22, 1981.

[47] *Technical Assessment Guide*, Electric Power Research Institute Report No. PS-1202-SR, July 1979.

[48] *Federal Register*, Federal Energy Management and Planning Programs; Methodology and Procedures for Life Cycle Cost Analysis, January 23, 1980.

APPENDIX A

SOLPOND Input Parameters

APPENDIX A

SOLPOND INPUT PARAMETERS

The following parameters comprise a name list called MODELN. Any value which is not user-specified will assume the default value.

	Default	*Assumed*	*Limits*
1. Mean daily values for solar radiation, ambient temperature, and secant of angle of refraction for site.	Site-dependent values		
2. ISTART — The day of the year that the simulation begins. It is not used in the "ANNUAL" mode.	1	1	$1 \leq ISTART \leq 365$
3. DUCL — Thickness of the pond upper convecting layer.	0.1 m	0.15 m	>0.0 m
4. DNCL — Thickness of the pond nonconvecting layer.	1.0 m	1.3 m	>0.0 m
5. DSL — Thickness of the pond storage layer.	1.0 m	3.5 m	>0.0 m
6. DGS — Depth of ground below the pond that is included in the thermal model.	10.0 m	10.0 m	>0.0 m
7. CSALT — Heat capacity of salt.	$3.98 \times 10^6 J/m^3\,°C$	3.98×10^6	$10^5 < x < 10^7$
8. CE — Heat capacity of earth.	$2.0 \times 10^6 J/m^3\,°C$	2.0×10^6	$10^5 < x < 10^7$
9. USALT — Thermal conductivity of salt.	0.65W/m°C	0.65	$0.01 < x < 10^2$
10. UE — Thermal conductivity of earth.	1.0W/m°C	1.0	$0.01 < x < 10^2$
11. NS — The number of temperature nodes used to model the salt solution.	5	5	$3 \leq x$
12. NE* — The number of radial (vertical for one-dimensional model) temperature nodes used to model the underlying earth.	3	5	$1 \leq x$
13. NC — The number of temperature nodes used to model the perimeter losses.	5	1	$6 \geq x$

* $NS + NE \leq 10$ when pond type = S
$NS + NE \leq 12$ when pond type = L

	Default	*Assumed*	*Limits*
14. T — A node temperature array that describes the initial conditions of the pond. In large pond simulations up to 15 positions are used and in small pond simulations up to 60 positions are used.	12° × 60	12° ×10	None
15. DT — Length of the simulation time step in days.	7	30	>0
16. AOPT — A 5-element array that holds the optical transmission exponential decay coefficients for a range of light wavelengths. These parameters model the transmission of light through a salt solution. Values typical of a clear pond are the default parameters.	-0.32, -0.45, -3.0, -35.0, -300.0	-0.32, -0.45, -3.0, -35.0, -300.0	<0
17. DIA — Diameter of the pond (needed only for small pond simulations).	5.5 m	n.a.	
18. PERINS — Value of the thermal conductivity of the perimeter insulation.	0.0	0.0	
19. UAIR — The thermal conductivity of the air.	300 W/m°C	300 W/m°C	
20. PRINT — The logical variable which, when TRUE, prints a brief output to Tape 6.	.TRUE.	.TRUE.	
21. DETPRT — The logical variable which, when TRUE, prints a detailed output to Tape 6.	.FALSE.	.FALSE.	
22. DMNTMP — The value of the minimum desired pond temperature. Used with the MINTMP option.	40 °C	75 °C	

The following values are not part of the MODELN name list but also must be input to SOLPOND.

1. Type of analysis

   a. TRANS — A transient simulation is performed.
   b. ANNUAL — A steady-state simulation is performed.
   c. MINTMP — A load is found which maintains the pond above a minimum user-selected temperature.

2. Pond type

   a. S — Small pond
   b. L — Large pond

3. Loads (W/m²)

   Input 365 load values, one for each day of the year. Multiple values may be input as follows:

   243 × 0., 7 × 30., 115 × 0.

APPENDIX B

Sample SOLPOND Output Data for Tularosa Basin, Malaga Bend, and Canadian River

Table B-1. - SOLPOND thermal power and temperature output data for Tularosa Basin

```
                                INPUT PARAMETER VALUES
*****************************************************************************************************

    ANLY=MINTMP    SITE= 1    START=   1    POND=L     DUCL=  .30    DNCL= 1.30    DSL= 3.50    DGS=10.00
    CSALT= .400E+07    CE= .200E+07    USALT= .65    UE=1.00    NS=  5    NE= 5    NC= 1    NDAYS= 365    DMNTMP=75.0
    DT= 30    UAIR=300.0    DIA=  5.5    PERINS=  0.0    PRINT= T    DETPRT= F


    AOPT(1-5)
*****************************************************************************************************

       -.032       -.450       -3.000       -35.000      -300.000


  INCREMENT
  OF YEAR                          INITIAL POND NODE TEMPERATURES
*****************************************************************************************************
    1    12.00    12.00    12.00    12.00    12.00    12.00    12.00    12.00    12.00    12.00
UPDATE PARAMETERS% X,Y,Z,ICNT .6667E+00 .1671E+010.          0
UPDATE PARAMETERS% X,Y,Z,ICNT .1502E+01-.8289E+020.          1
```

INCREMENT OF YEAR	AVERAGE AMBIENT TEMP.	AVERAGE INSOLATION	AVERAGE LOAD	AVERAGE POND STORAGE TEMP.
1	2.60	123.89	40.18	76.65
2	6.73	174.48	37.47	74.91
3	10.17	227.83	35.42	76.45
4	15.64	292.47	34.95	81.37
5	19.60	321.01	36.22	87.24
6	25.13	337.78	38.72	93.26
7	25.51	301.59	41.54	96.59
8	24.41	282.14	44.36	98.22
9	22.63	249.01	46.49	97.63
10	15.75	189.70	47.06	93.80
11	9.51	154.24	45.95	88.46
12	4.99	122.07	43.52	82.20

LOAD WASTED TO AVOID OVERHEATING THE POND STORAGE LAYER =   0.00

Table B-2. - SOLPOND thermal power and temperature output data for Malaga Bend

```
                                 INPUT PARAMETER VALUES
*************************************************************************************************

ANLY=MINTMP   SITE=12   START=  1   POND=L   DUCL=  .30   DNCL= 1.30   DSL= 3.50   DGS=10.00
CSALT= .400E+07   CE= .200E+07   USALT= .65   UE=1.00   NS=  5   NE= 5   NC= 1   NDAYS= 365   DMNTMP=75.0
DT= 30   UAIR=300.0   DIA=  5.5   PERINS=  0.0   PRINT= T   DETPRT= F


AOPT(1-5)
*************************************************************************************************

   -.032      -.450      -3.000      -35.000      -300.000


INCREMENT
OF YEAR                          INITIAL POND NODE TEMPERATURES
*************************************************************************************************
   1   12.00   12.00   12.00   12.00   12.00   12.00   12.00   12.00   12.00   12.00
UPDATE PARAMETERS% X,Y,Z,ICNT .6673E+00 .3773E+01 .5520E+00    0
UPDATE PARAMETERS% X,Y,Z,ICNT .2002E+01-.1278E+030.            1
UPDATE PARAMETERS% X,Y,Z,ICNT .7056E+00 .2454E+01 .3033E+00    2
UPDATE PARAMETERS% X,Y,Z,ICNT .7300E+00 .1355E+01 .1405E+00    3
UPDATE PARAMETERS% X,Y,Z,ICNT .7589E+00-.8916E+000.            4
```

INCREMENT OF YEAR	AVERAGE AMBIENT TEMP.	AVERAGE INSOLATION	AVERAGE LOAD	AVERAGE POND STORAGE TEMP.
1	6.89	129.22	46.87	76.97
2	9.41	187.76	43.77	75.33
3	13.50	237.17	40.82	76.92
4	18.87	291.31	38.67	81.61
5	23.36	329.86	38.27	88.04
6	27.53	338.73	39.76	94.25
7	28.23	312.97	42.54	98.24
8	26.84	289.97	45.73	100.00
9	23.58	245.02	48.70	98.96
10	19.36	215.04	50.94	95.99
11	11.31	153.83	51.45	89.90
12	7.88	120.12	50.13	82.78

LOAD WASTED TO AVOID OVERHEATING THE POND STORAGE LAYER = .08

Table B-3. - SOLPOND thermal power and temprature output data for Canadian River

```
                                        INPUT PARAMETER VALUES
**************************************************************************************************

    ANLY-MINTMP    SITE- 1     START-    1     POND-L      DUCL-   .30     DNCL- 1.30     DSL- 3.50    DGS-10.00
    CSALT- .400E+07    CE- .200E+07    USALT- .65    UE-1.00     NS-    5    NE- 5     NC- 1    NDAYS- 365    DMNTMP-75.0
    DT- 30     UAIR-300.0     DIA-  5.5     PERINS-  0.0     PRINT- T     DETPRT- F


    AOPT(1-5)-
**************************************************************************************************

       -.032       -.450       -3.000       -35.000      -300.000


  INCREMENT
  OF YEAR                                 INITIAL POND NODE TEMPERATURES
**************************************************************************************************
     1    12.00     12.00     12.00     12.00     12.00     12.00     12.00     12.00     12.00     12.00
UPDATE PARAMETERS% X,Y,Z,ICNT .6673E+00-.9700E+010.          0
UPDATE PARAMETERS% X,Y,Z,ICNT0.          .2080E+02 .5273E+01    1
UPDATE PARAMETERS% X,Y,Z,ICNT .4551E+00 .6722E+01 .9790E+00    2
UPDATE PARAMETERS% X,Y,Z,ICNT .6458E+00-.5825E+010.            3
UPDATE PARAMETERS% X,Y,Z,ICNT .5573E+00 .1949E+01 .5528E-01    4
```

INCREMENT OF YEAR	AVERAGE AMBIENT TEMP.	AVERAGE INSOLATION	AVERAGE LOAD	AVERAGE POND STORAGE TEMP.
1	2.65	117.43	36.34	77.23
2	5.05	152.47	33.93	74.76
3	7.97	212.95	31.65	75.97
4	13.56	271.95	29.98	80.47
5	18.81	282.07	29.67	85.32
6	24.02	310.37	30.82	91.19
7	25.65	299.14	32.98	95.74
8	25.32	275.52	35.46	98.31
9	21.23	238.76	37.75	98.30
10	16.49	183.04	39.49	95.05
11	8.60	132.94	39.89	89.29
12	3.61	105.24	38.87	82.66

LOAD WASTED TO AVOID OVERHEATING THE POND STORAGE LAYER =   0.00

APPENDIX C

Mass Balance Data

TULAROSA BASIN - 50MWe BASE w/o DESAL

SEPARATE BRINE AND DILUTE SOURCE - FLUSHING BLOWDOWN TO PRODUCTION/MAKEUP POND (SCENERIO 2)

UPPER CONVECTING LAYER DEPTH = .30 m
NONCONVECTING LAYER DEPTH = 1.30 m
STORAGE LAYER DEPTH = 3.50 m

SYSTEM INFLUENT BRINE FLOWRATE = 4955 gal/min
= 7992 AF/yr
SYSTEM INFLUENT DILUTE FLOWRATE = 11890 gal/min
= 19179 AF/yr

SYSTEM INFLUENT BRINE CONCENTRATION = 112000 mg/L
SYSTEM INFLUENT DILUTE CONCENTRATION = 3000 mg/L

NET EVAPORATION RATE = 1.68 m/yr
SALT TRANSPORT COEFFICIENT = .0086 gm/d cm2

CONC AT SURFACE LAYER FLUSH = 50000 mg/L
STORAGE LAYER CONCENTRATION = 260000 mg/L
FLUSHING CYCLE = 154.0 days
TOTAL ANNUAL FLUSHING DEPTH = 2.39 m
ADJUSTED ANNUAL FLUSHING DEPTH = 2.27 m

SOLAR POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT (AF/yr)	MAKEUP INFLUENT (AF/yr)	EFFLUENT TO PROD (AF/yr)	EVAPORATION LOSSES (AF/yr)
1.00	1841	98	577	1362
2.00	3682	196	1153	2724
3.00	5522	294	1730	4086
4.00	7363	392	2306	5448
5.00	9204	489	2883	6810
6.00	11045	587	3460	8172
7.00	12885	685	4036	9534
8.00	14726	783	4613	10896
9.00	16567	881	5190	12258
10.00	18400	978	5764	13615

PRODUCTION/MAKEUP POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT BRINE (AF/yr)	SURFACE FLUSH INFLUENT (AF/yr)	MAKEUP EFFLUENT (AF/yr)	EFFLUENT SOLAR POND EXPANSION (AF/yr)	EVAPORATION LOSSES (AF/yr)	ADJUSTED EVAPORATION RATE (m/yr)
1.00	7992	577	98	3335	5136	1.360
2.00	7992	1153	196	3341	5609	1.363
3.00	7992	1730	294	3348	6081	1.366
4.00	7992	2306	392	3354	6553	1.368
5.00	7992	2883	489	3361	7025	1.370
6.00	7992	3460	587	3368	7497	1.372
7.00	7992	4036	685	3375	7969	1.373
8.00	7992	4613	783	3382	8440	1.375
9.00	7992	5190	881	3389	8912	1.376
10.00	7992	5764	978	3396	9382	1.378

SOLAR POND EXPANSION RATE AND PRODUCTION/MAKEUP POND AREA:

SOLAR POND SIZE INC (km2)	SYSTEM DILUTE TO POND EXPANSION (AF/yr)	TOTAL DILUTE USED (AF/yr)	EXPANSION RATE (km2/yr)	TOTAL TIME (years)	PRODUCTION/ MAKEUP POND AREA (km2)	SALT PREC IN PROD POND (%)
1.00	763	2604	.99	1.01	4.7	3.41
2.00	765	4446	.99	2.02	5.1	3.49
3.00	766	6289	.99	3.02	5.5	3.56
4.00	768	8131	1.00	4.03	5.9	3.62
5.00	769	9973	1.00	5.03	6.3	3.68
6.00	771	11816	1.00	6.03	6.7	3.73
7.00	773	13658	1.00	7.03	7.2	3.77
8.00	774	15500	1.01	8.02	7.6	3.81
9.00	776	17343	1.01	9.02	8.0	3.85
10.00	777	19178	1.01	10.00	8.4	3.88

TULAROSA BASIN - 50MWe BASE w/o DESAL

SEPARATE BRINE AND DILUTE SOURCE - FLUSHING BLOWDOWN TO WASTE (SCENERIO 3)

UPPER CONVECTING LAYER DEPTH = .30 m
NONCONVECTING LAYER DEPTH = 1.30 m
STORAGE LAYER DEPTH = 3.50 m

SYSTEM INFLUENT BRINE FLOWRATE = 2405 gal/min
= 3879 AF/yr
SYSTEM INFLUENT DILUTE FLOWRATE = 11820 gal/min
= 19066 AF/yr

SYSTEM INFLUENT BRINE CONCENTRATION = 260000 mg/L
SYSTEM INFLUENT DILUTE CONCENTRATION = 3000 mg/L

NET EVAPORATION RATE = 1.68 m/yr
SALT TRANSPORT COEFFICIENT = .0086 gm/d cm2

CONC AT SURFACE LAYER FLUSH = 50000 mg/L
STORAGE LAYER CONCENTRATION = 260000 mg/L
FLUSHING CYCLE = 153.9 days
TOTAL ANNUAL FLUSHING DEPTH = 2.39 m
ADJUSTED ANNUAL FLUSHING DEPTH = 2.27 m

SOLAR POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT (AF/yr)	MAKEUP INFLUENT (AF/yr)	EFFLUENT TO WASTE (AF/yr)	EVAPORATION LOSSES (AF/yr)
1.00	1841	98	577	1362
2.00	3682	196	1154	2724
3.00	5523	294	1731	4086
4.00	7364	392	2307	5448
5.00	9205	489	2884	6810
6.00	11046	587	3461	8172
7.00	12887	685	4038	9534
8.00	14728	783	4615	10896
9.00	16569	881	5192	12258
10.00	18410	979	5768	13620

INFLUENT BRINE DISTRIBUTION:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT BRINE (AF/yr)	MAKEUP INFLUENT (AF/yr)	SOLAR POND EXPANSION (AF/yr)
1.00	3879	98	3781
2.00	3879	196	3684
3.00	3879	294	3586
4.00	3879	392	3488
5.00	3879	489	3390
6.00	3879	587	3292
7.00	3879	685	3194
8.00	3879	783	3096
9.00	3879	881	2998
10.00	3879	979	2900

SOLAR POND EXPANSION RATE:

SOLAR POND SIZE INC (km2)	SYSTEM DILUTE TO POND EXPANSION (AF/yr)	TOTAL DILUTE USED (AF/yr)	EXPANSION RATE (km2/yr)	TOTAL TIME (years)
1.00	866	2707	1.12	.89
2.00	843	4525	1.09	1.79
3.00	821	6344	1.07	2.72
4.00	798	8162	1.04	3.67
5.00	776	9981	1.01	4.65
6.00	754	11800	.98	5.65
7.00	731	13618	.95	6.69
8.00	709	15437	.92	7.76
9.00	686	17256	.89	8.87
10.00	664	19074	.86	10.01

TULAROSA BASIN - 5MWe BASE w/o DESAL

SEPARATE BRINE AND DILUTE SOURCE - FLUSHING BLOWDOWN TO WASTE (SCENERIO 3)

UPPER CONVECTING LAYER DEPTH = .30 m
NONCONVECTING LAYER DEPTH = 1.30 m
STORAGE LAYER DEPTH = 3.50 m

SYSTEM INFLUENT BRINE FLOWRATE = 2100 gal/min
= 3387 AF/yr
SYSTEM INFLUENT DILUTE FLOWRATE = 1600 gal/min
= 2581 AF/yr

SYSTEM INFLUENT BRINE CONCENTRATION = 260000 mg/L
SYSTEM INFLUENT DILUTE CONCENTRATION = 3000 mg/L

NET EVAPORATION RATE = 1.68 m/yr
SALT TRANSPORT COEFFICIENT = .0086 gm/d cm2

CONC AT SURFACE LAYER FLUSH = 50000 mg/L
STORAGE LAYER CONCENTRATION = 260000 mg/L
FLUSHING CYCLE = 153.9 days
TOTAL ANNUAL FLUSHING DEPTH = 2.39 m
ADJUSTED ANNUAL FLUSHING DEPTH = 2.27 m

SOLAR POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT (AF/yr)	MAKEUP INFLUENT (AF/yr)	EFFLUENT TO WASTE (AF/yr)	EVAPORATION LOSSES (AF/yr)
.10	184	10	58	136
.20	368	20	115	272
.30	552	29	173	409
.40	736	39	231	545
.50	921	49	288	681
.60	1105	59	346	817
.70	1289	69	404	953
.80	1473	78	461	1090
.90	1657	88	519	1226
1.00	1837	98	576	1359

INFLUENT BRINE DISTRIBUTION:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT BRINE (AF/yr)	MAKEUP INFLUENT (AF/yr)	SOLAR POND EXPANSION (AF/yr)
.10	3387	10	3378
.20	3387	20	3368
.30	3387	29	3358
.40	3387	39	3348
.50	3387	49	3338
.60	3387	59	3329
.70	3387	69	3319
.80	3387	78	3309
.90	3387	88	3299
1.00	3387	98	3290

SOLAR POND EXPANSION RATE:

SOLAR POND SIZE INC (km2)	SYSTEM DILUTE TO POND EXPANSION (AF/yr)	TOTAL DILUTE USED (AF/yr)	EXPANSION RATE (km2/yr)	TOTAL TIME (years)
.10	773	957	1.00	.10
.20	771	1139	1.00	.20
.30	769	1321	1.00	.30
.40	766	1503	1.00	.40
.50	764	1685	.99	.50
.60	762	1867	.99	.60
.70	760	2048	.99	.70
.80	757	2230	.98	.80
.90	755	2412	.98	.91
1.00	753	2590	.98	1.01

TULAROSA BASIN - 50MWe INTER w/o DESAL

SEPARATE BRINE AND DILUTE SOURCE - FLUSHING BLOWDOWN TO WASTE (SCENERIO 3)

UPPER CONVECTING LAYER DEPTH	=	.30	m
NONCONVECTING LAYER DEPTH	=	1.30	m
STORAGE LAYER DEPTH	=	1.75	m

SYSTEM INFLUENT BRINE FLOWRATE	=	1365	gal/min
	=	2202	AF/yr
SYSTEM INFLUENT DILUTE FLOWRATE	=	6115	gal/min
	=	9863	AF/yr

SYSTEM INFLUENT BRINE CONCENTRATION	=	260000	mg/L
SYSTEM INFLUENT DILUTE CONCENTRATION	=	3000	mg/L

NET EVAPORATION RATE	=	1.68	m/yr
SALT TRANSPORT COEFFICIENT	=	.0086	gm/d cm2

CONC AT SURFACE LAYER FLUSH	=	50000	mg/L
STORAGE LAYER CONCENTRATION	=	260000	mg/L
FLUSHING CYCLE	=	153.9	days
TOTAL ANNUAL FLUSHING DEPTH	=	2.39	m
ADJUSTED ANNUAL FLUSHING DEPTH	=	2.27	m

SOLAR POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT (AF/yr)	MAKEUP INFLUENT (AF/yr)	EFFLUENT TO WASTE (AF/yr)	EVAPORATION LOSSES (AF/yr)
.50	921	49	288	681
1.00	1841	98	577	1362
1.50	2762	147	865	2043
2.00	3682	196	1154	2724
2.50	4603	245	1442	3405
3.00	5523	294	1731	4086
3.50	6444	343	2019	4767
4.00	7364	392	2307	5448
4.50	8285	440	2596	6129
5.00	9200	489	2883	6806

INFLUENT BRINE DISTRIBUTION:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT BRINE (AF/yr)	MAKEUP INFLUENT (AF/yr)	SOLAR POND EXPANSION (AF/yr)
.50	2202	49	2153
1.00	2202	98	2104
1.50	2202	147	2055
2.00	2202	196	2006
2.50	2202	245	1957
3.00	2202	294	1908
3.50	2202	343	1859
4.00	2202	392	1810
4.50	2202	440	1761
5.00	2202	489	1713

SOLAR POND EXPANSION RATE:

SOLAR POND SIZE INC (km2)	SYSTEM DILUTE TO POND EXPANSION (AF/yr)	TOTAL DILUTE USED (AF/yr)	EXPANSION RATE (km2/yr)	TOTAL TIME (years)
.50	852	1773	1.11	.45
1.00	833	2674	1.08	.91
1.50	813	3575	1.06	1.38
2.00	794	4476	1.03	1.86
2.50	775	5377	1.01	2.35
3.00	755	6278	.98	2.85
3.50	736	7179	.96	3.37
4.00	717	8081	.93	3.90
4.50	697	8982	.91	4.44
5.00	678	9877	.88	5.00

TULAROSA BASIN - 5MWe INTER w/o DESAL

SEPARATE BRINE AND DILUTE SOURCE - FLUSHING BLOWDOWN TO WASTE (SCENERIO 3)

UPPER CONVECTING LAYER DEPTH = .30 m
NONCONVECTING LAYER DEPTH = 1.30 m
STORAGE LAYER DEPTH = 1.75 m

SYSTEM INFLUENT BRINE FLOWRATE = 1210 gal/min
= 1952 AF/yr
SYSTEM INFLUENT DILUTE FLOWRATE = 1025 gal/min
= 1653 AF/yr

SYSTEM INFLUENT BRINE CONCENTRATION = 260000 mg/L
SYSTEM INFLUENT DILUTE CONCENTRATION = 3000 mg/L

NET EVAPORATION RATE = 1.68 m/yr
SALT TRANSPORT COEFFICIENT = .0086 gm/d cm2

CONC AT SURFACE LAYER FLUSH = 50000 mg/L
STORAGE LAYER CONCENTRATION = 260000 mg/L
FLUSHING CYCLE = 153.9 days
TOTAL ANNUAL FLUSHING DEPTH = 2.39 m
ADJUSTED ANNUAL FLUSHING DEPTH = 2.27 m

SOLAR POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT (AF/yr)	MAKEUP INFLUENT (AF/yr)	EFFLUENT TO WASTE (AF/yr)	EVAPORATION LOSSES (AF/yr)
.05	92	5	29	68
.10	184	10	58	136
.15	276	15	87	204
.20	368	20	115	272
.25	460	24	144	341
.30	552	29	173	409
.35	644	34	202	477
.40	736	39	231	545
.45	828	44	260	613
.50	916	49	287	677

INFLUENT BRINE DISTRIBUTION:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT BRINE (AF/yr)	MAKEUP INFLUENT (AF/yr)	SOLAR POND EXPANSION (AF/yr)
.05	1952	5	1947
.10	1952	10	1942
.15	1952	15	1937
.20	1952	20	1932
.25	1952	24	1927
.30	1952	29	1922
.35	1952	34	1917
.40	1952	39	1913
.45	1952	44	1908
.50	1952	49	1903

SOLAR POND EXPANSION RATE:

SOLAR POND SIZE INC (km2)	SYSTEM DILUTE TO POND EXPANSION (AF/yr)	TOTAL DILUTE USED (AF/yr)	EXPANSION RATE (km2/yr)	TOTAL TIME (years)
.05	771	863	1.00	.05
.10	769	953	1.00	.10
.15	767	1043	1.00	.15
.20	765	1133	.99	.20
.25	763	1223	.99	.25
.30	761	1313	.99	.30
.35	759	1403	.99	.35
.40	757	1493	.98	.40
.45	755	1584	.98	.45
.50	753	1669	.98	.50

TULAROSA BASIN - DESAL DEMO ANALYSIS

CATIONS	mg/L	meq/L	moles/L
CALCIUM (Ca)	225.00	11.23	.00561
MAGNESIUM (Mg)	94.00	7.73	.00387
SODIUM (Na)	210.00	9.13	.00913
POTASSIUM (PO4)	3.00	.08	.00008
IRON (Fe)	.25	.01	.00000
MANGANESE (Mn)	.05	.00	.00000
STRONTIUM (Sr)	0.00	0.00	0.00000
BARIUM (Ba)	.20	.00	.00000

ANIONS	mg/L	meq/L	moles/L
BICARBONATE (HCO3)	260.00	4.26	.00426
CARBONATE (CO3)	0.00	0.00	0.00000
SULFATE (SO4)	690.00	14.37	.00718
CHLORIDE (Cl)	298.00	8.41	.00841
PHOSPHATE (PO4)	0.00	0.00	0.00000

SUMMATION OF CATIONS = 28.2 meq/L
SUMMATION OF ANIONS = 27.0 meq/L
RATIO CATIONS:ANIONS = 1.04

TDS (SUMMATION) = 1781 mg/L

IONIC STRENGTH = .04428

CaSO4 CONCENTRATION = 764 mg/L
PERCENT CaSO4 = 42.9

TDS (mg/L)	CUMMULATIVE REDUCTION IN CaSO4 (mg/L) - BASED ON ORIGINAL CONCENTRATION	CUMMULATIVE REDUCTION IN CaSO4 (%)
10000	275	36.0
16909	493	64.5
21696	573	75.0
27117	618	80.9
32644	646	84.6
38215	662	86.6
43970	680	89.0
49436	689	90.2

TULAROSA BASIN - 50MWe BASE with DESAL

SEPARATE BRINE AND DILUTE SOURCE - FLUSHING BLOWDOWN TO WASTE; DESALINATION WITH BRINE REJECT TO SURFACE FLUSH (SCENERIO 3a)

UPPER CONVECTING LAYER DEPTH = .30 m
NONCONVECTING LAYER DEPTH = 1.30 m
STORAGE LAYER DEPTH = 3.50 m

SYSTEM INFLUENT BRINE FLOWRATE = 2405 gal/min
= 3879 AF/yr
SYSTEM INFLUENT DILUTE FLOWRATE = 39525 gal/min
= 63754 AF/yr

SYSTEM INFLUENT BRINE CONCENTRATION = 260000 mg/L
SYSTEM INFLUENT DILUTE CONCENTRATION = 1780 mg/L

NET EVAPORATION RATE = 1.68 m/yr
SALT TRANSPORT COEFFICIENT = .0086 gm/d cm2

DESALINATION MODULE PRODUCTION CAPACITY = 5.0 Mgal/d
PERCENT RECOVERY = 70
REJECT CONCENTRATION = 5929 mg/L
ELECTRICAL ENERGY REQUIREMENT = 9.5 MWhe/Mgal product
NET ELECTRICAL ENERGY PRODUCTION = 3.44 MWe/km2
PERCENT PLANT FACTOR = 90

CONC AT SURFACE LAYER FLUSH = 50000 mg/L
STORAGE LAYER CONCENTRATION = 260000 mg/L
FLUSHING CYCLE = 136.8 days
TOTAL ANNUAL FLUSHING DEPTH = 2.48 m (based on brine reject conc.)
ADJUSTED ANNUAL FLUSHING DEPTH = 2.36 m

SOLAR POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT (AF/yr)	DESAL REJECT INFLUENT (AF/yr)	MAKEUP INFLUENT (AF/yr)	EFFLUENT TO WASTE (AF/yr)	EVAPORATION LOSSES (AF/yr)
1.00	0	1913	98	649	1362
2.00	0	3826	196	1298	2724
3.00	0	5739	294	1947	4086
4.00	0	7652	392	2595	5448
5.00	0	9565	489	3244	6810
6.00	0	11478	587	3893	8172
7.00	0	13391	685	4542	9534
8.00	0	15304	783	5191	10896
9.00	0	17217	881	5840	12258
10.00	0	19126	979	6487	13618

INFLUENT BRINE DISTRIBUTION:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT BRINE (AF/yr)	MAKEUP INFLUENT (AF/yr)	SOLAR POND EXPANSION (AF/yr)
1.00	3879	98	3781
2.00	3879	196	3684
3.00	3879	294	3586
4.00	3879	392	3488
5.00	3879	489	3390
6.00	3879	587	3292
7.00	3879	685	3194
8.00	3879	783	3096
9.00	3879	881	2998
10.00	3879	979	2901

SOLAR POND EXPANSION RATE:

SOLAR POND SIZE INC (km2)	SYSTEM DILUTE TO POND EXPANSION (AF/yr)	TOTAL DILUTE USED (AF/yr)	EXPANSION RATE (km2/yr)	TOTAL TIME (years)
1.00	866	8067	1.12	.89
2.00	843	22446	1.09	1.79
3.00	821	36825	1.07	2.72
4.00	798	51205	1.04	3.67
5.00	776	65584	1.01	4.65
6.00	754	72763	.98	5.65
7.00	731	72740	.95	6.69
8.00	709	72718	.92	7.76
9.00	686	72695	.89	8.87
10.00	664	72673	.86	10.00

DESALINATION PLANT BALANCE:

SOLAR POND SIZE INC (km2)	PLANT INFLUENT (AF/yr)	PRODUCT WATER (Mgal/d)	PRODUCT WATER (AF/yr)	BRINE REJECT -TOTAL (AF/yr)	REJECT TO SOLAR POND (AF/yr)	REJECT TO WASTE (AF/yr)
1.00	7201	4.5	5041	2160	1913	247
2.00	21603	13.5	15122	6481	3826	2655
3.00	36005	22.5	25203	10801	5739	5062
4.00	50406	31.5	35284	15122	7652	7470
5.00	64808	40.5	45366	19442	9565	9878
6.00	72009	45.0	50406	21603	11478	10125
7.00	72009	45.0	50406	21603	13391	8212
8.00	72009	45.0	50406	21603	15304	6299
9.00	72009	45.0	50406	21603	17217	4386
10.00	72009	45.0	50406	21603	19126	2477

TULAROSA BASIN - 5MWe BASE with DESAL

SEPARATE BRINE AND DILUTE SOURCE - FLUSHING BLOWDOWN TO WASTE; DESALINATION WITH BRINE REJECT TO SURFACE FLUSH (SCENERIO 3a)

UPPER CONVECTING LAYER DEPTH	=	.30	m
NONCONVECTING LAYER DEPTH	=	1.30	m
STORAGE LAYER DEPTH	=	3.50	m

SYSTEM INFLUENT BRINE FLOWRATE	=	2100	gal/min
	=	3387	AF/yr
SYSTEM INFLUENT DILUTE FLOWRATE	=	3950	gal/min
	=	6371	AF/yr

SYSTEM INFLUENT BRINE CONCENTRATION	=	260000	mg/L
SYSTEM INFLUENT DILUTE CONCENTRATION	=	1780	mg/L

NET EVAPORATION RATE	=	1.68	m/yr
SALT TRANSPORT COEFFICIENT	=	.0086	gm/d cm2

DESALINATION MODULE PRODUCTION CAPACITY	=	5.0	Mgal/d
PERCENT RECOVERY	=	70	
REJECT CONCENTRATION	=	5929	mg/L
ELECTRICAL ENERGY REQUIREMENT	=	9.5	MWhe/Mgal product
NET ELECTRICAL ENERGY PRODUCTION	=	3.44	MWe/km2
PERCENT PLANT FACTOR	=	90	

CONC AT SURFACE LAYER FLUSH	=	50000	mg/L
STORAGE LAYER CONCENTRATION	=	260000	mg/L
FLUSHING CYCLE	=	136.8	days
TOTAL ANNUAL FLUSHING DEPTH	=	2.48	m (based on brine reject conc.)
ADJUSTED ANNUAL FLUSHING DEPTH	=	2.36	m

SOLAR POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT (AF/yr)	DESAL REJECT INFLUENT (AF/yr)	MAKEUP INFLUENT (AF/yr)	EFFLUENT TO WASTE (AF/yr)	EVAPORATION LOSSES (AF/yr)
.10	191	0	10	65	136
.20	383	0	20	130	272
.30	574	0	29	195	409
.40	765	0	39	260	545
.50	956	0	49	324	681
.60	0	1148	59	389	817
.70	0	1339	69	454	953
.80	0	1530	78	519	1090
.90	0	1722	88	584	1226
1.00	0	1911	98	648	1361

INFLUENT BRINE DISTRIBUTION:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT BRINE (AF/yr)	MAKEUP INFLUENT (AF/yr)	SOLAR POND EXPANSION (AF/yr)
.10	3387	10	3378
.20	3387	20	3368
.30	3387	29	3358
.40	3387	39	3348
.50	3387	49	3338
.60	3387	59	3329
.70	3387	69	3319
.80	3387	78	3309
.90	3387	88	3299
1.00	3387	98	3290

SOLAR POND EXPANSION RATE:

SOLAR POND SIZE INC (km2)	SYSTEM DILUTE TO POND EXPANSION (AF/yr)	TOTAL DILUTE USED (AF/yr)	EXPANSION RATE (km2/yr)	TOTAL TIME (years)
.10	773	964	1.00	.10
.20	771	1154	1.00	.20
.30	769	1343	1.00	.30
.40	766	1532	1.00	.40
.50	764	1721	.99	.50
.60	762	7963	.99	.60
.70	760	7961	.99	.70
.80	757	7958	.98	.80
.90	755	7956	.98	.91
1.00	753	7954	.98	1.01

DESALINATION PLANT BALANCE:

SOLAR POND SIZE INC (km2)	PLANT INFLUENT (AF/yr)	PRODUCT WATER (Mgal/d)	PRODUCT WATER (AF/yr)	BRINE REJECT -TOTAL (AF/yr)	REJECT TO SOLAR POND (AF/yr)	REJECT TO WASTE (AF/yr)
.10	0	0.0	0	0	0	0
.20	0	0.0	0	0	0	0
.30	0	0.0	0	0	0	0
.40	0	0.0	0	0	0	0
.50	0	0.0	0	0	0	0
.60	7201	4.5	5041	2160	1148	1012
.70	7201	4.5	5041	2160	1339	821
.80	7201	4.5	5041	2160	1530	630
.90	7201	4.5	5041	2160	1722	439
1.00	7201	4.5	5041	2160	1911	249

TULAROSA BASIN - 50MWe INTER with DESAL

SEPARATE BRINE AND DILUTE SOURCE - FLUSHING BLOWDOWN TO WASTE; DESALINATION WITH BRINE REJECT TO SURFACE FLUSH (SCENERIO 3a)

UPPER CONVECTING LAYER DEPTH = .30 m
NONCONVECTING LAYER DEPTH = 1.30 m
STORAGE LAYER DEPTH = 1.75 m

SYSTEM INFLUENT BRINE FLOWRATE = 1420 gal/min
= 2290 AF/yr
SYSTEM INFLUENT DILUTE FLOWRATE = 20550 gal/min
= 33147 AF/yr

SYSTEM INFLUENT BRINE CONCENTRATION = 260000 mg/L
SYSTEM INFLUENT DILUTE CONCENTRATION = 1780 mg/L

NET EVAPORATION RATE = 1.68 m/yr
SALT TRANSPORT COEFFICIENT = .0086 gm/d cm2

DESALINATION MODULE PRODUCTION CAPACITY = 5.0 Mgal/d
PERCENT RECOVERY = 70
REJECT CONCENTRATION = 5929 mg/L
ELECTRICAL ENERGY REQUIREMENT = 9.5 MWhe/Mgal product
NET ELECTRICAL ENERGY PRODUCTION = 3.44 MWe/km2
PERCENT PLANT FACTOR = 90

CONC AT SURFACE LAYER FLUSH = 50000 mg/L
STORAGE LAYER CONCENTRATION = 260000 mg/L
FLUSHING CYCLE = 136.8 days
TOTAL ANNUAL FLUSHING DEPTH = 2.48 m (based on brine reject conc.)
ADJUSTED ANNUAL FLUSHING DEPTH = 2.36 m

SOLAR POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT (AF/yr)	DESAL REJECT INFLUENT (AF/yr)	MAKEUP INFLUENT (AF/yr)	EFFLUENT TO WASTE (AF/yr)	EVAPORATION LOSSES (AF/yr)
.50	956	0	49	324	681
1.00	0	1913	98	649	1362
1.50	0	2869	147	973	2043
2.00	0	3826	196	1298	2724
2.50	0	4782	245	1622	3405
3.00	0	5739	294	1947	4086
3.50	0	6695	343	2271	4767
4.00	0	7652	392	2595	5448
4.50	0	8608	440	2920	6129
5.00	0	9565	489	3244	6810
5.20	0	9944	509	3373	7080

INFLUENT BRINE DISTRIBUTION:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT BRINE (AF/yr)	MAKEUP INFLUENT (AF/yr)	SOLAR POND EXPANSION (AF/yr)
.50	2290	49	2242
1.00	2290	98	2193
1.50	2290	147	2144
2.00	2290	196	2095
2.50	2290	245	2046
3.00	2290	294	1997
3.50	2290	343	1948
4.00	2290	392	1899
4.50	2290	440	1850
5.00	2290	489	1801
5.20	2290	509	1782

SOLAR POND EXPANSION RATE:

SOLAR POND SIZE INC (km2)	SYSTEM DILUTE TO POND EXPANSION (AF/yr)	TOTAL DILUTE USED (AF/yr)	EXPANSION RATE (km2/yr)	TOTAL TIME (years)
.50	887	1844	1.15	.43
1.00	868	8069	1.13	.87
1.50	849	15250	1.10	1.32
2.00	829	22432	1.08	1.78
2.50	810	29613	1.05	2.25
3.00	790	36795	1.03	2.73
3.50	771	43977	1.00	3.23
4.00	752	51158	.98	3.73
4.50	732	58340	.95	4.25
5.00	713	65521	.93	4.78
5.20	705	72714	.92	5.00

DESALINATION PLANT BALANCE:

SOLAR POND SIZE INC (km2)	PLANT INFLUENT (AF/yr)	PRODUCT WATER (Mgal/d)	PRODUCT WATER (AF/yr)	BRINE REJECT -TOTAL (AF/yr)	REJECT TO SOLAR POND (AF/yr)	REJECT TO WASTE (AF/yr)
.50	0	0.0	0	0	0	0
1.00	7201	4.5	5041	2160	1913	247
1.50	14402	9.0	10081	4321	2869	1451
2.00	21603	13.5	15122	6481	3826	2655
2.50	28804	18.0	20163	8641	4782	3859
3.00	36005	22.5	25203	10801	5739	5062
3.50	43205	27.0	30244	12962	6695	6266
4.00	50406	31.5	35284	15122	7652	7470
4.50	57607	36.0	40325	17282	8608	8674
5.00	64808	40.5	45366	19442	9565	9878
5.20	72009	45.0	50406	21603	9944	11659

TULAROSA BASIN - 5MWe INTER with DESAL

SEPARATE BRINE AND DILUTE SOURCE - FLUSHING BLOWDOWN TO WASTE; DESALINATION WITH BRINE REJECT TO SURFACE FLUSH (SCENERIO 3a)

UPPER CONVECTING LAYER DEPTH = .30 m
NONCONVECTING LAYER DEPTH = 1.30 m
STORAGE LAYER DEPTH = 1.75 m

SYSTEM INFLUENT BRINE FLOWRATE = 1280 gal/min
= 2065 AF/yr
SYSTEM INFLUENT DILUTE FLOWRATE = 2060 gal/min
= 3323 AF/yr

SYSTEM INFLUENT BRINE CONCENTRATION = 260000 mg/L
SYSTEM INFLUENT DILUTE CONCENTRATION = 1780 mg/L

NET EVAPORATION RATE = 1.68 m/yr
SALT TRANSPORT COEFFICIENT = .0086 gm/d cm2

DESALINATION MODULE PRODUCTION CAPACITY = 5.0 Mgal/d
PERCENT RECOVERY = 70
REJECT CONCENTRATION = 5929 mg/L
ELECTRICAL ENERGY REQUIREMENT = 9.5 MWhe/Mgal product
NET ELECTRICAL ENERGY PRODUCTION = 3.44 MWe/km2
PERCENT PLANT FACTOR = 90

CONC AT SURFACE LAYER FLUSH = 50000 mg/L
STORAGE LAYER CONCENTRATION = 260000 mg/L
FLUSHING CYCLE = 136.8 days
TOTAL ANNUAL FLUSHING DEPTH = 2.48 m (based on brine reject conc.)
ADJUSTED ANNUAL FLUSHING DEPTH = 2.36 m

SOLAR POND BALANCE:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT (AF/yr)	DESAL REJECT INFLUENT (AF/yr)	MAKEUP INFLUENT (AF/yr)	EFFLUENT TO WASTE (AF/yr)	EVAPORATION LOSSES (AF/yr)
.05	96	0	5	32	68
.10	191	0	10	65	136
.15	287	0	15	97	204
.20	383	0	20	130	272
.25	478	0	24	162	341
.30	574	0	29	195	409
.35	670	0	34	227	477
.40	765	0	39	260	545
.45	861	0	44	292	613
.50	956	0	49	324	681
.52	0	997	51	338	710

INFLUENT BRINE DISTRIBUTION:

SOLAR POND SIZE INC (km2)	SYSTEM INFLUENT BRINE (AF/yr)	MAKEUP INFLUENT (AF/yr)	SOLAR POND EXPANSION (AF/yr)
.05	2065	5	2060
.10	2065	10	2055
.15	2065	15	2050
.20	2065	20	2045
.25	2065	24	2040
.30	2065	29	2035
.35	2065	34	2030
.40	2065	39	2025
.45	2065	44	2021
.50	2065	49	2016
.52	2065	51	2014

SOLAR POND EXPANSION RATE:

SOLAR POND SIZE INC (km2)	SYSTEM DILUTE TO POND EXPANSION (AF/yr)	TOTAL DILUTE USED (AF/yr)	EXPANSION RATE (km2/yr)	TOTAL TIME (years)
.05	815	911	1.06	.05
.10	813	1005	1.06	.09
.15	811	1098	1.05	.14
.20	810	1192	1.05	.19
.25	808	1286	1.05	.24
.30	806	1380	1.05	.28
.35	804	1473	1.04	.33
.40	802	1567	1.04	.38
.45	800	1661	1.04	.43
.50	798	1754	1.04	.48
.52	797	7998	1.03	.50

DESALINATION PLANT BALANCE:

SOLAR POND SIZE INC (km2)	PLANT INFLUENT (AF/yr)	PRODUCT WATER (Mgal/d)	PRODUCT WATER (AF/yr)	BRINE REJECT -TOTAL (AF/yr)	REJECT TO SOLAR POND (AF/yr)	REJECT TO WASTE (AF/yr)
.05	0	0.0	0	0	0	0
.10	0	0.0	0	0	0	0
.15	0	0.0	0	0	0	0
.20	0	0.0	0	0	0	0
.25	0	0.0	0	0	0	0
.30	0	0.0	0	0	0	0
.35	0	0.0	0	0	0	0
.40	0	0.0	0	0	0	0
.45	0	0.0	0	0	0	0
.50	0	0.0	0	0	0	0
.52	7201	4.5	5041	2160	997	1163

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