

**SOLAR PONDS FOR ELECTRIC POWER GENERATION:  
COST MODEL AND FEASIBILITY STUDY.**

BY

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(Mechanical Engineering, 1983)

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Submitted in Partial Fulfillment  
of the Requirements for the  
Degree of

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**ABSTRACT**

This research study examines the construction and feasibility of solar ponds for electric power generation. The objective of this thesis is to show that the high cost of solar pond electric power facilities as well as the financial and regulatory environment of the electric utility industry provides little or no incentive to invest in this fuel conserving technology.

A cost model is presented to explore the different cost structure that solar ponds may have and to examine which structure and construction scenario would enhance this effectiveness in the eyes of the electric utility industry.

To quantify these costs, a 50 MW case study is developed to show that the primary drawback of solar ponds is their cost. This is followed by an evaluation of the regulatory and financial environment of the utilities to determine their influence on solar pond investment.

Thesis Supervisor: Dr. David H. Marks  
Professor of Civil Engineering

**ACKNOWLEDGEMENTS**

Special thanks are given to Professor David H. Marks, who fully supported this research study with his experience, comments and encouragement.

The cooperation of Mr Michael J. Markow was fully appreciated in structuring the cost model and the construction analysis. The research on the cost model and construction analysis was sponsored by the Electric Power Research Institute for a state-of-the-art study conducted at M.I.T. on salt gradient solar ponds.

I also thank my parents for their love and support.

Philippe L. Dintrans

### Biographical Note

The author of this thesis was raised in France, Senegal, Lebanon and in New York where he graduated from the Lycee Francais de New York. He received his undergraduate education at Swarthmore College and graduated with a Bachelor of Science in mechanical Engineering and a Bachelor of Arts in Economics with the Concentration in Public Policy.

The undergraduate thesis in Mechanical Engineering was entitled "Design and Testing of a Recreational Hovercraft". The hovercraft attained a speed of 25mph and demonstrated the use of a bag-type skirt to increase lift and stability. The author was named finalist for the Scott Leadership Award at Swarthmore.

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Je dedie cette these a mes parents pour  
leur amour et support.

I also dedicate this thesis to Annie for  
her love and friendship.

## CHAPTER 1

## INTRODUCTION

For many years, a major factor in the long term price stability of electrical energy has been the low cost of oil. Low prices were enjoyed until the dramatic oil embargo of 1973. This single event, the changing proportion of fuel cost in electrical power production induced a major shift in the planning of the electric utility industry.

The expansion plans of these utilities had included investments in oil based plants because of their ease of operations and load flexibility compared to coal and nuclear generating facilities. But as 1973 came to an end, nuclear and coal power plants began to dominate the new planning schedules.

Historically, technological innovation in the electric utility industry has been characterized by economies of scale involving the generating facilities and the transmission networks. These effects were to diminish as nuclear and coal power plants approached the gigawatt range.

Several promising technological approaches have started

to emerge to reduce the high cost of fossil fuel and in some cases to eventually reduce the need for conventional coal and nuclear baseload.

These new promising technologies for electric power generation can be categorized as follows: wind, solar thermal electric, and photovoltaics. One of the most promising of these new technologies is salt gradient solar ponds. Except for solar ponds, solar thermal electric, wind and photovoltaics have one common characteristic: intermittency. Their energy output is variable and depends on solar radiation and wind speed. They also do not possess any storage capability eliminating their use as a baseload energy source.

The great advantage of salt gradient solar ponds is their unique ability to store thermal energy in the bottom layers of the brine. This attribute is useful for process heating and power production by eliminating the intermittency factor.

The purpose of this thesis is to show that the high cost of solar pond electric power facilities as well as the financial regulatory environment of the electric utility industry provides little or no incentive to invest in these fuel conserving technologies.

To develop and illustrate this hypothesis, a cost model and a feasibility study are presented. Solar ponds are horizontal surface collectors using the absorption of solar radiation at the bottom of a 3 or 4 meter deep body of water to generate low temperature heat. The low temperature from these ponds may be used to provide heat for buildings, for crop drying, for salt production or for distillation. Electrical power generation using solar ponds coupled to low temperature Rankine cycles (Figure 1.1) has been accomplished in Israel and has been studied for various sites in the United States. A brief engineering description of solar ponds is presented in Chapter 2 along with a review of existing solar ponds in Israel and the United States.

In order to conduct this study on the feasibility of solar ponds, a new method for construction analysis of these facilities is presented in Chapter 3 to explore the different cost structure that these facilities may have and to examine which structure and construction scenario would enhance their cost effectiveness in the eyes of the electric utility industry. The approach taken is innovative and can be used to predict costs for a wide range of capital intensive land intensive facilities.

To quantify these costs, a proposed 50 Mw solar pond site in Southern California is used as a base case in Chapter

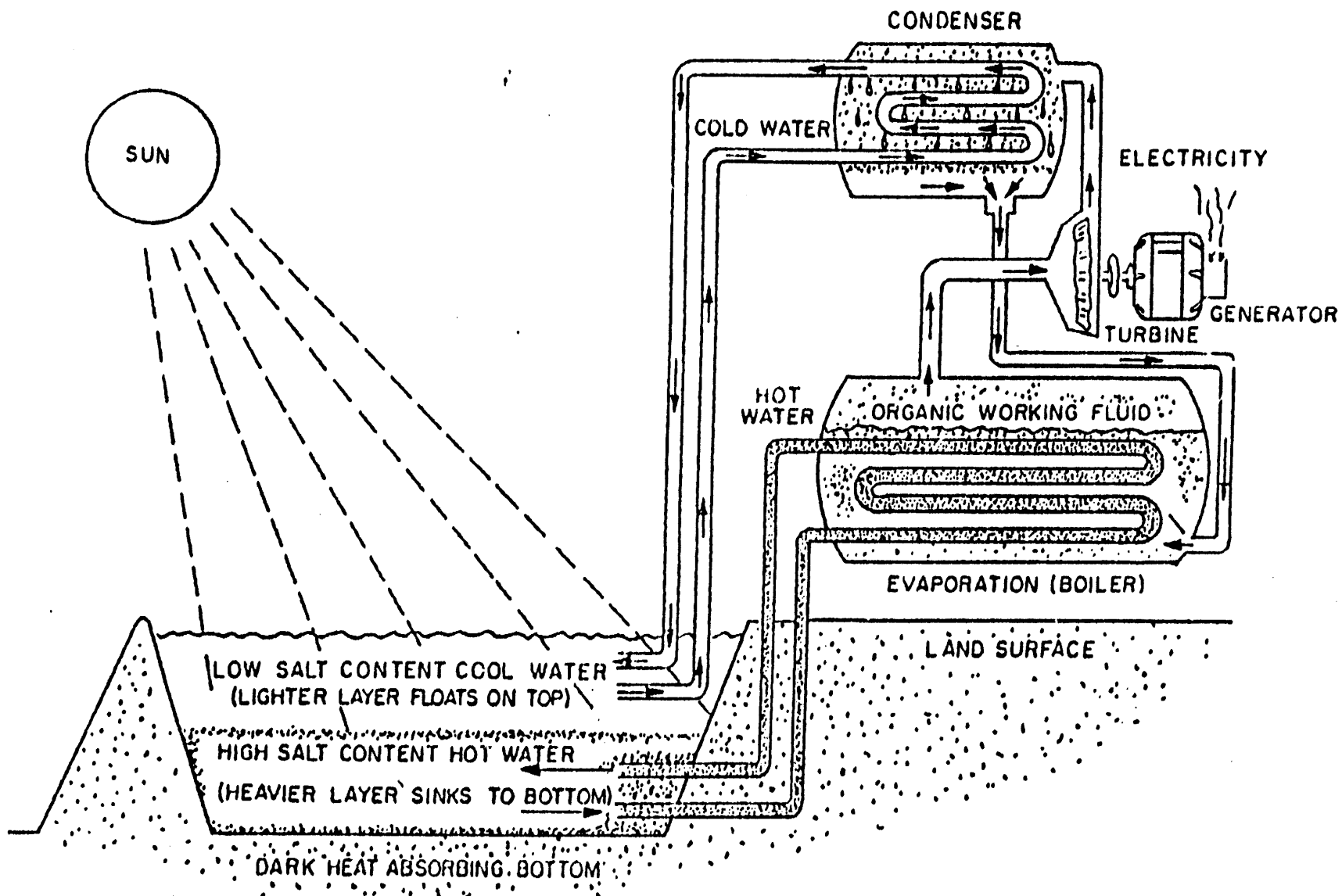


Figure 1.1 : Schematic diagram of solar pond. (source Adams)

4. At this point, we discovered that the major adverse effects of solar ponds were limited to the high cost of these facilities. These costs show that solar ponds are not competitive with conventional energy sources.

To evaluate the overall climate for electric utility investment in solar ponds, a range of complex and often controversial issues such as the impact of solar systems on electric utilities, the financial condition of the utilities, and the effect of the Public Utilities Regulatory Act (PURPA) are presented to determine their positive or negative consequence on the utility investment.

The final analysis of this thesis topic concludes, assuming the technical feasibility of solar ponds, that the major barrier to such highly capital intensive investments is the predominantly high cost of these facilities coupled with the uncertain financial and regulatory environment of the electric utility industry.

REVIEW OF SOLAR POND CONSTRUCTION AND TECHNOLOGY

2.1.-Technical review.

To understand the issues involved in evaluating the economic feasibility of salt gradient solar ponds for the purpose of electric power generation, a brief technical and historical review of solar pond development is presented.

Salt gradient ponds or lakes which exhibit an increase in temperature with depth have existed in nature for a long time. If the salt concentration is sufficiently steep and the surface of the pond is protected from mixing induced by the wind, then the solar radiation can raise the temperature of the main body of water well above the ambient temperature.

A solar pond is a body of liquid, usually brine, which collects the energy from the sun and stores it as heat. The brine, about three meters deep is introduced into the pond and maintained in such a way as to establish a salt gradient of increasing concentration with depth to suppress natural convection. The bottom layer of the brine collects and retains solar energy as heat. This heat gradient serves as the source of energy for generating electric power in a vapor cycle unit similar to a conventional steam power plant. The structure, salinity, and temperature profiles for a typical solar pond are shown in Figure 2.1.

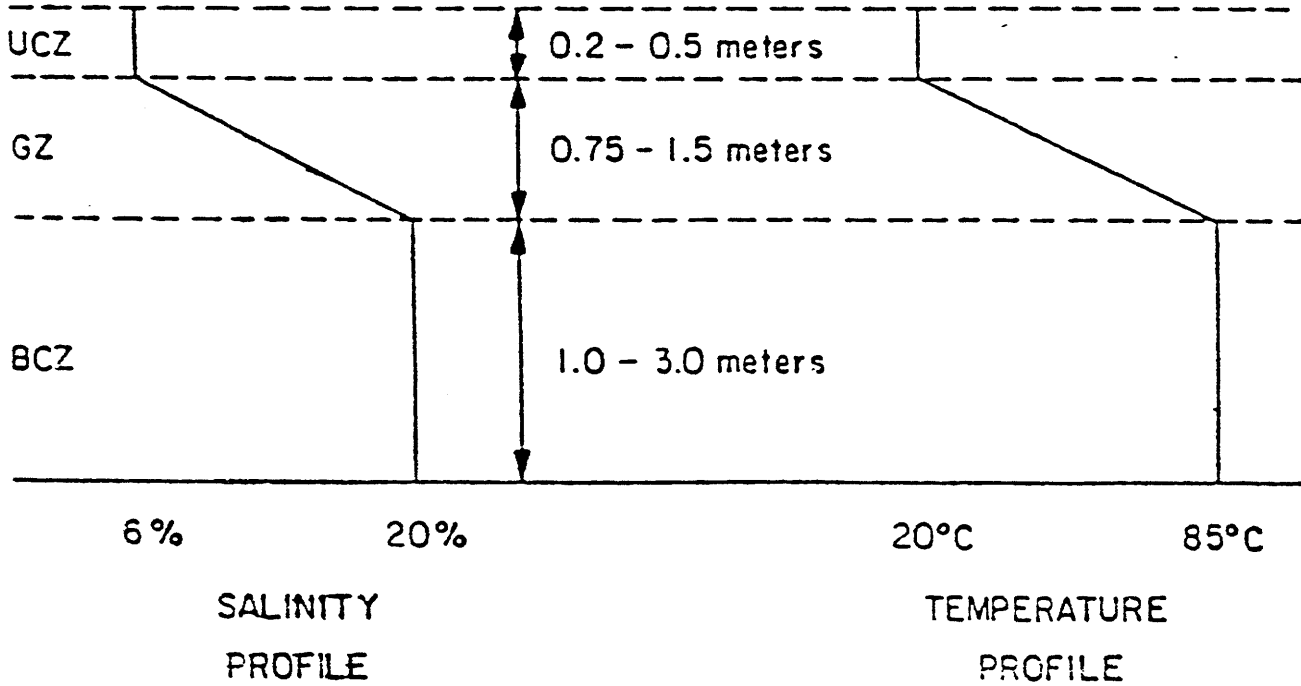
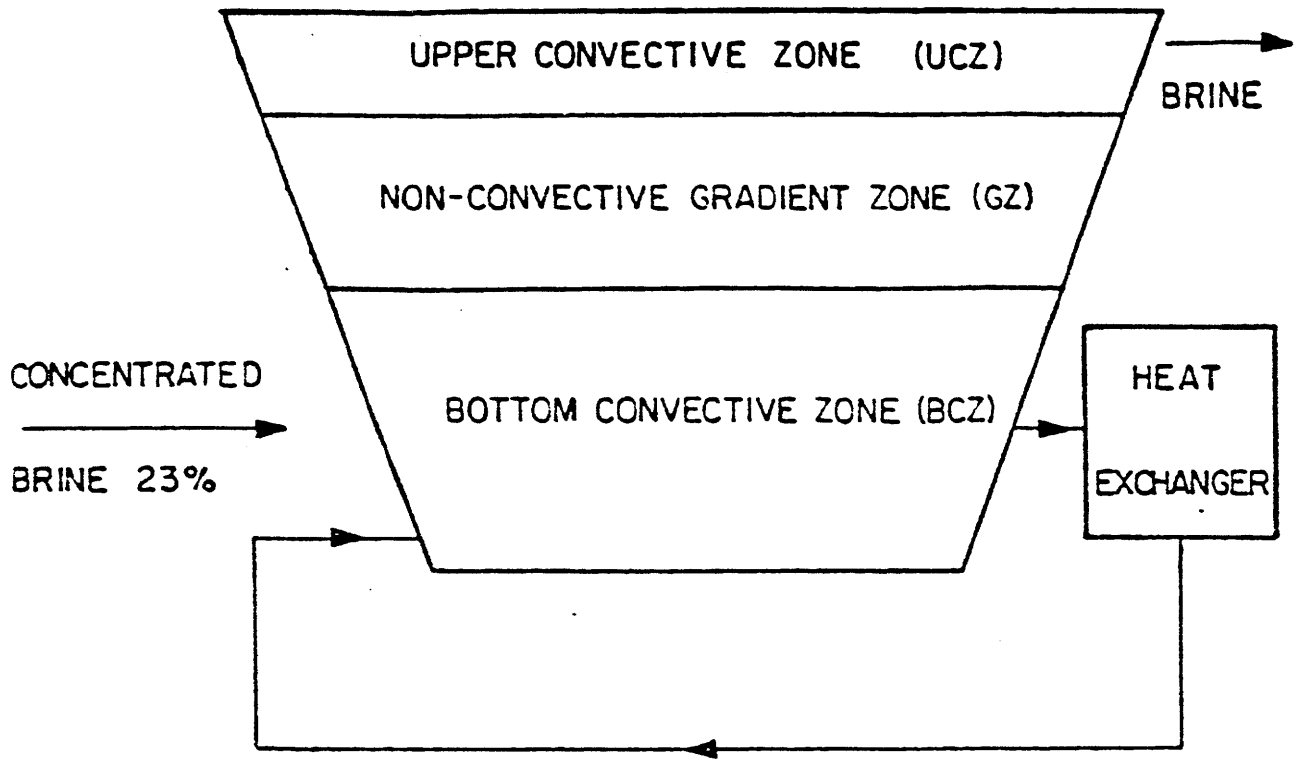


Figure 2.1: Structure, Salinity and Temperature Profiles for a typical solar pond (Adams MIT, 1982).



The state-of-the-art solution is to use a vapor as the working fluid in the turbine of a Rankine cycle. The closed cycle unit operates as a simple Rankine cycle engine. The arrangements are shown in Figure 2.2 . The evaporator uses heat transferred from the hot brine to produce vapor to generate power in the turbine and is discharged at the condenser, it is then condensed by heat transferred from the cooling water. the cooling water could come from the cool upper convective layer of the solar pond, from a separate cooling pond which could also serve as the evaporation pond or from a conventional source of cooling water. The condensate is then raised in pressure by the feed pump and returned to the evaporator to complete the cyclic process (Carmichael, MIT 1984).

The energy budget for a solar pond depends on four primary factors:

- Penetration and absorption of short wave solar energy.
- Diffusion of heat to the gradient zone from the bottom convective zone.
- Ground heat loss from the bottom from the bottom of the pond and
- Heat extraction.

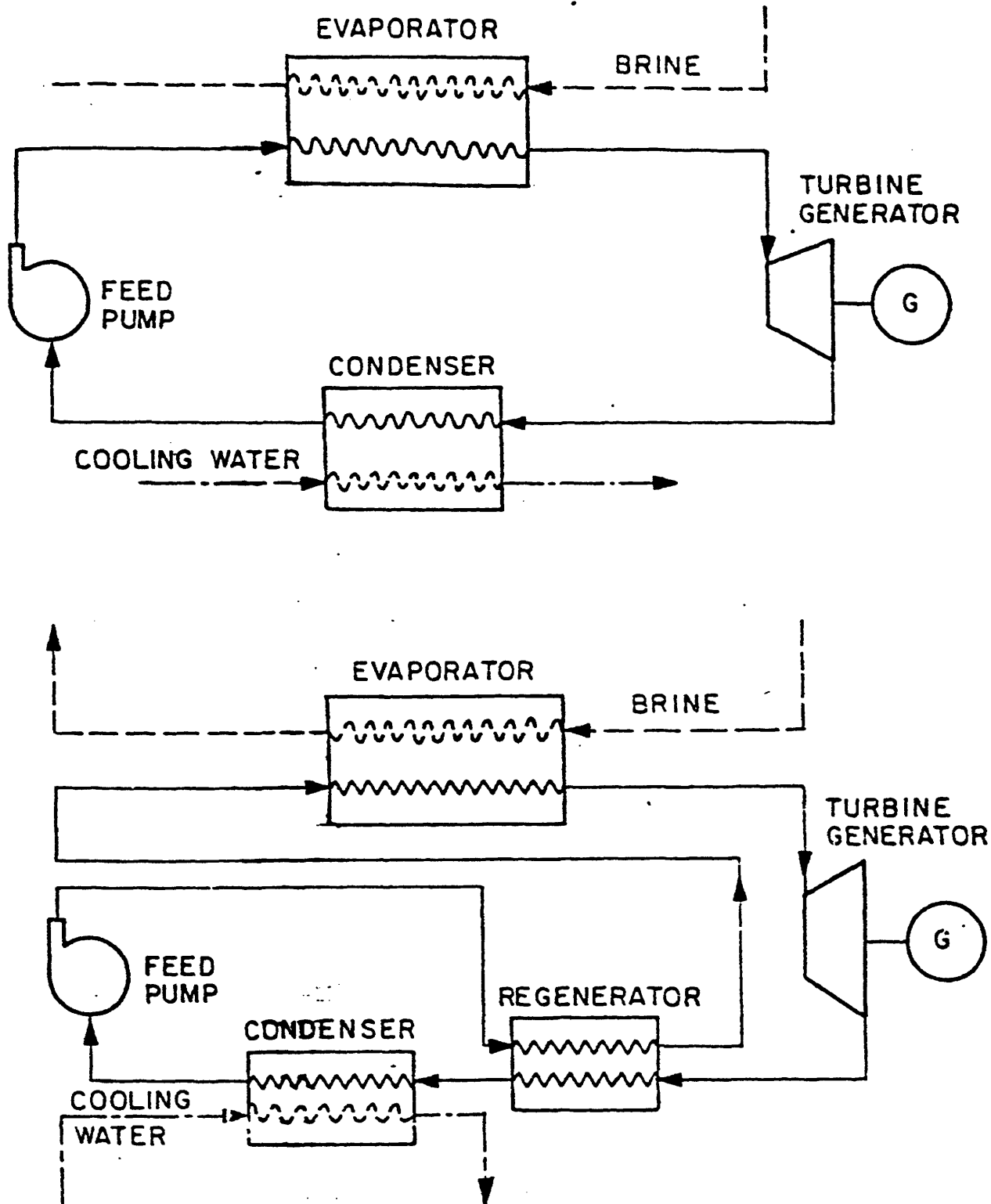


Figure 2.2. : top- Arrangement of a Rankine cycle

bottom- Arrangement of a Rankine Cycle with a regenerative heat exchanger (Carmichael, MIT 1904)

## 2.2.-LITERATURE REVIEW.

Emphasis on the literature review is placed upon the Israeli and American experience.

### 2.2.1.-Israeli experience.

It was in 1954 that the Israeli scientists Rudolph Bloch and Harry Tabor first proposed the construction of artificial solar ponds. In his work at the National Physical Laboratory of Israel and in a paper published in 1963 (Tabor, 1961), Tabor indicated that if a solar pond could be constructed on flat ground, with a suitable embankment, and a free source of concentrated brine, the estimated cost of solar ponds per square meter would be two lower of magnitude lower than the cheapest contemporary solar collectors.

In a follow-up report in 1981 (Tabor, 1981), Tabor, in what can perhaps be considered the major review article on solar ponds, covered the state-of -the-art of this new technology. The review explains the history and the motivation to create a large area solar collector with built in heat storage; summarizes relevant basic theory and discusses technical problems of operation such as the adverse effects of wind and brine leakage. Practical details of the construction process are also included.

Following are a few important points brought up by the review article. Tabor conceived of solar pond construction

as leveling a site area and building a retaining wall around the perimeter. This would lead as Tabor points out, to a considerable difference between the upper surface area and the lower surface area and to a large increase in the area of lining needed vis-a-vis the active area for small ponds. This effect is small for large ponds. The article recommends a slope of 1 in 3 for the embankments. Furthermore loss of collected heat can occur either by the leaking of the brine from the bottom of the pond, or by conduction of heat into the ground. To ensure no leakage earthliners and synthetic liners are examined, the latter being strongly recommended.

The cost according to Tabor is tolerable assuming that there are many areas where salt is locally available. Also, in large installations, solid salt may be imported to get the project going but concentrated salt will then be produced on the site through evaporation. Ponds discussed in the article include Yavne and Ein Bokek in Israel, the Aspendale 1964 Australian solar pond project (which had poor efficiency results compared to Israeli ponds), and some US ponds: the Ohio State pond, the University of New Mexico pond, and the Miamisburg pond.

Tabor's discussion of costs is of particular interest to our study. The Solmat Company (Tabor, 1981) calculated that it could build ponds in most areas for \$13 per square meter. Small ponds are considerably more expensive per unit area

than the large ponds because of greater embankment costs and liner per unit surface area. The figure quoted is for ponds larger than 100,000 square meter. The cost of water for the pond is estimated at 0.67 per cubic meter, and estimates a need as high as 3 cubic meter of water per square meter of collector area may be needed per year to make up for evaporation.

Tabor concludes that at the present stage, the solar pond concept described above cannot be regarded as a large source of power (i.e. gigawatt range). An approach which might make this range feasible is taken from Assaf (Assaf) and given consideration by Tabor. The concept is the creation of a solar pond within an existing salt lake. Thus the problem of soil lining and excavation would be eliminated.

As a part of the development process, several small indoor ponds were developed and four ponds were constructed to demonstrate the practicality of producing electric power and to develop the technology (Carmichael, MIT 1984):

- a 1500 square meter pond was built in Yavne, 1977 to operate a 6 kw turbogenerator.

- a 7000 square meter pond was built at Ein Bokek , at the Dead Sea in 1979 to provide 150 kw of peak power.

- a 40,000 square meter pond was constructed at the northern end of the Dead Sea in 1982 and is expected to

provide the energy for a 2.5 MW turbine operating as a peaking unit.

- a 250,000 square meter pond was completed at the northern end of the Dead Sea in 1983 and is expected to develop 5 MW.

Although considerable expertise has been reached by the Israelis in the operation of these ponds little technical information has been made readily available. Since 1977 the solar pond projects have been supervised by the Solmat Systems Company and the Ormat Company has built the turbines. Much of the technology of solar ponds in Israel has been developed by the Ormat Company and this organization has participated in several design studies of large solar pond projects like the Salton Sea in California(Ormat,1981).

#### 2.2.2.-UNITED STATES.

Solar ponds of various sizes and for various applications have been built and operated in Illinois, Ohio, New Mexico, and Tennessee. The largest operating solar pond outside Israel is believed to be the 2000 square meter pond at Miamisburg, Ohio. This pond is used to heat the city's swimming pool and recreational hall. Engineering studies of the applications of solar ponds for power production have been published for various sites in the US. Detailed analysis of electric power production have been presented for the

Truscott Brine Lake in Texas, the Great Salt Lake in Utah and the Salton Sea in California.

2.2.2.1.- University of New Mexico.

F.Zagrande and H.Bryant of the Department of Physics and Astronomy of the University of New Mexico (Zagrande and Bryant,1977) provide us with a thorough description of their solar pond. The report reviews the research done to establish operational parameters as well as cost, material and performance criteria to be used for the design and construction of the ponds.

The pond at the University was built in 1975 with a diameter of 15 meters, a depth of 2.5 meters, and bank angle of 34 degrees.(see Figure 2.3). The pit was excavated to about one half of the desired depth and the dirt removed raised the banks to the height desired. The walls were made smooth and compact to prevent possible liner perforation since no insulation separated the liner from the walls. The paragraph on materials reveals that a Hypalon liner 45 mils, 3 plies, with the nylon mesh reinforcement between them was used. Experience with it shows that it softens at 100 degree Celsius but remains hard enough for the purpose. For the evaporation pond a black polyethylene 8 mils thick with no reinforcement was installed directly on sand and dirt. The costs estimated in 1982 dollars are for the 105 square meter of collecting area.

(n) Number of thermocouples at location

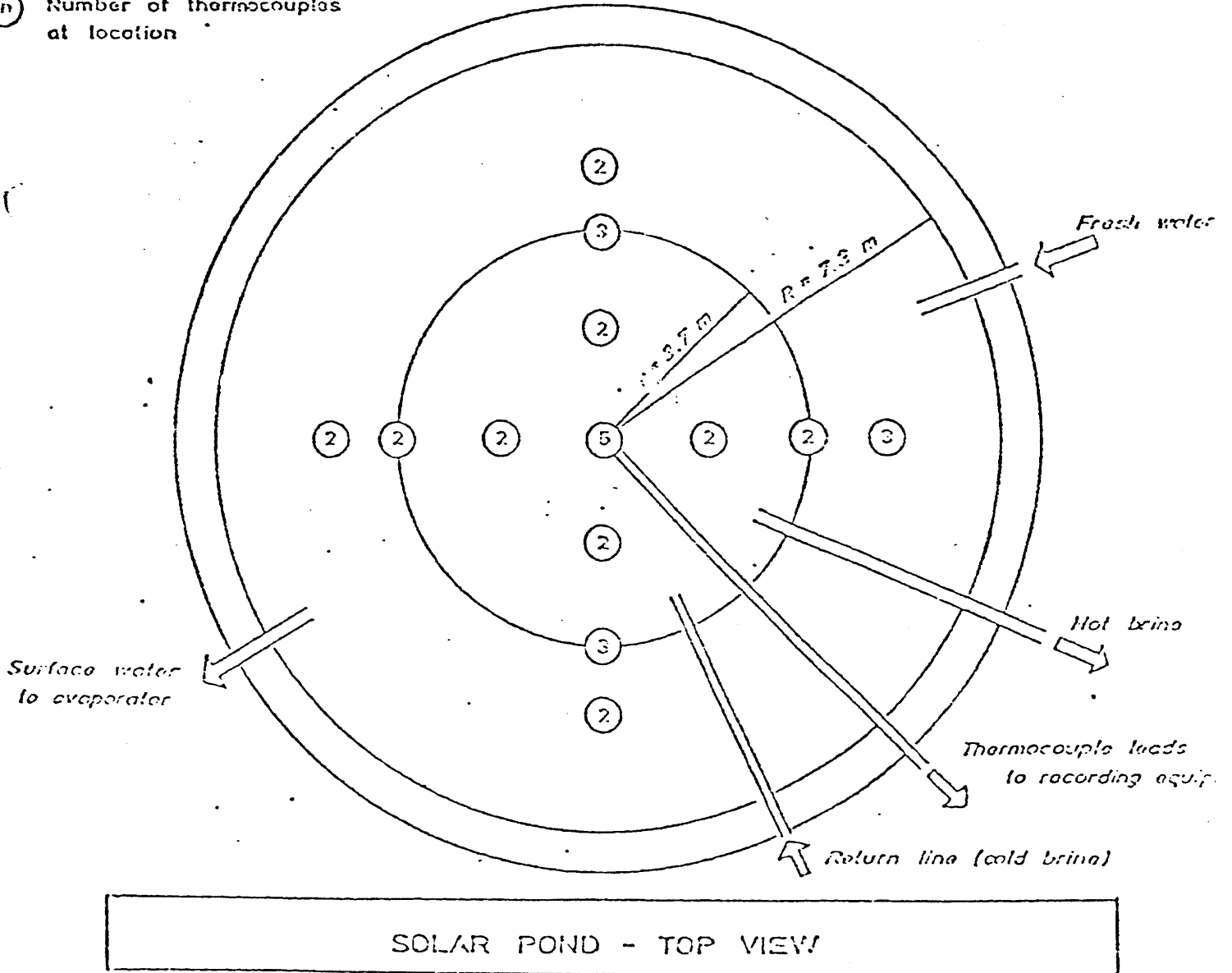


Figure 2.3 : University of New Mexico pond  
(source Lagrando)



|                 |         |
|-----------------|---------|
| 1. Excavation   | \$1,341 |
| 2. Hand Labor   | 596     |
| 3. Liner        | 2,235   |
| 4. Salt 40 tons | 2,086   |
| Total           | \$6,258 |

or 59.6 dollars per square meter.

#### 2.2.2.2.-Ohio State University.

A solar pond of 200 square meter and a depth of 2.5 m depth was built in 1975 at the Ohio State University (Nielsen,1980). The pond was planned to be an economic prototype pond for space heating and was designed according to Ohio State Physicist Carl Nielsen for minimum cost compatible with reliability. The pond has a square configuration and is lined by an 0.8 mm thick nylon reinforced black chlorinated polyethylene. The banks are above the level of the surrounding field. The specified dimensions of the pit were 12 m across the bottom, a 45 degree bank angle and 18 m at the top of the bank giving a 3 m depth to contain 2.5 m of water. The cost to duplicate the pond as described is as follows:

|                 |          |
|-----------------|----------|
| 1. Salt 60 tons | \$3,744  |
| 2. Liner        | 3,725    |
| 3. Other        | 3,874    |
| Total           | \$11,175 |

or 55.8 dollars per square meter.

Maintenance costs were not included in the estimate except for \$50 per year for salt replacement.

#### 2.2.2.3.- Argonne National Laboratory.

The construction and first year's operational results of the Argonne National Laboratory Research pond are discussed in (Hull,1982). The 1000 square meter pond was completed in 1980. The pond is 43m x 25m at the top with sides tapered at 45 degrees to a depth of 4.27 meters. Excavation dirt was used to build a berm above the original ground level and the clay soil was compacted enough to be stable at a 45 degree slope. The liner used is XR5, manufactured by Shelter Rite ( a division of the Seaman Corporation) and was loosely fitted on the soil to provide allowance for ground movement without stressing the liner. A cost of \$80 per square meter for the pond is provided but no cost breakdown for the different components was available.

#### 2.2.2.4.- Miamisburg.

During 1977, the city of Miamisburg, Ohio started construction of what was at the time the largest solar pond in the United States. The pond developed as part of the Miamisburg Community Park Development Project was designed to heat an outdoor swimming pool in the summer and to heat a recreational building in the winter.

The pond has a collecting area of 2000 square meter

and is 54.5 m long and 36.4 m wide. The sides are tapered at an angle of 45 degree to a depth of about 3 meters. L.J. Wittenberg from the Monsanto Research Corporation (Wittenberg and Etter, 1982) not only addresses the construction costs of the facility but also the maintenance costs. These maintenance costs will be reviewed in a later chapter. The cost of the Miamisburg pond amounted to \$76,972 in 1982 dollars. The breakdown of costs is:

1. Salt 1100 tons \$23,974
2. Excavation 12,100
3. Liner 27,830
4. Miscellaneous 14,278

These costs amount to a unit cost of \$38.2 dollars per square meter. The liner and the salt represent the largest capital investment. The liner used is a 0.7 mm thick, chemically resistant polymer coated polyester fabric. The fabric was supplied in sections that were welded during installation in the pond excavation.

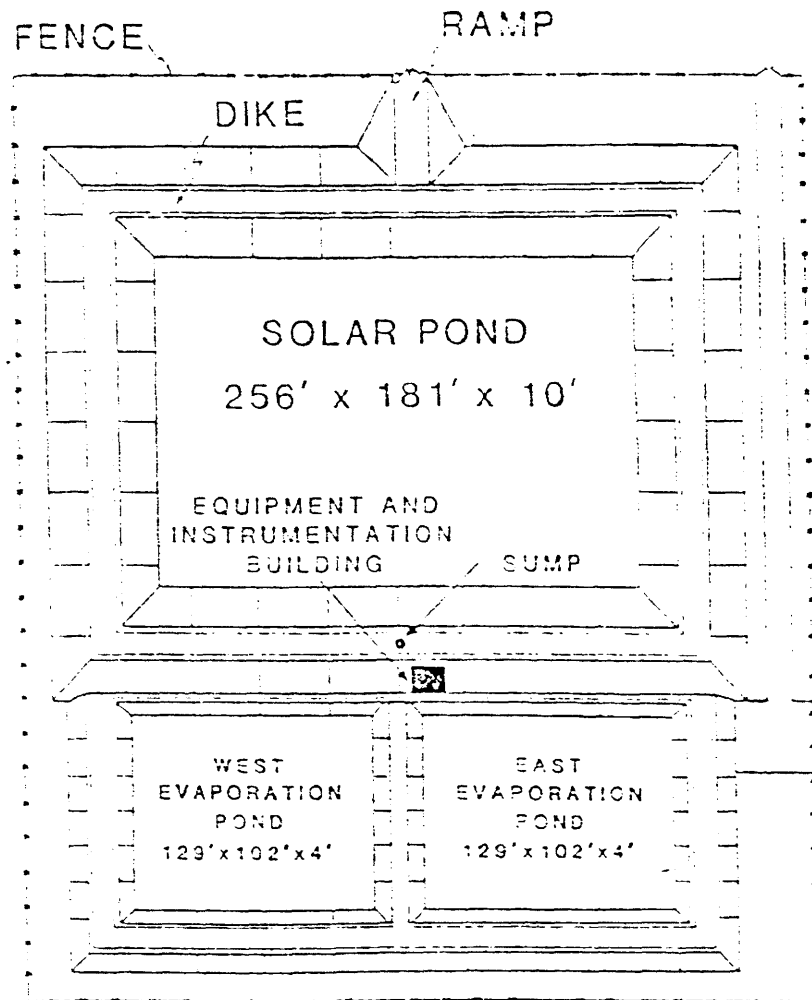
#### 2.2.2.5.- Tennessee Valley Authority (TVA).

The largest pond in the United States is the Tennessee Valley Authority pond near Chatanooga; approximately one mile north of the Tennessee River Chickamonga dam. The 400 square meter pond was constructed in 1981 and 1982 to demonstrate the technical and the economical feasibility of the

non-convecting solar pond concept for producing direct heat for agriculture, buildings and industrial process applications in the TVA region. The environmental concerns in the construction of the pond were zero leakage of brine to the environment and no degradation of the site. The 4000 square meter (1 acre) pond is rectangular with a length of 75 meters, a width of 55 meters, and a depth of 3 meters with a bank angle of 34 degrees.(Chinery and Siegel,1982).

To prevent brine leakage, the TVA pond has the most elaborate liner system using an XR5 primary liner that covers the pond bottom and the interior walls. The primary liner is underlaid by a sand drainage field which increases in thickness. A second leak liner of Hypalon lies below the sand drainage field. Figure 2.4 represents a diagram of the TVA pond and its two evaporation ponds. Table 2.1 represents the design criteria and construction considerations. Table 2.2 represents a breakdown of the costs.

Chinery and Siegel describe the construction of the pond. Site preparation such as clearing trees and removing topsoil was done first and was followed by surveying to lay out the pond dimensions. The excavation of the TVA pond was very easy since few rocks were discovered. Bottom scrapers were used for the excavation and shaping of the pond. Compaction tests were done to obtain the compactibility desired on the dike walls. A normal liner preparation and



PLAN VIEW  
1 ACRE SALT GRADIENT POND

Figure 2.4 : TVA pond

Table 2.1 DESIGN CRITERIA AND CONSTRUCTION SPECIFICATIONS

Location: Chattanooga, TVA reservation land, approximately 1.5 km (1 mi) north of the Tennessee River's Chickamauga Dam, just east of State Highway 153. Latitude = 35°N. Elevation approximately 183 m (600 ft)

Environmental: Zero leakage of brine to the environment. Out of 100-year flood plain. Nondusty environment. No degradation of archaeologically valuable sites.

Topographical, Geological: Original land slope less than 10 degrees. Out of wetlands. No bedrock above or sinkholes below 1.8 m (6-ft) depth. No ground water above 10 m (30-ft) depth.

Estimated annual amount of thermal energy collected, stored, and available for distribution:

$4.9 \times 10^9$  kJ ( $1.4 \times 10^9$  Btu)

Average temperature of LCZ brine:

37°C (approx. 100°F)

Operating temperature range of LCZ brine:

20-50°C (approx. 100-125°F)

Average efficiency of pond:

18-24%

Salt:

Sodium chloride

Mass of salt:

$1.8 \times 10^6$  kg (2,000 tons)

LCZ salt concentration:

$0.206 \frac{\text{kg salt}}{\text{kg water}} = 0.172 \frac{\text{kg salt}}{\text{kg brine}}$

|  | Solar Pond   | East<br>Evaporation<br>Pond                                     | West<br>Evaporation<br>Pond              |
|--|--|---|--|
| Area   | 4000 m <sup>2</sup> (1-acre)                       | 1000 m <sup>2</sup> (1/4 acre)                                  | 1000 m <sup>2</sup> (1/4 acre)           |
| Water depth                                  | 3 m (10 ft)  | 1.07 m (3 ft 6 in.)   | 1.07 m (3 ft 6 in.)                      |
| Distance from bottom of pond to top of dikes | 3.66 m (12 ft)                                     | 1.22 m (4 ft)   | 1.22 m (4 ft)                            |
| Function                                     | Solar energy collection, heat storage              | Take up overflow and leakage, concentrate brine, dissipate heat | Provide fresh water for surface flushing |
| Primary liner                                | HR-5<br>(0.762 mm(0.030 in.))                      | Hypalon<br>(0.762 mm(0.030 in.))                                | Hypalon<br>(0.762 mm(0.030 in.))         |
| Secondary (leak) liner                       | Hypalon<br>(0.762 mm(0.030 in.))                   | --  | --                                       |
| Interior dike slope                          | 34° from horizontal                                | 34°   | 34°                                      |
| Exterior dike slope                          | 18.5° from horizontal                              | 18.5°   | 18.5°                                    |
| Location of intake                           | Approximate center of east and west halves of pond | NW. corner  | NE. corner                               |
| Fixed height of intake above pond bottom     | 1.37 m (3 ft 6 in.)                                | Bottom  | Bottom                                   |
| Location of outlet (discharge) diffusers)    | Center of pond                                     | --  | --                                       |
| Height of outlet diffuser above pond bottom  | Adjustable   | --  | --                                       |
| LCZ thickness                                | 1.5 m (5 ft)                                       | --  | --                                       |
| GZ thickness                                 | 1.2 m (4 ft)                                       | --  | --                                       |
| UCZ thickness                                | 0.3 m (1 ft)                                       | --  | --                                       |

See drawings listed as reference No. 8 for additional construction details.

|                                 | <u>Actual Expenditures</u> |                    |
|---------------------------------|----------------------------|--------------------|
| EVA                             | \$ 64,985.27               |                    |
| Design and Detailed Engineering |                            | 28,367.43          |
| Drafting                        |                            | 4,159.50           |
| Engineering Procurement         |                            | 1,321.43           |
| Construction Supervision        |                            | 1,445.32           |
| Project Cost Estimating         |                            | 705.99             |
| Construction Labor              |                            | 27,500.82          |
| Travel                          |                            | 1,578.50           |
| Major Equipment                 | 207,487.42                 |                    |
| Clearing                        |                            | 1,432.00           |
| Excavation                      |                            | 35,985.00          |
| Gravel Road                     |                            | 9,060.00           |
| Survey                          |                            | 929.00             |
| Testing                         |                            | 1,690.00           |
| Thermo-Borings                  |                            | 204.00             |
| Sand Blanket                    |                            | 24,131.00          |
| Fine Grading for Hypalon        |                            | 1,725.00           |
| Sterilization                   |                            | 1,935.00           |
| Underdrains                     |                            | 10,190.00          |
| Mobilization                    |                            | 2,000.00           |
| Hypalon Underliner              |                            | 27,258.00          |
| Hypalon Evaporation Pond Liner  |                            | 28,020.00          |
| XR-5 S130 Liner                 |                            | 40,675.00          |
| Bonding                         |                            | 3,240.00           |
| Piping, Valves, etc.            | 12,948.00                  |                    |
| Electrical                      | 5,349.07                   |                    |
| Concrete                        | 2,300.76                   |                    |
| Freight                         | 131.19                     |                    |
| Miscellaneous (Fence)           | 10,846.06                  |                    |
| Salt                            | 58,600.00                  |                    |
|                                 |                            | <u>5375,249.02</u> |
| Grand Total                     | \$375,249.02               |                    |

Table 2.2.: Breakdown of pond costs

installation procedure was followed and will be described later. The seams were bonded on site and thoroughly checked resulting in the discovery of many leaks that had to be repaired before the job could go on.

Table 2.3 summarizes the solar ponds in operation and the sites under consideration.



Table 2.3 : Solar Ponds in Operation and Proposed

| LOCATION                                      | DATE COMPLETED | DIMENSION                                 | PURPOSE                                       | COST (installation)   |
|---|----------------|---|---|---|
| Yavne,<br>Israel                              | 1977           | 1500 m <sup>2</sup>                       | Research. 6KWe power generated                |   |
| Ein Bokek,<br>Israel                          | Dec. 1979      | 7000 m <sup>2</sup><br>3 m deep           | Research 150 KWe peak power operation         |   |
| Miamisburg,<br>Ohio, USA                      | 1978           | 2000 m <sup>2</sup><br>3 m deep           | Heating an indoor swimming pool               | \$70,000  |
| Ohio State Univ.,<br>Ohio                     | Aug. 1975      | 200 m <sup>2</sup><br>2.5 m deep          | Study and possible commercialization          | \$7,500<br>Exclusive of research equipment.<br>Salt - \$2,400<br>Liner - \$2,500    |
| Argonne National Laboratory,<br>Illinois, USA | Nov. 1980      | 1080m <sup>2</sup><br>43 m x 25 m x 4.3 m | Research                                      |   |
| University of New Mexico, USA                 | Fall 1975      | 15 m diameter<br>area 105 m <sup>2</sup>  | Research and heating 185 m <sup>2</sup> house | \$5,700<br>Liner - \$1,500<br>Salt - \$1,400<br>+ equipment, labor and construction |
| Tennessee Valley Authority                    | Spring 1982    | 4000m <sup>2</sup><br>3 m deep            | Research, 140 KWT Energy Extraction.          | \$1,640,000<br>(Refer to Table 4.4 for details)                                     |
| Wooster, Ohio                                 | 1975           | 18.3 m x 8.5 m x 3 m                      | For heating a greenhouse                      |   |
| Alice Springs,<br>Australia                   |                | 2000 m <sup>2</sup><br>> 2 m deep         | Research                                      | Not available   |

Table 2.3 : Continued

PROPOSED PONDS

| LOCATION                      | DATE COMPLETED | DIMENSION  | PURPOSE  | COST (installation)                       |
|-------------------------------|----------------|--|--|---|
| Salton Sea,<br>California     |                | 1 km <sup>2</sup><br>5 m deep                      | 5 MWe Demonstration pond   | \$25*10 <sup>6</sup> - 30*10 <sup>6</sup> |
| Salton Sea,<br>California     |                | 12 modules<br>(50 MWe each)<br>106 km <sup>2</sup> | Energy generation<br>600 MWe + salinity<br>reduction of lake   | \$1.1*10 <sup>9</sup>                     |
| Truscott Brine<br>Lake, Texas |                | 80000 m <sup>2</sup>                               | To supply energy for<br>Red River chloride<br>control project<br>1.9 MWe at 15% plant<br>capacity factor | \$5*10 <sup>6</sup>                       |
| New Dead Sea<br>Pond I        |                | 10 acre  | 5 MWe peaking<br>(few hours/week)<br>Research  |   |
| New Dead Sea<br>Pond II       | Fall 1982      | 60 acre  | 5 MWe peaking<br>Research  |   |

CONSTRUCTION COST ANALYSIS

3.1.- Approach.

The approach used to arrive at our findings was twofold: first we identified the cost structure of current solar pond technology. This structure was developed through the review of the literature done in the preceding chapter to identify the major cost components of solar ponds as well as their respective percentages of total construction expenditures. Data from bid abstracts for several classes of heavy construction projects were then used to establish cost curves, to investigate likely variations in costs, and to determine whether economies of scale exist in solar pond construction. Data gained from conversations with material suppliers are also presented for the calculation of construction costs.

The projects for which data was available were reviewed and are listed in Table 3.1. These ponds have a collecting area ranging from 105 to 4000 square meters. Except for the Miamisburg pond which heats a swimming pool, they can all be classified as research oriented ponds. As we have seen from the review the only project for which relevant, well documented detailed construction cost data are available is the Tennessee Valley Authority pond. The other

Table 3.1: Solar Pond Projects Reviewed for Construction Costs

| <u>Name<br/>Date of Operation</u> | <u>Collecting Area<br/>(m<sup>2</sup>)</u> | <u>Shape</u> | <u>Dimensions<br/>(m)</u> | <u>Depth<br/>(m)</u> | <u>Bank<br/>Angle</u> |
|-----------------------------------|--|--------------|---------------------------|----------------------|-----------------------|
| TVA 1982                          | 4000                                       | rectangular  | 75 x 55                   | 3                    | 34°                   |
| Miamisburg 1978                   | 2000                                       | rectangular  | 36.4 x 54.5               | 3                    | 45°                   |
| Argonne Lab 1980                  | 1080                                       | rectangular  | 43 x 25                   | 4.3                  |                       |
| Ohio State 1975                   | 200  | square       | 14.25 x 14.25             | 2.5                  | 45°                   |
| N.N.M. 1975                       | 105  | circular     | Diameter: 15 m            | 2.5                  | 34°                   |

projects give only aggregate or summary statistics; few details on cost itemization or construction procedures. For the Argonne National Laboratory pond, only total construction costs appear in the literature; no further breakdowns have been published. No data could be found on the ponds being built in Hawaii, or the pond at SUNY in Buffalo.

### 3.2.-Cost structure and comparison of existing ponds.

The costs to construct a solar pond are influenced by several factors:

- The site location, land costs and regional construction cost factors;

- The facility scheme (i.e., whether the pond is located in an existing body of water, or is a man made pond;

- The area and the depth of the pond required (for power generation, evaporation, emergency storage);

- Soil properties (related to both excavation and permeability);

- Availability and cost of salt;

- Lining requirements (influenced by both soil properties noted above and environmental and construction regulations); and

- Other facility requirements for security, safety,

monitoring and so forth.

The major cost categories of pond construction were given as follows: land, excavation, liner, salt, and miscellaneous costs. We have conformed to this structure as much as possible. In tabulating the data all costs were in 1982 dollars and have represented the fully installed or as built cost of each item including the labor, equipment and material costs.

#### 3.2.1.- Earthwork.

The earthwork costs include the excavation, haul, compaction, fine grading, and sterilization of native soil or borrow and range from 10% to 20% of total pond construction as shown in Table 3.2. The costs may vary for several reasons, including economies of scale, difference in local site conditions, and variations in local construction rates. More will be said about earthwork in the next section.

#### 3.2.2.- Salt.

The cost of salt represents about 20% to 33% of the total solar pond construction; costs per square meter range from \$11.75 to \$20.00. (All costs per square meter in this report are based upon the nominal area of the pond surface during operation.). Since the expense of salt is determined mostly by the need to transport it from mine to site, the difference in cost must be partially accounted for by the

Table 3.2 : Construction Cost Breakdowns for Existing Solar Ponds

|            | <u>Salt</u> |                         |          | <u>Excavation</u> |                         |          | <u>Liner</u> |   |          | <u>Miscellaneous</u> |                         |          | <u>Total Cost</u>                   |
|------------|-------------|-------------------------|----------|-------------------|-------------------------|----------|--------------|---|----------|----------------------|-------------------------|----------|-------------------------------------|
|            | <u>\$</u>   | <u>\$/m<sup>2</sup></u> | <u>%</u> | <u>\$</u>         | <u>\$/m<sup>2</sup></u> | <u>%</u> | <u>\$</u>    | <u>\$/m<sup>2</sup></u>                   | <u>%</u> | <u>\$</u>            | <u>\$/m<sup>2</sup></u> | <u>%</u> | <u>Square Meter Cost</u>            |
| TVA        | 68,000      | 17                      | 21       | 34,645            | 8.6                     | 10.8     | 150,425      | 37 (for<br>2 liners)<br>18.5 per<br>liner | 47       | 66,789               | 16.7                    | 21       | \$319,859<br>\$/m <sup>2</sup> 80   |
| Miamisburg | 23,974      | 11.75                   | 30       | 12,100            | 6                       | 15.8     | 27,830       | 14  | 36       | 14,278               | 7.2                     | 18.6     | \$76,972<br>\$/m <sup>2</sup> 38.2  |
| Ohio State | 3744        | 18.78                   | 33       |                   |                         |          | 3,725        | 18.62                                     | 33       | 3,874                | 19.37                   | 34       | \$11,175<br>\$/m <sup>2</sup> 55.88 |
| U.N.M.     | 2086        | 19.8                    | 33       | 1,341             | 1275                    | 21       | 2,235        | 21.3                                      | 35       | 596                  | 5.7                     | 9.5      | \$6,258<br>\$/m <sup>2</sup> 59.6   |

distances to the nearest salt supplies and by slight differences in salt concentrations.

### 3.2.3.- Liners.

The liner costs consist of the sand blanket, underdrains, liner and underliner. These costs vary from about \$14.00 to \$21.00 per square meter and represent 35% to 47% of the total cost. The difference in cost is best explained by the thickness and quantity of liners used. Although economies of scale exist in liner installation, the larger ponds may need more refined and elaborate systems for environmental protection, and unit costs will rise. The use of an underliner and a sand blanket underneath the liner at TVA is a prime example of the growing importance of liner protection and increasing share of costs.

### 3.2.4.- Miscellaneous costs.

Testing, supervision, travel, borings and fences are included in the miscellaneous category. These costs will grow as pond size increases, and more extensive testing will be required. A more elaborate fence and a security system might be needed to prevent accidents and keep away vandals and animals out.

The composition of construction costs for the several ponds reviewed is shown graphically in Figure 3.1.



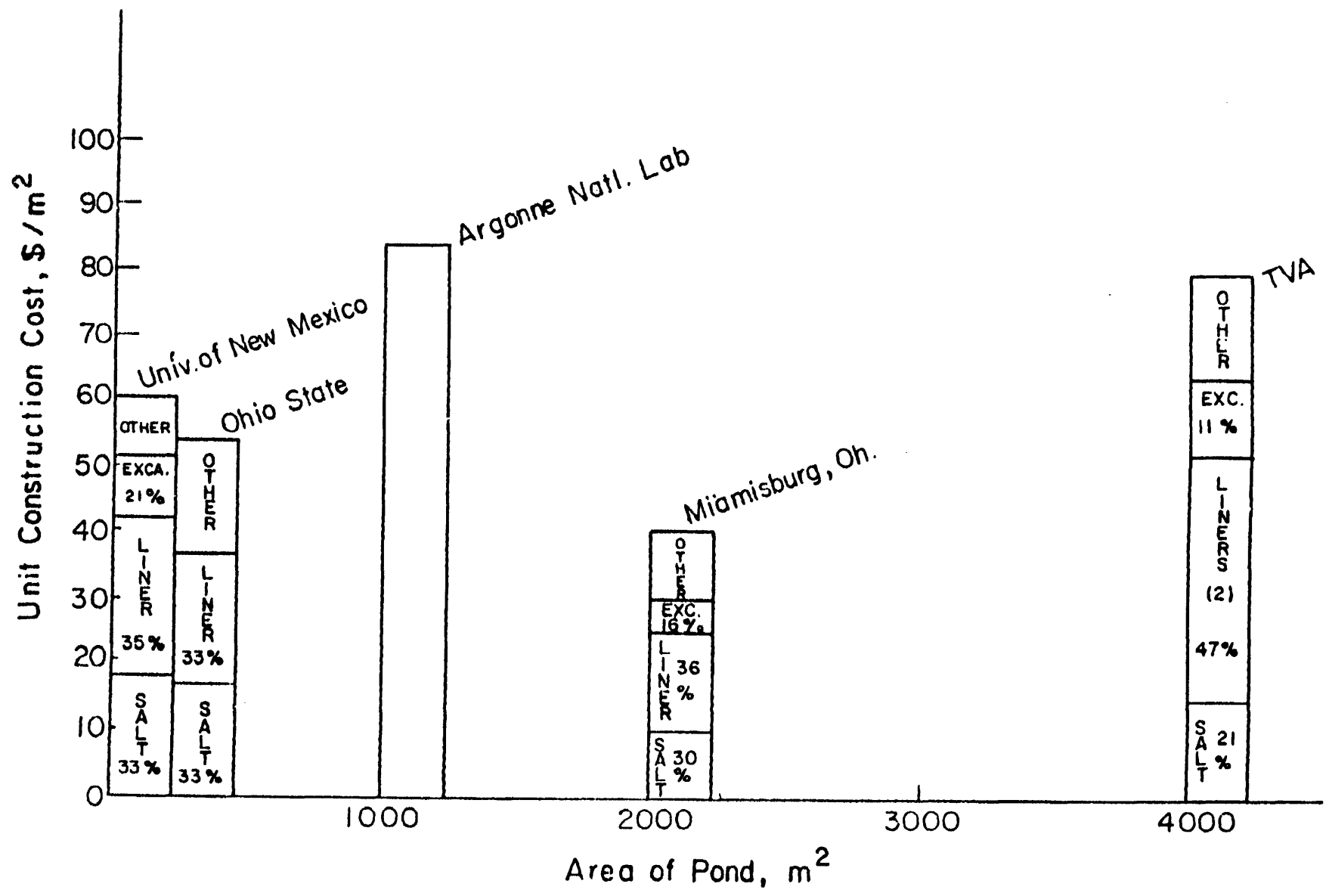


Figure 3.1. : Cost breakdown of existing ponds

### 3.3.- Categorization of proposed ponds.

The pond projects reviewed gave us a preliminary indication of the components required for construction and their relative costs. However these costs cannot be reliably extrapolated to ponds of much larger dimensions (e.g.  $10^{EE+6}$  square meters or more) for the following reasons:

- Existing ponds were intended for research and experimentation. Larger ponds, intended as demonstration projects, or as production power plants, must be build to withstand natural or man made hazards and to meet public safety and environmental standards, engineering or building code provisions, and efficient operational requirements.

- An increase in pond size may in itself require additional facilities (e.g., wind and hurricane protection, more stringent security, more elaborate monitoring systems), which would alter the cost structure.

- Larger ponds may present economies of scale or diseconomies of scale, thereby altering the cost structure already observed. Also, the unit costs of some items may change over time due to the increased scale of protection and progress along the learning curve.

As a result, we found it useful to distinguish among different orders of magnitude of solar pon facility size as follows:

1. Research ponds            0 - 10<sup>4</sup> m<sup>2</sup>
2. Demonstration ponds 10<sup>4</sup> - 10<sup>6</sup> m<sup>2</sup>
3. Production ponds        greater than 10<sup>6</sup> m<sup>2</sup>

These are intended as very rough classifications, simply to attempt to account for major differences across projects of various scales. For example, all the ponds built today in the United States fall under the first consideration. Some proposed projects would be considered under the scheme either as demonstration ponds (e.g., proposed 40,000 square meter TVA pond) or as production facilities (e.g., Salton Sea project).

#### 3.4.- Construction scenarios.

In the realm of demonstration and production ponds, different designs must be envisioned to account for all the possibilities encountered in pond construction. The two broadest designs can be categorized as follows:

The first will be a site specific design involving an existing salt lake, which will significantly reduce the construction cost of solar ponds since little or no excavation will be needed and salt will be available on site. The second design encompasses the total construction needed to build the solar pond.

Figure 3.2 details the different solar pond construction alternatives. Once the location of the site is accepted, the following cost considerations occur. Materials on site can be used if they are suitable otherwise they will have to be imported from other locations. When it comes to dike construction, if we use an already existing salt lake, the excavation cost will be minimal compared to the construction of dikes at the perimeter of a man made pond. If the construction of the pond is the alternative, a distinction between using the earth available on site for the dike and the use of a borrow pit must be made.

The use of the liner is an important aspect of the pond construction since it represents a high percentage of the total pond investment. Three possibilities exist:

- In case of an already existing salt lake, no liner may need to be used rendering land preparation very limited and reducing by a high percentage the cost of the facility.

- The second alternative is the use of a clay liner. These liners will require a lot of testing and preparation to obtain the required clay compactibility to ensure minimal land penetration, but should be less costly than the third alternative.

- The synthetic liners require a great deal of preparation and installation but offer a much higher

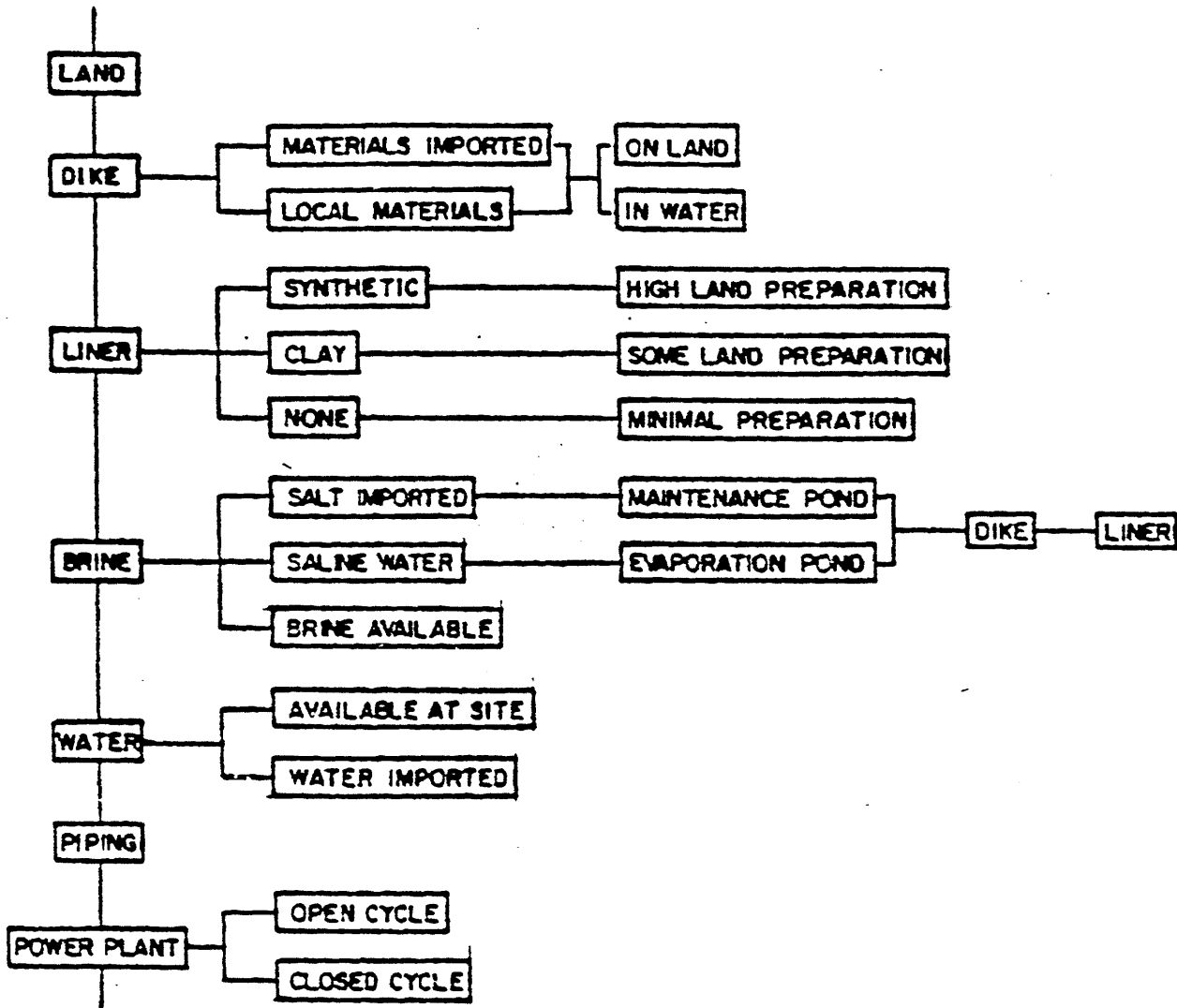


Figure 3.2. Factors in the Selection of a Solar Pond System

permeability than clay liners.

Another aspect in pond construction is the availability of salt. The cheapest solution is the availability of brine near by. In the case of an already existing salt lake, an evaporation pond and a maintenance pond will be necessary to ensure the operation of the pond , and will increase the cost of the pond. Finally, the most expensive solution will be the importation of salt from a mine requiring the need for a maintenance pond. In any case, for the last two alternatives some dike and liner construction will have to be considered.

Water if not available on site will have to be imported. Choices will also have to be made concerning the piping and between an open or closed cycle power plant.

### 3.5.- Projection of construction costs.

Because of the absence of any historical guidance for estimating costs of large pond facilities, the projection of cost trends were based not only upon the data on existing ponds described earlier but also other sources primarily cost data from heavy construction projects employing related techniques or material. and interviews with suppliers of liners.

#### 3.5.1.- Excavation.

Solar ponds are cut-and-fill excavations and their shape will most certainly be dictated by the topography of the site where they are located. The excavated soil is graded into embankments that add to the height of the walls. From a civil engineering viewpoint, earthdam technology is directly applicable (Fynn and Short). The wall slopes must be compacted and pitched to avoid slumping. The soil must be compacted in order to form a firm base for the liner, to support pressure from the fluid and resist wave action on the pond surface. The slope ratio, soil type, degree of compaction needed, and proximity of the water table will vary with location and influence the design phase. It is important to realize that the pond should not be located in a watercourse, a lakebed, or other depression where flooding could occur. Any pond adjacent to such depressions should be located above the highest possible water levels.

#### 3.5.2.- Site preparation.

The soil should be compacted in a similar way to that of the soils used for road construction. The sidewalls and the slopes away from the sidewalls should all be well compacted to avoid later movement and subsidence and ensure a correct liner installation. The base of the pond needs proper preparation to remove all rocks and any debris (Personal communication with Hypalon manufacturer). This entails raking, compacting and rolling the pond slopes after grading.

Soil compaction should run 90 to 95% Proctor and should retain stability wet and dry (Ibid). If roots are present and vegetation has been growing, a soil sterilizer should be used to prevent any such growth. A layer of sand may be used to smooth out a rough surfaced or rocky substrate bottom.

### 3.5.3.- Earthwork costs.

Using 1983 bid data for highways, dams and waste water excavations, an average excavation cost of about \$2.60 per cubic meter was obtained and shown in Figure 3.3 . These bids were taken from 1983 Engineering News Record bid abstracts (ENR, 1983 issues). The winning bid was consistently used and no apparent trend in the scatter of data points shown in Figure 3.4 appeared.

However, these costs vary from about \$1.00 to 3.00-4.00 per cubic meter depending upon the difficulty of the soil to be excavated, the construction technology used, and bidding practices which may bias the observed data. One might expect that for favorable soil and construction conditions, earthwork costs would be about \$1.00-1.50 per cubic meter; approximately this value has been estimated by Ormat for the Salton Sea project (Ormat, Feasibility Study). Considering the diversity in soil conditions throughout the country, some variation in earthwork costs should therefore be expected. Furthermore, in building and protecting the dikes to contain a solar pond, additional features are



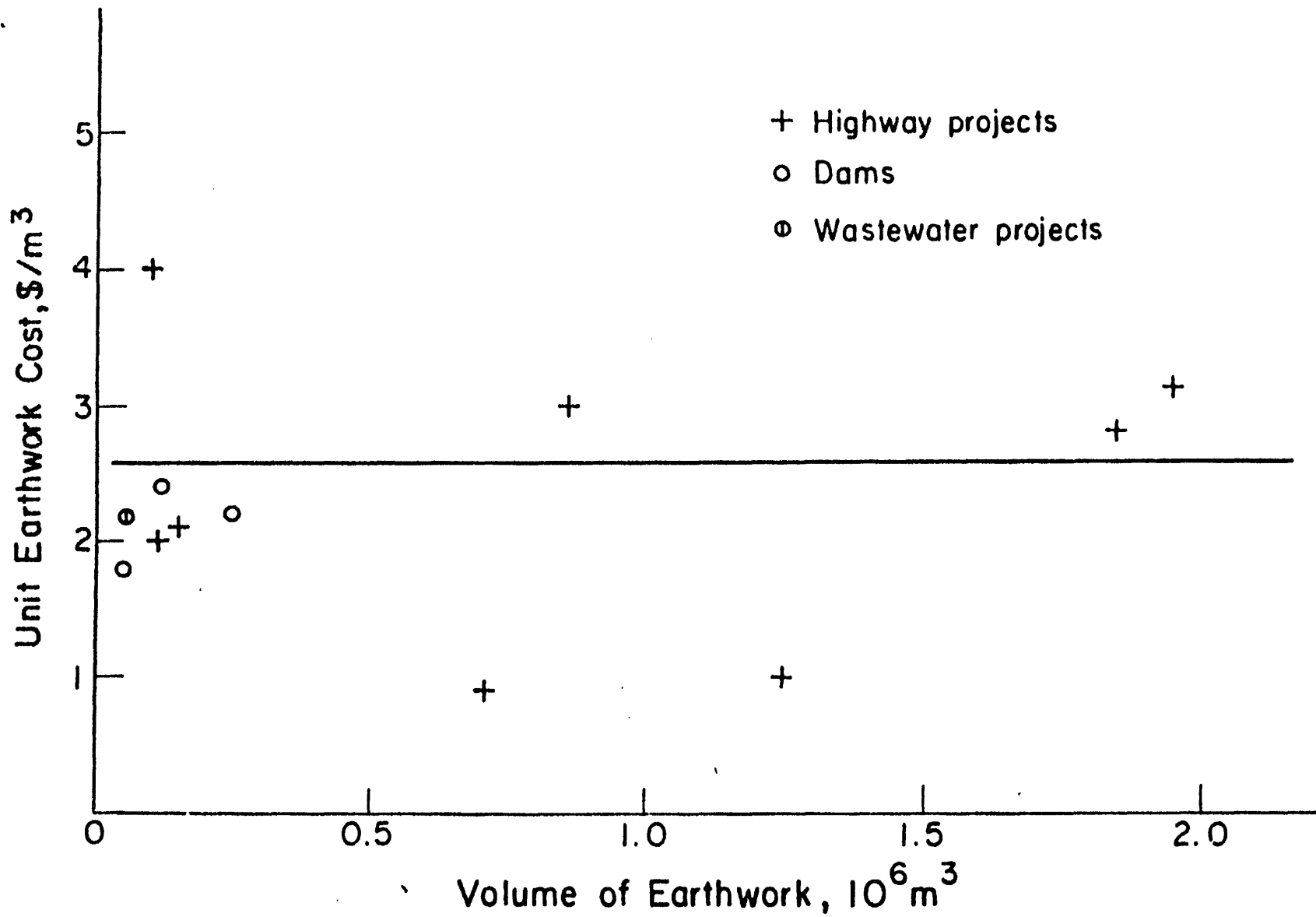


Figure 3.3 : Projected unit excavation costs.

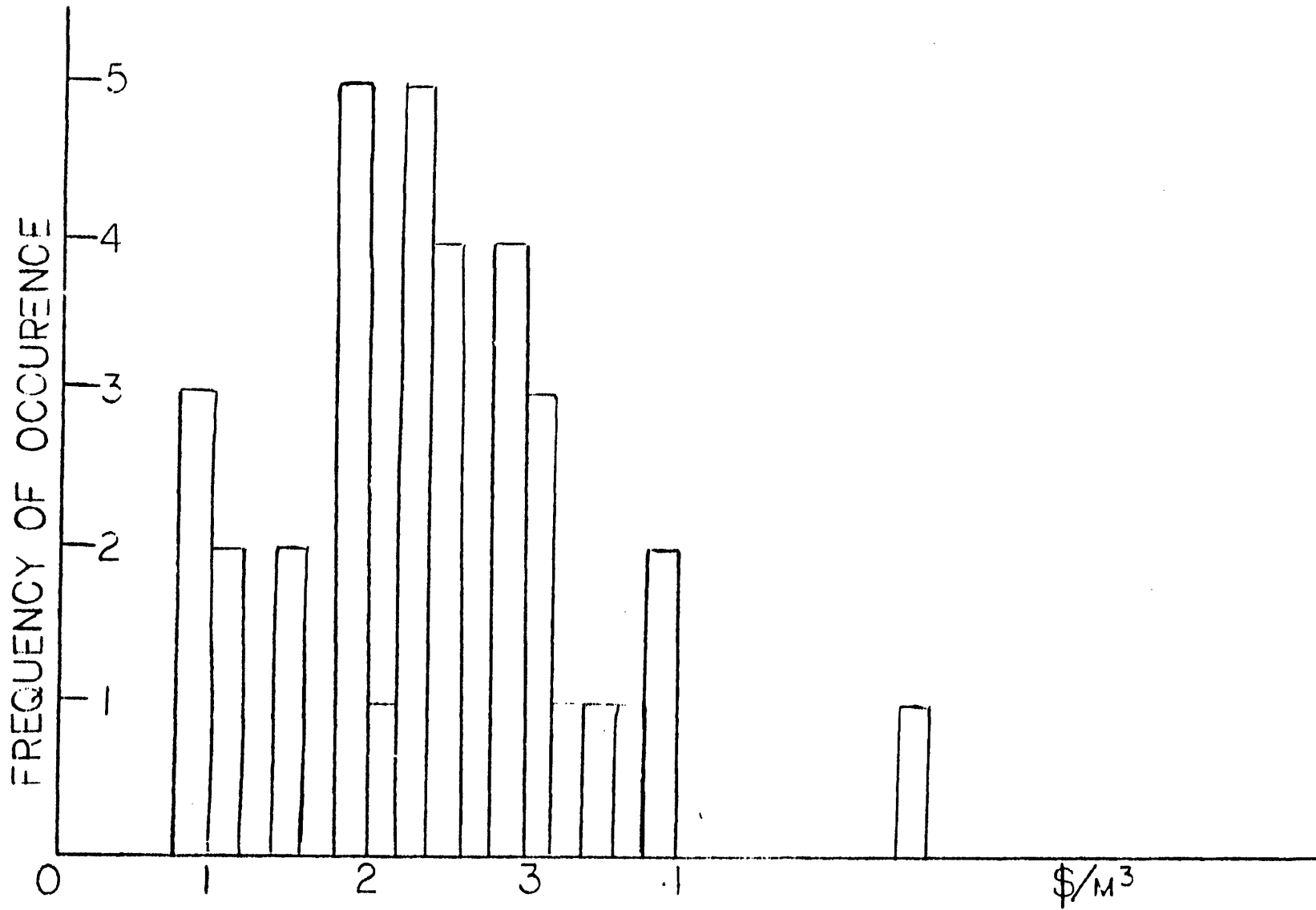


Figure 3.4 : histogram of projected unit excavation costs

required such as riprap, access roads, excavation cut-offs, etc. The additional cost of these construction items has been estimated at from \$1.00 to \$2.25 per cubic meter of dike construction (Ormat, Feasibility Study). Economies of scale with respect to the pond size may be expected in certain conditions. These situations are dependent upon site conditions as described in the next paragraph.

#### 3.5.4.- Site conditions and economies of scale.

As seen in Figure 3.3 there is no apparent engineering or construction basis for identifying economies of scale since the unit cost of the earthwork remains constant over a wide range of earthwork volume. However, since dike construction is proportional to the perimeter of the pond, while the power output is proportional to the pond area, we may expect economies of scale in earthwork costs due to these geometric arguments.

In general, the unit cost of dike construction would be expected to decrease with the square root of the pond area. This premise is shown by the following equations and leads to the curve in Figure 3.5 for the dike section shown.

Assume a dike cross sectional area  $A_c$

For a pond with collecting area  $A_p$  and perimeter  $P_p$ , the volume of earthwork needed is:

$$V = A_c * P_p \quad (1)$$

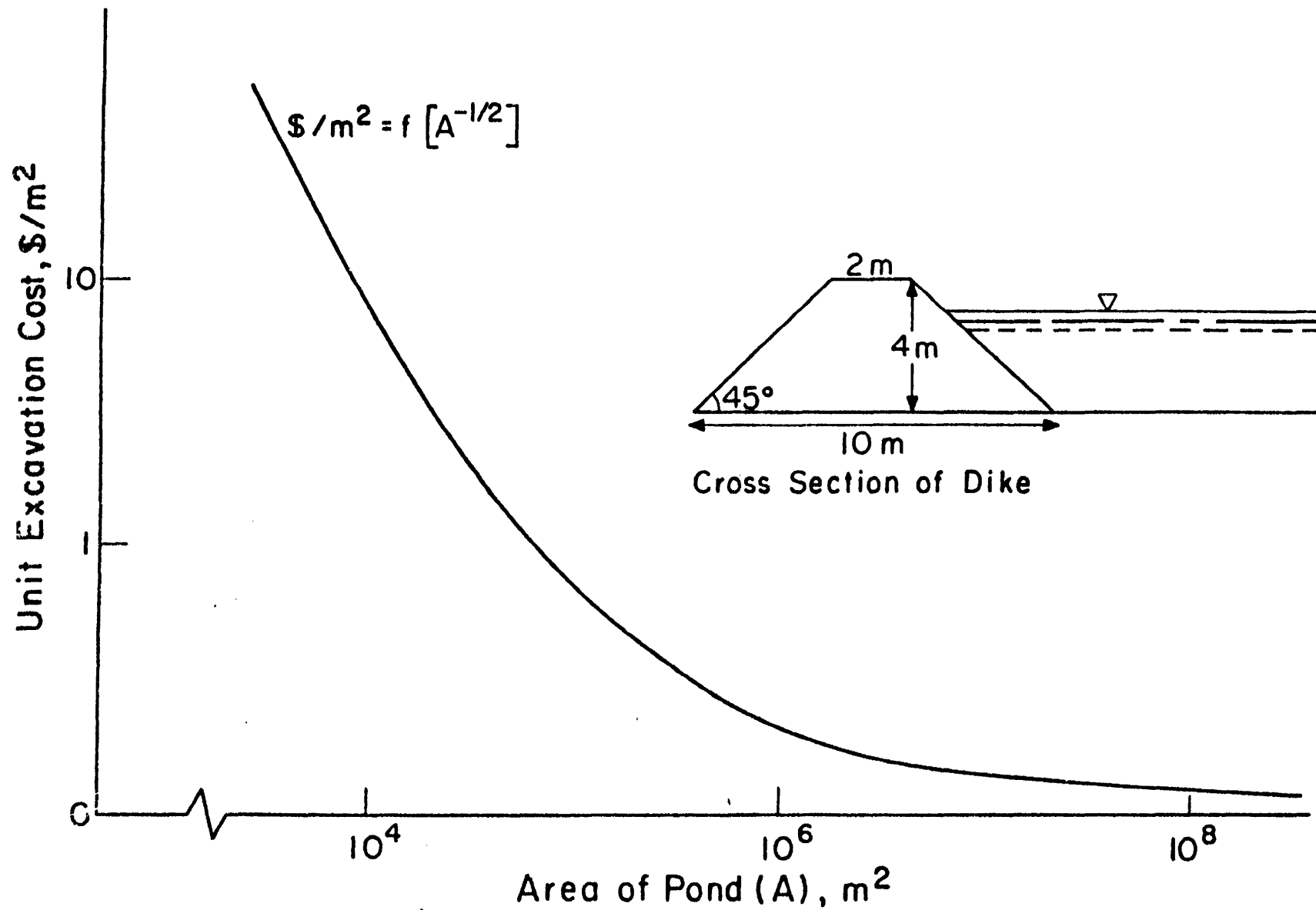


figure 3.5. : Pond area v.s. excavation costs for dike construction

The cost of earthwork per cubic meter is  $C = \$2.60/m^3$

The total cost of earthwork is thus:

$$TC = V * C = A_c * P_p * C \quad (2)$$

The cost per unit collecting area is:

$$UC = A_c * P_p * C / A_p \quad (3)$$

Assuming a solar pond to be square with a side of length  $S$ , the perimeter of the pond can be denoted by:

$$P_p = 4 * S$$

and the area  $A_p$  as  $S^2$ ;

Equation (3) becomes:

$$UC = A_c * 4 * C / S \quad (4)$$

The following graphs show these calculations for the particular dike cross section shown. As the cross sectional area of the dikes increases, the unit cost of excavation increases for each respective pond area. The large dike cross sectional area has a top width of 10 meters making it possible for the construction of a monitoring road on which small trucks can check and repair the pond.

Although the unit cost of dike construction would be expected to decrease with the square root of the area, some

earthwork will also be expended to level the basin of the pond, grade it, remove rocks and other debris and so forth; and these costs vary in proportion with the area of the pond. To make these calculations we have assumed different depths:  $d$  for leveling.

For small ponds, it is likely that the earthwork attributable to leveling will be less than or equal to the earthwork needed for dike construction as shown in Figure 3.6. In these cases the two earthwork volumes balance, or some gravel must be imported from a borrow pit to complete dike construction. The point where earthwork volumes are equal is when the leveling volume equals the excavation volume.

$$A_p * d = A_c * P_p \quad (5)$$

For a square pond,

$$S^2 * d = A_c * 4 * S \quad (6)$$

The leveling depth equals,

$$d = A_c * 4 / S = A_c * S * 4 / \sqrt{A_p} \quad (7)$$

As the sides  $S$  increase and assuming that the cross sectional area of dikes is constant as collecting area increases, it is likely that for even very small depth of leveling (i.e., for small values of  $d$  in Figure 3.6), earthwork requirements to level the basin area may exceed the volume of earthwork needed for dike construction.

The implications of this conclusion are that site

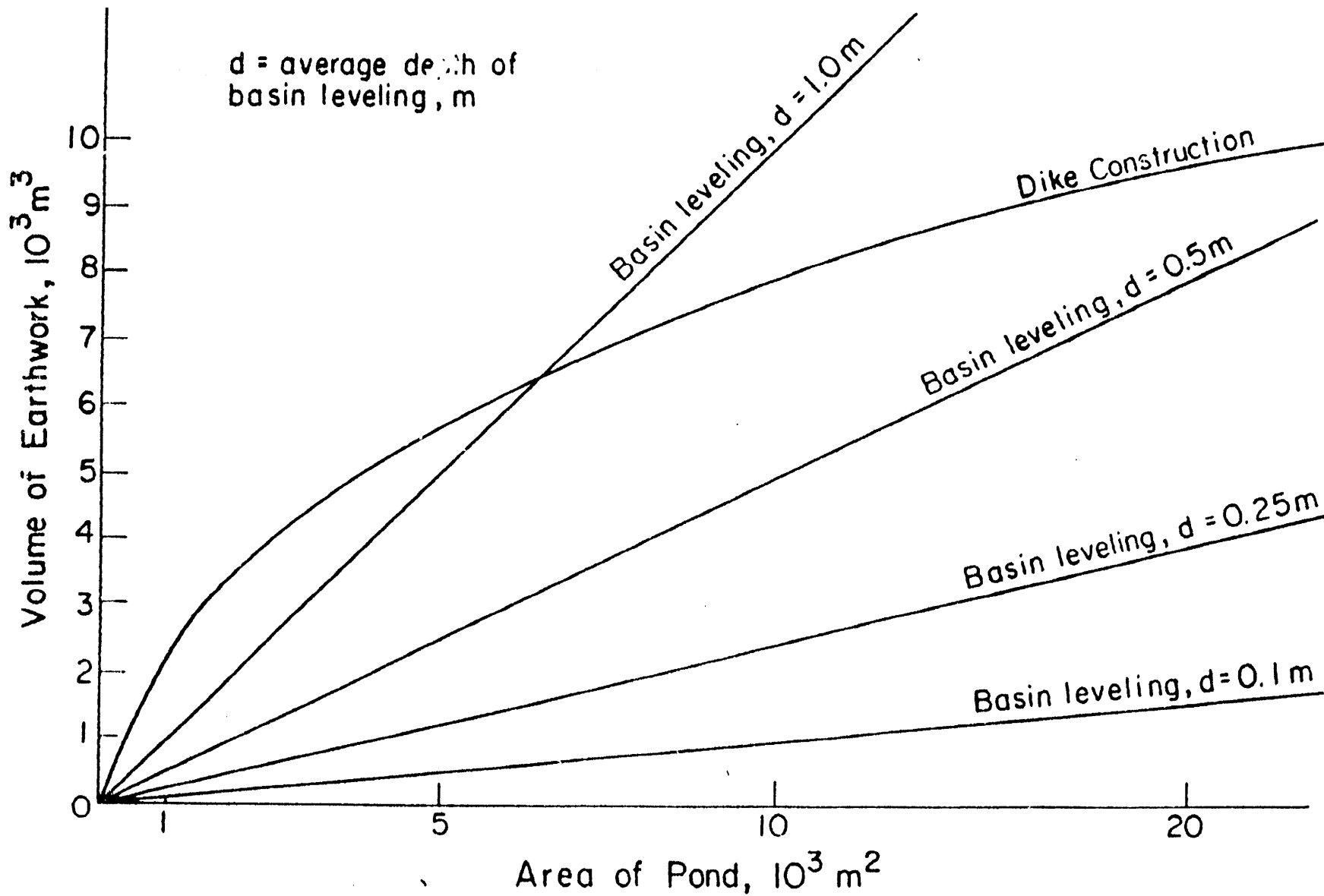


Figure 3.6 : excavation volume - Dike construction and basin leveling

specific characteristics become increasingly important for large ponds regarding excavation and presumed economies of scale may not always hold. Therefore from the point of view of earthwork, the most economical site is a wet or dry site where little or no dredging is required.

#### 3.5.5.- Dredging costs.

In wet sites, it may be necessary to dredge sediments at the bottom of the existing lake, either to provide the depth required for a solar pond or to remove soil which might later contaminate the pond and reduce water clarity. The dredging is done from a dredge which is a floating machine for loading and hauling materials from beneath the surface of the water or from beneath the existing water table in water bearing materials.

The costing practice is the cubic yard bank measurement also called cubic yard apparent volume (Church, Excavation Handbook). The unit costs of dredging vary with the type of soil being removed and the method of dredging used; therefore, they are site specific and can exhibit a range of values depending on local conditions.

This point is illustrated by the variation in unit costs of dredging cited by Ormat, ranging from \$0.80 per cubic yard for unconsolidated sediments to \$1.50 per cubic yard for clayey loam. These costs are in general agreement



with an estimate of \$1.05 per cubic yard (in 1978 dollars) calculated from the Excavation Handbook. Updating these costs to 1983, and converting cubic yards to cubic meters, result in a unit dredging cost of about \$1.20-\$2.20 per cubic meter (based on Ormat) or \$1.80 per cubic meter based on the heavy construction data.

#### 3.5.6.- Salt.

Various types of salt can be used in solar ponds. The most common being (NaCl) Sodium Chloride. If salt is purchased, it is recommended that Sodium Chloride be used with a purity of 99% (Fynn and Short).

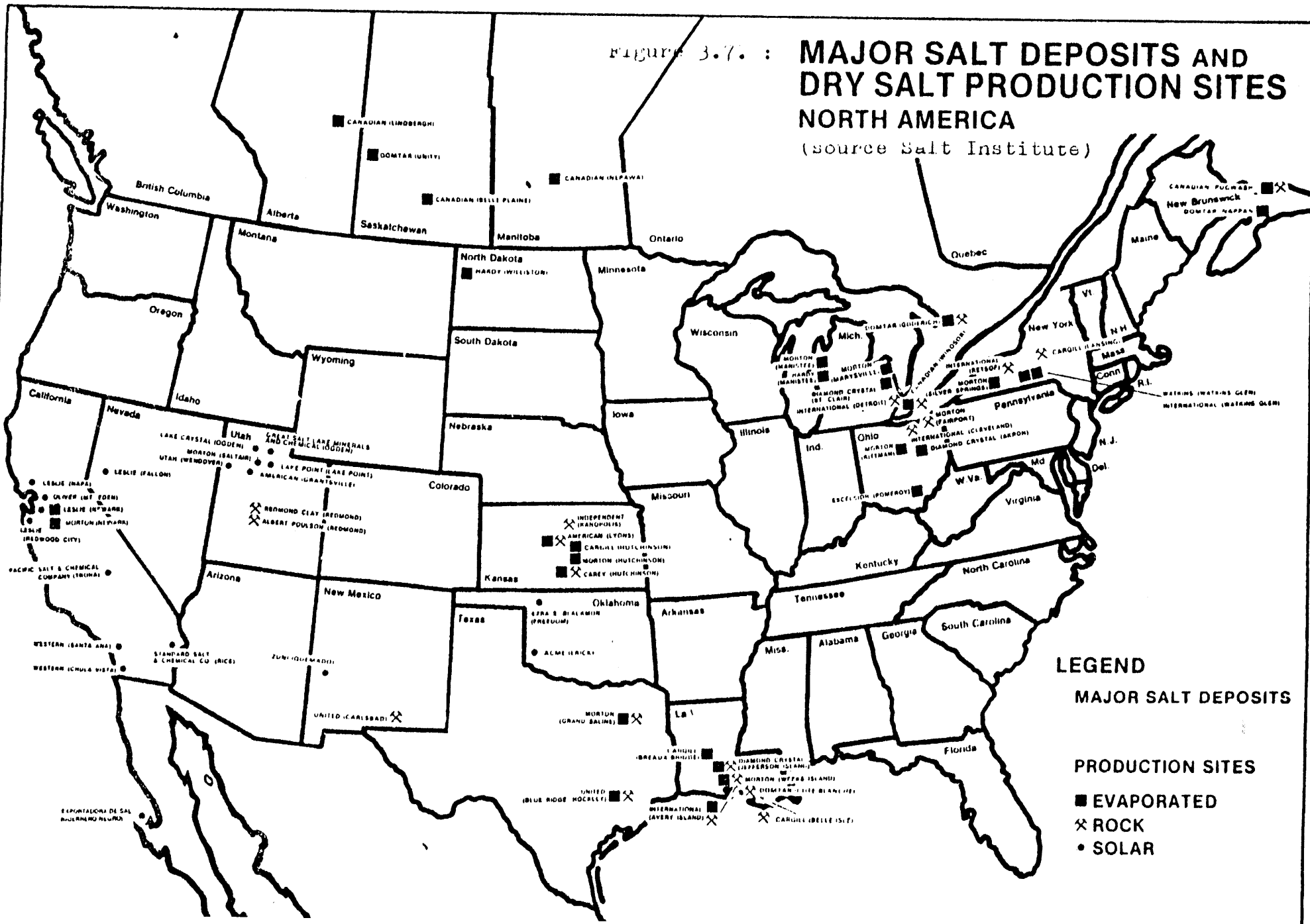
The characteristics of salt used in a solar pond should include low cost, ease of transportation to the site, and availability in an amenable form. Salt costs were estimated from existing ponds and delivered costs from suppliers to \$17 per square meter. These costs will fluctuate depending upon the transportation requirements.

Figure 3.7 is a map of salt deposits in the United States obtained from the Salt Institute of America. Areas with salt deposits are the South (Texas, Louisiana.....), the West (California, Nevada, Utah, Arizona, Wyoming, Montana and the Dakotas). Some of the Northern Industrial States also have salt deposits.

Many proposed solar pond projects are located at sites

# FIGURE 3.7. : MAJOR SALT DEPOSITS AND DRY SALT PRODUCTION SITES NORTH AMERICA

(source Salt Institute)



**LEGEND**

MAJOR SALT DEPOSITS

PRODUCTION SITES

- EVAPORATED
- ⊗ ROCK
- SOLAR

where salt is readily available from existing bodies of water; in terms of construction, this situation should be the most economical way of obtaining salt.

#### 3.5.7.- Land.

Although some data are available on residential land costs and in specific areas of the country, no nationwide source of data on costs of land in rural or non-inhabited areas (where large ponds are likely to be built) could be identified. The reports reviewed for both existing and proposed ponds did not include land as a cost item. Therefore, land costs have been excluded from the estimates prepared below.

#### 3.5.8.- Liner.

The liquid in the solar pond must be contained properly to prevent heat loss to the ground and leakage to the ground water. If this containment is not absolute, the salt solution will be lost and pollute the ground water. Furthermore, these losses will seriously reduce the thermal efficiency of the pond (Tabor, Zagrande).

The two types of liners used for seepage prevention are membrane liners and soil liners. Membrane liners are manmade materials that have a low permeability (less than  $10^{-9}$  cm per second) and are relatively easily installed. These liners can resist chemicals and ultraviolet radiations.

Soil liners are much more likely to let water and salt leak into the soil beneath the pond. Many of the soil lining materials should not be used for salt gradient solar ponds. This conclusion reached by the Burke Rubber Company, manufacturer of Hypalon, states that compacted soils, swelling clays like bentonite, and native clays are not impermeable to high temperature saturated salt brine solution. The advantage of a soil liner is usually its price compared to the price of a synthetic liner. But, in order to use soil liners, their permeability will have to be reduced dramatically (Burke, Fynn and Short). More research has to be done, and at present the state-of-the-art dictates the use of synthetic liners for manmade ponds.

Salt gradient solar ponds present special problems in liner design that are not often encountered together:

- The liner must be resistant to salt brine and be heat resistant;

- The serviceability of the liner must be from temperatures below 0 to temperatures well above 100 degree celsius;

- The liner must be reliable and easily repairable. Thus proper selection of the impermeable liner is essential to the widespread use of salt gradient solar ponds.

Synthetic liners have been used in such applications

as containment reservoirs for potable water supplies, temporary storage of brine from underground salt domes, waste treatment or containment of various products. The industry leader is E.I. Dupont which is the main supplier of raw materials for the liners.

The membrane liners that have been used most successfully to date for solar ponds in the United States are Hypalon ® by Burke Rubber Company and XR-5 © by Shelter Rite. Other liners include HDPE (high density polyethylene), CPE (chlorinated polyethylene), EDPM (ethylene propylenedienomomer ).

Table 3.3 shows the liners that have been used for solar pond construction in North America.

#### 3.5.9.- Liner installation.

The liner is usually anchored at the perimeter in an anchor trench at the top of the berm. The trench must be dug around the perimeter of the pond and is usually one foot wide by two feet deep. Dirt from the trench excavation will be used to backfill once the liner has been tucked in the trench. This is illustrated in Figure 3.8 .

The liner panels are generally accordion folded and rolled on a core. They are then packaged and identified for proper placement around the pit. The manufacturers recommend that the panels remain covered and protected from direct

Table 3.3: Fond liners used (primary liners)

| <u>Location</u>          | <u>Date</u> | <u>Liner</u> |
|--------------------------|-------------|--------------|
| Ohio State University    | 1975        | CPE          |
| University of New Mexico | 1975        | Dypalon      |
| Miamisburg               | 1978        | XR5          |
| Ohio State University    | 1980        | XR5          |
| Argonne                  | 1980        | XR5          |
| EVA                      | 1981        | XR5          |

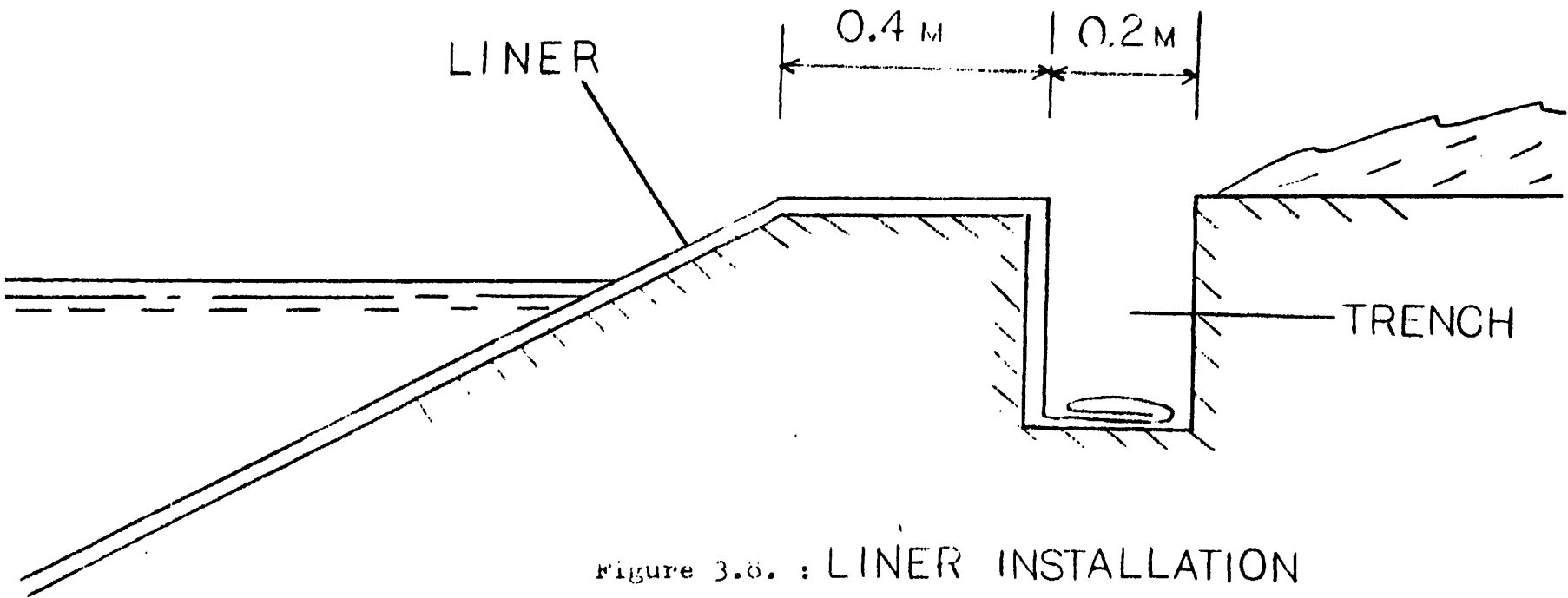


Figure 3.6. : LINER INSTALLATION

sunlight until they are ready for spreading. Only the panels for the day's field seaming should be spread each morning and sand bagged until the seaming is completed.

The lining materials differ in temperatures needed to have the proper sealing. It is often necessary to use hot air guns or other sources of heat to make a proper field joint. Usually, the bonding solution develops a bond quite rapidly but full strength is not attained until all the solvent diffuses through the membrane into the atmosphere. This may take a week but sufficient strength is generally obtained in half an hour to continue on. Covering the base of the liners at all times with just a few inches of water is recommended once the liner seaming is complete since this will stabilize the liner and hold it in place especially in the case of high winds (Burke Company).

#### 3.5.10.- Liner material costs.

The liner costs were obtained through communications with liner suppliers (Burke Company, Shelter Rite). These costs are for liners placed in a reasonable straight forward rectangular area with evenly sloped sides. The costs include installations and freight and assume a reasonable traveling distance.

As was discussed above, the liners are prefabricated as panels in the factory and are bounded on the site. Hypalon



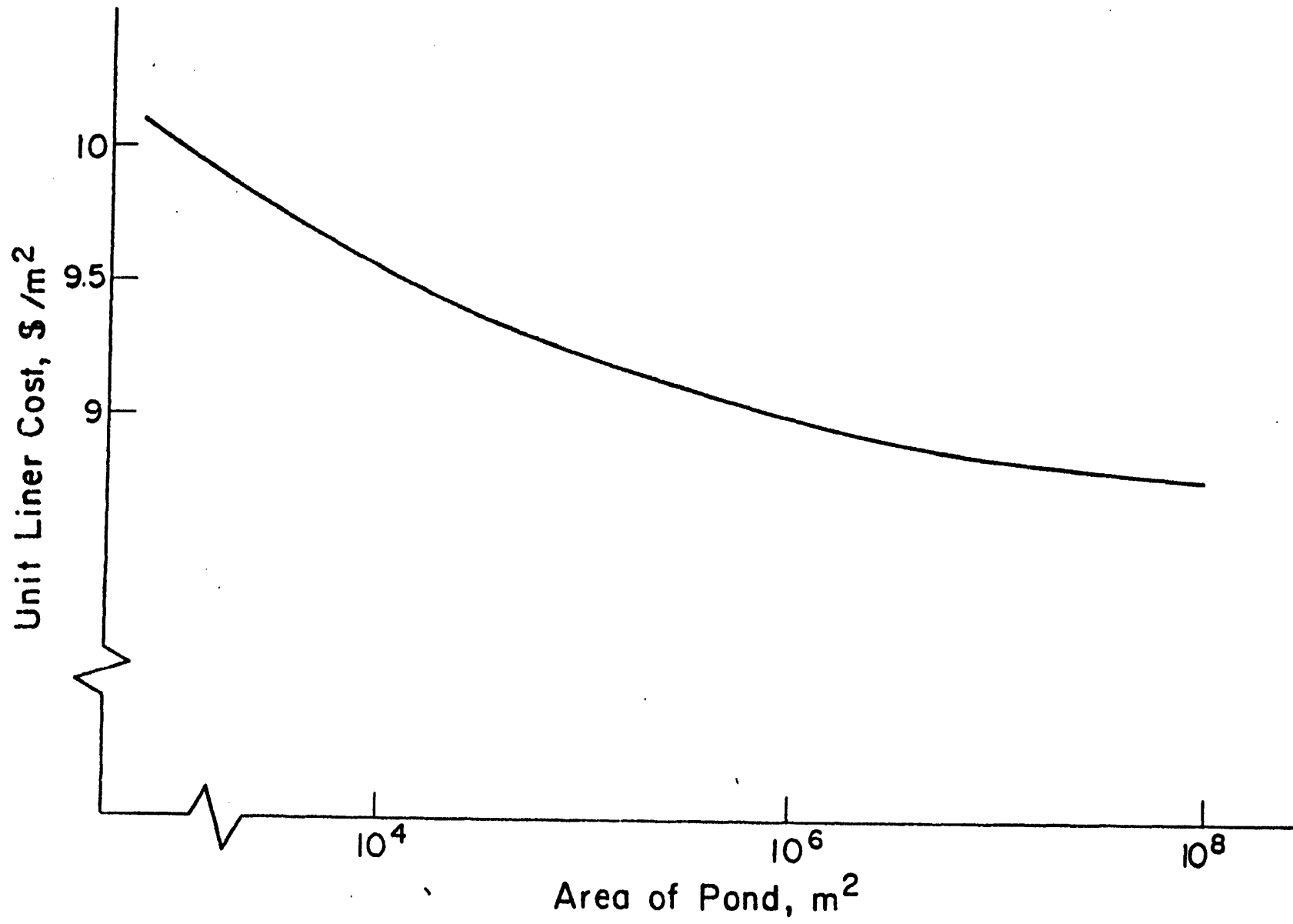


Figure 3.9 : Liner costs as a function of solar pond size

is cheaper but thinner and less resistant to rupture than XR-5. With the thin geotextile fabric generally added to protect against punctures, abrasions and gas venting, the two liners have an equivalent cost of \$10.00 per square meter for a 50,000 square meter pond. Economies of scale will reduce the costs to \$9.50 for a 100,000 square meter pond and to \$9.00 per square meter for one million square meters as shown in Figure 3.9 .

Liner costs represent an important percentage of the total pond investment. Every effort should be made to develop cheaper materials or construct a pond in a specific site where no liner would be needed. In such event, the cost savings of using a clay liner with a high permeability rate could be substantial.

#### 3.5.11.- Miscellaneous costs.

The miscellaneous cost category includes fence, detection systems, road and any other component deemed necessary for the construction and operation of the pond.

For security reasons, it is considered advisable to provide fencing immediately surrounding the pond. The fence will keep vandals out and prevent accidents.

Many states require a leak detection system to monitor the lining integrity. The options of an underliner electrical resistivity grid, a probe or other leak detection system or

alarm should be given consideration during the design phase. In the TVA pond for example, a leak detection system was installed in the drainage field (Chinery and Siegel). The system consisted of a 10 x 10 grid of bare copper conductor insulated at crossover junctions. The brine leakage to the ground should be detected and found by measuring a drop in the electrical resistance of two adjacent conductors. Gypsum block moisture sensors and linear vertical thermocouple arrays were also installed in the sand drainage field.

These miscellaneous costs are hard to estimate since they are site specific. Ormat, the company that made a feasibility study of the Salton Sea estimated for both the 5 Mw and the 600 Mw plant that the miscellaneous costs ranged from 10 to 13% of the construction cost items discussed above (earthwork, dredging, salt, liner). Therefore for purpose of this study, a value of 12% of the construction costs described above has been assumed to cover miscellaneous costs.

### 3.6.- Construction cost summary.

Figure 3.10 illustrates the variation in construction costs per square meter of pond collecting area, and shows the economies of scale in liner construction and in dike construction if no leveling is required. For purposes of illustration, the range in dike construction costs from \$2.55 to \$4.85 per cubic meter is shown. These estimates include

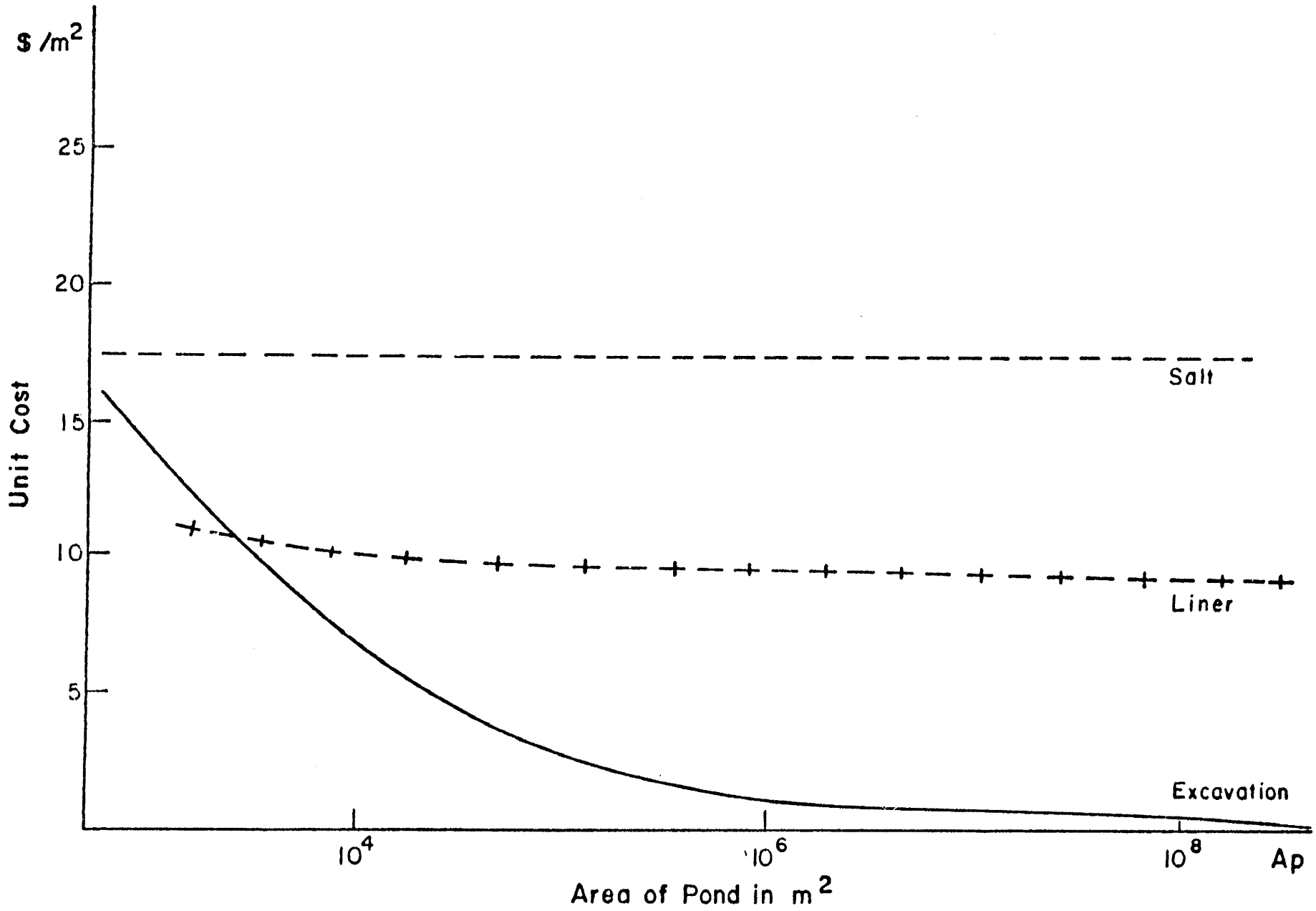


Figure 3.10 Projected costs

both earthwork costs of \$1.55-\$2.60 per cubic meter and then dike related costs of \$1.00 to \$2.25 per cubic meter. Unit costs of dredging are not shown.

### 3.7.- Projection of maintenance costs.

Although solar ponds are highly capital intensive facilities, maintenance costs are a non negligible factor in addressing their overall feasibility. The maintenance costs are recurrent costs that the utility will have to assume every year to maintain the efficient operation of the constructed facility.

The most detailed operation and cost breakdown for an existing pond is provided by L.J. Wittenberg and M.J. Harris on the Miamisburg pond. The main aspects are listed here along with our cost estimates.

- Salt losses: We consider only the salt losses due to the continuous upward diffusion during the pond operation in the bottom convective zone. These losses are estimated to be about 2.5% of the salt in the pond each year. This percentage may vary with location but not significantly. This loss amounts to \$0.40 per square meter of collecting area. In this category of salt losses we do not consider large losses that would happen should the liner fail since these losses would not be tolerable for environmental reasons.

- Chemicals: The clarity of the pond is extremely

important to maintain the thermal efficiency of the pond. In the Miamisburg pond, for example, copper sulfate was used to prevent algae growth. A solution of concentrated hydrochloric acid had to be used a few times during the year to maintain the copper sulfate in solution.

The reports on existing or proposed solar ponds generally furnish very limited data on operation and maintenance; and even for existing ponds, the costs shown are estimates, not firm figures based on actual operating maintenance.

The Jet Propulsion Laboratory of the California Institute of Technology estimated a value of \$2.50 per cubic meter for their study. This value was considered highly conservative by their estimators in light of US experience with research ponds. No further presentation of their calculation was given (Lin et al., volume 2).

For the Miamisburg pond, the operation and maintenance costs were estimated from the cost of chemicals used for algae control. Also 2% per year of salt (20 ton/year x \$30/ton equals \$600 per year) diffuses to the surface and is not recovered. Therefore the cost of maintenance is \$0.35 per square meter per year (Wittenberg and Harris).

The Ormat study came up with a value of \$0.51 per square meter based on experience of the company on the

Israeli solar ponds. This cost assumes that there is no specific consumable cost associated with the water and the brine. The chemicals used for water treatment include chlorine and other anti-scaling and corrosion additives.

Since the value of \$0.35 per square meter per year was estimated for a research pond much smaller than a prototype facility for power generation and since this research pond, lacking an evaporation pond, required the purchase of replacement salt, the value of \$0.51 per square meter per year estimated by Ormat was judged to be the best available estimate of annual maintenance costs. Updating these costs to 1983 dollars results in a projected maintenance cost of \$0.57 per square meter per year.

### 3.8.- Construction schemes and their implication for utilities.

As we have shown in this chapter, the cost of solar ponds is most often determined by site specific considerations. For the electric utility it is important to know which factors will be most likely to enhance or impede the decision to invest in these facilities. For purposes of this thesis, four cases have been selected to show the cost sensitivity of solar ponds to these scenarios. Case 1 represents a project built at an existing "ideal site" (e.g., a salt lake) where salt would be plentiful and no liner would be required. Case 2 represents a project similar to Case 1,

with the exception that an outside supply of salt is required. Case 3 denotes a project where salt is assumed to be available, but a synthetic liner would be required. Case 4 represents construction of a manmade pond with minimal earthwork required to level the basin but requiring both an outside source of salt and a synthetic liner. Using the data presented earlier, the unit costs of solar pond construction for each of these four cases are shown in Figure 3.11. The influence of both the local site conditions (and availability of resources), and economies of scale with respect to the pond area are evident.

This case comparison on a unit cost basis presents some preliminary evidence of the high capital cost of solar ponds. For preliminary studies, it would seem that by just looking at the civil engineering construction of these ponds, cases 2,3,4 will be prohibitively expensive for the development of solar ponds. This implies that this "non-intermittent" solar thermal electric technology will be attractive from an electric utility investment point of view only in very site specific cases where the actual construction of these ponds will be reduced to a minimum.



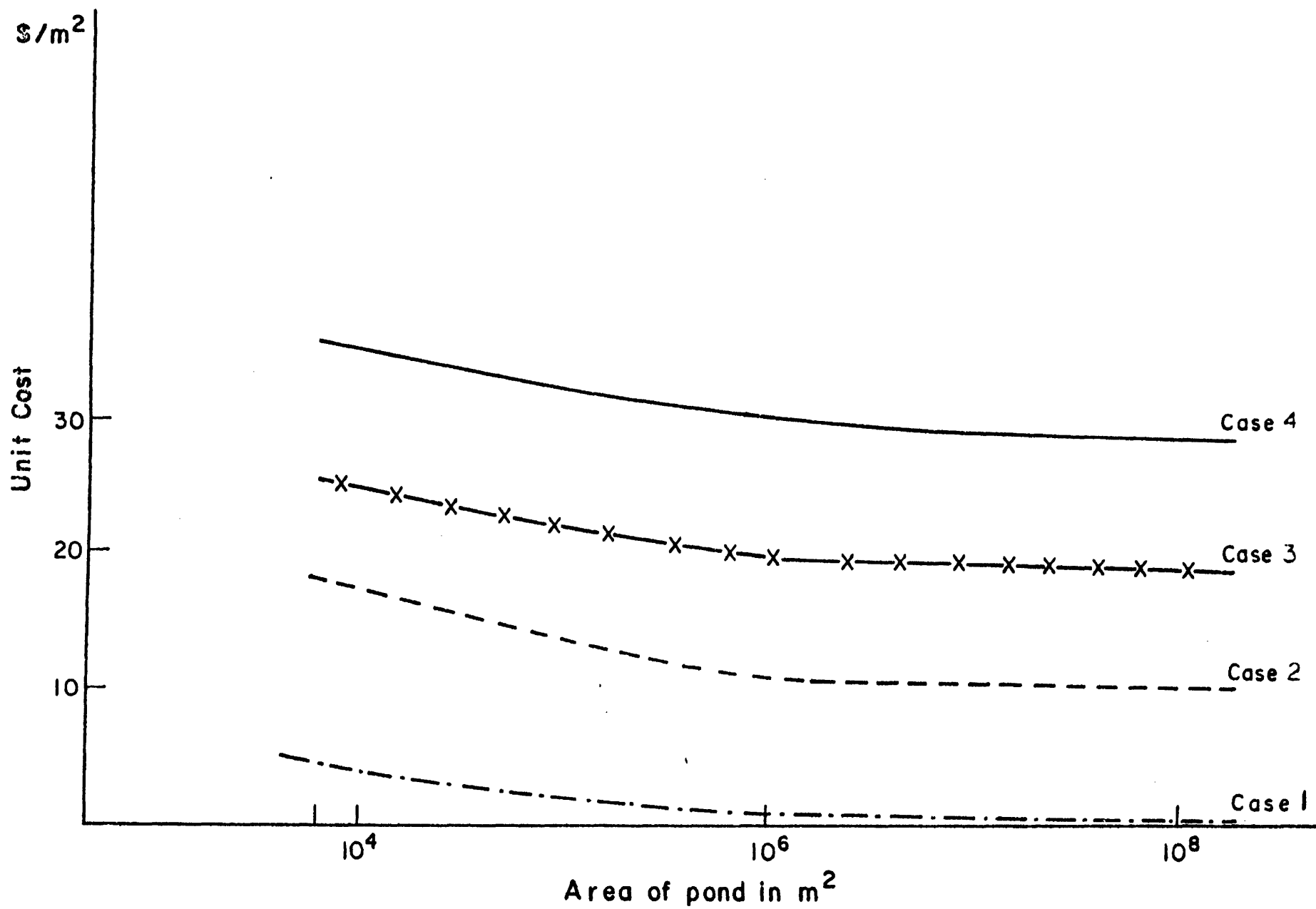


Figure 3.11 : Unit costs, case comparison

## CASE STUDY: 50 MW SOLAR POND

4.1.-Approach

The cost estimation performed in chapter 3 detailed the unit costs of the different pond construction scenarios. To quantify the total cost of a solar pond facility, we chose a proposed favorable site as a case study. The case study examines the construction of a 50 MW solar pond facility for electric power generation at the Salton Sea location in Southern California. As we will see, the Salton Sea site cannot be compared to the ideal site that we defined in chapter 3, but it represents one of the most favorable sites to be found in the United States. This section also serves the purpose of a literature review for the feasibility studies conducted on the proposed California sites.

The case study is based to some degree on the data and project configurations developed by Ormat for the California Energy Commission and the Southern California Edison Company (Ormat, vol 1,2, 1981). In the feasibility study done by Ormat, the environmental benefits, the design characteristics, the schedule and estimated costs of a 5 Mw pond are presented as well as the physiochemical and climatological conditions of the Salton Sea.

The cost and ultimate expansion of the Salton Sea's

demonstration plant to a 600 MW commercial pond power complex using modules of 20 to 50 MW are also detailed. The Ormat feasibility study concludes by considering that the cost of commercial power generated by the salt gradient solar ponds will be comparable to those of coal fired or nuclear generating systems.

Since the Ormat estimates were prepared for plants of 5 Mw and 600 Mw capacity, and since it is not possible to extrapolate linearly between these two projects to obtain costs for a 50 Mw facility, our estimates below include some assumptions on project configurations and site conditions.

It should be noted that according to Ormat, both the pond location and layout as well as the dikes cross section shown are presented following generally accepted engineering practice as a possible planning solution which may be used as the basis for a preliminary cost estimate only. Thus further on site civil engineering study is required to reach a final design.

#### 4.2.- Site description

Two sites were examined in the Ormat report:

##### 4.2.1.- Bristol Dry Lake

The first site is located at Bristol Dry Lake in San Bernadino County, California. The salt lake covers the lowest

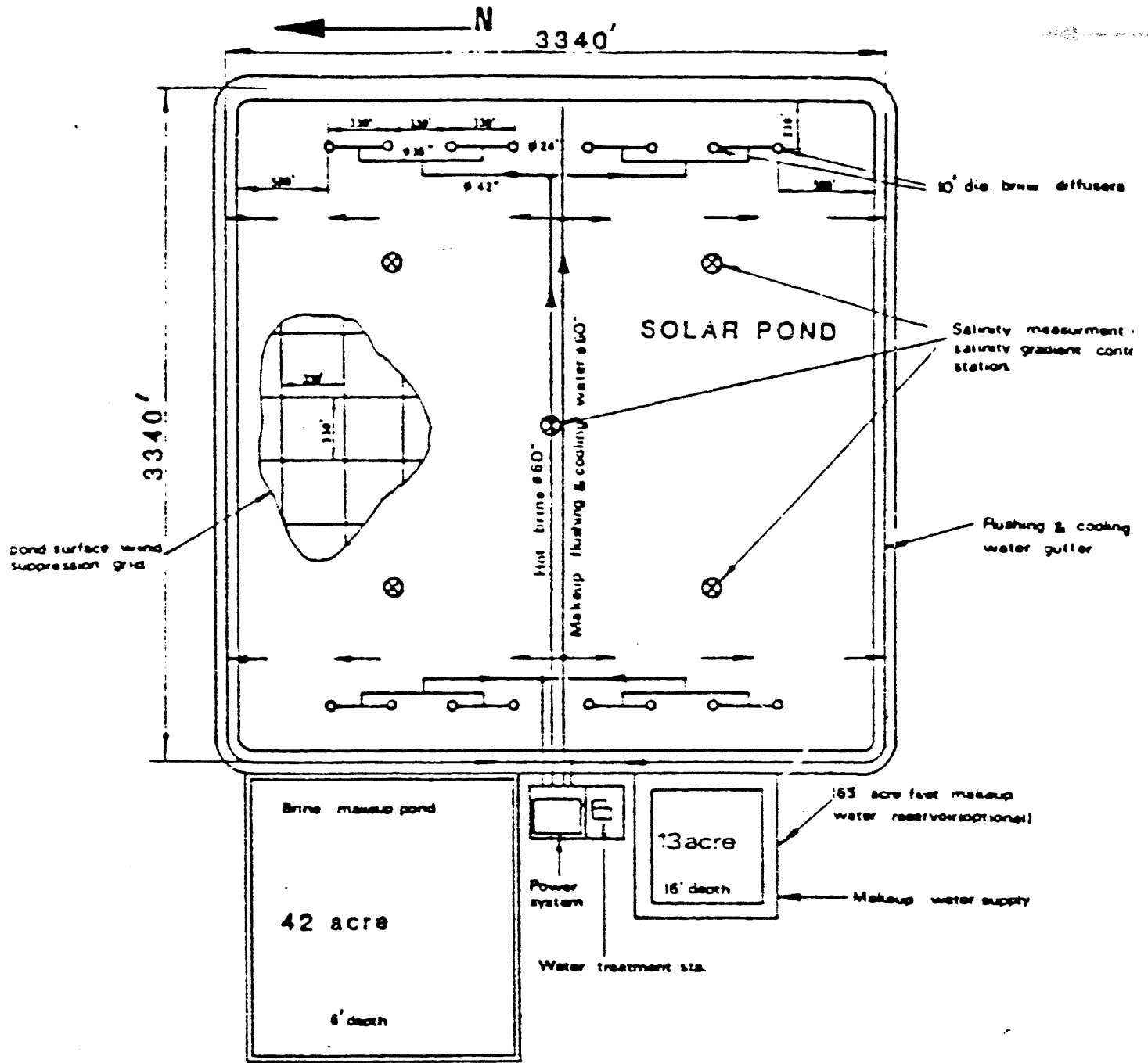


FIG. NO. 10.2 BRISTOL DRY LAKE DEMO 5MW SPFP

GENERAL LAYOUT

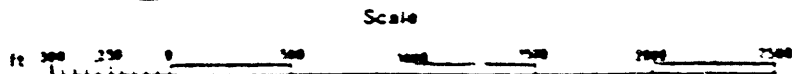
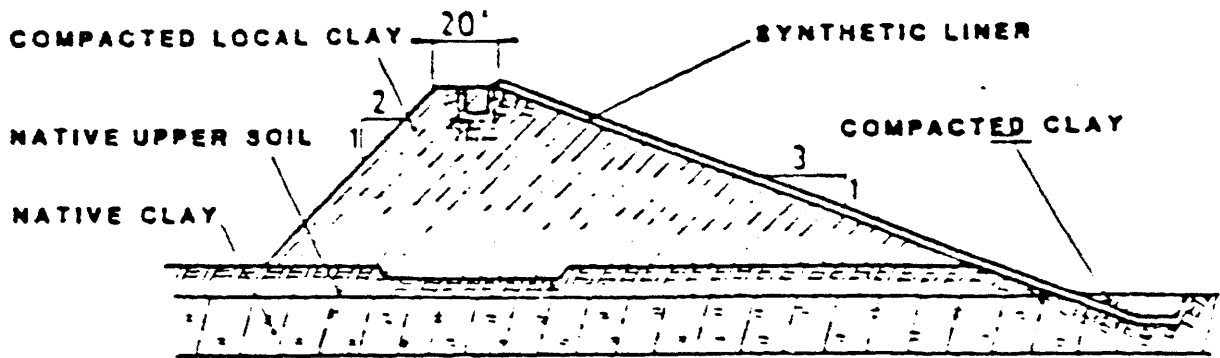
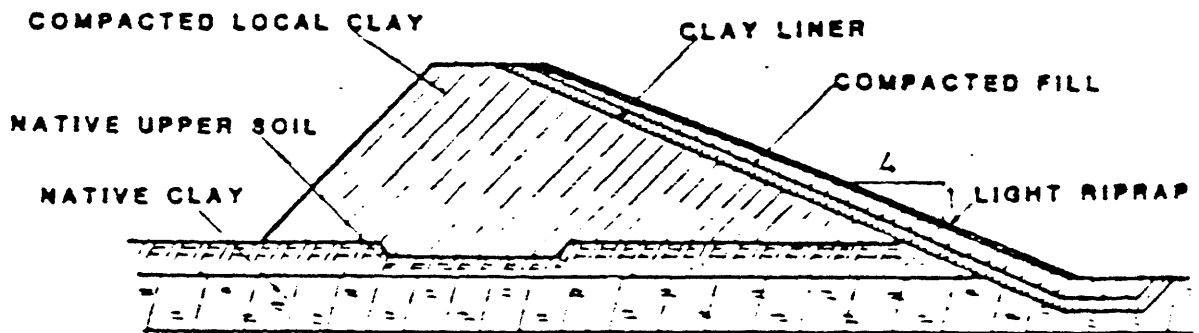


Figure 4.1: General Layout of 5 MW Bristol Dry Lake Solar Pond. (reproduced from Ormat, page 10-12)

### a) SYNTHETIC WEATHER - PROOF LINER

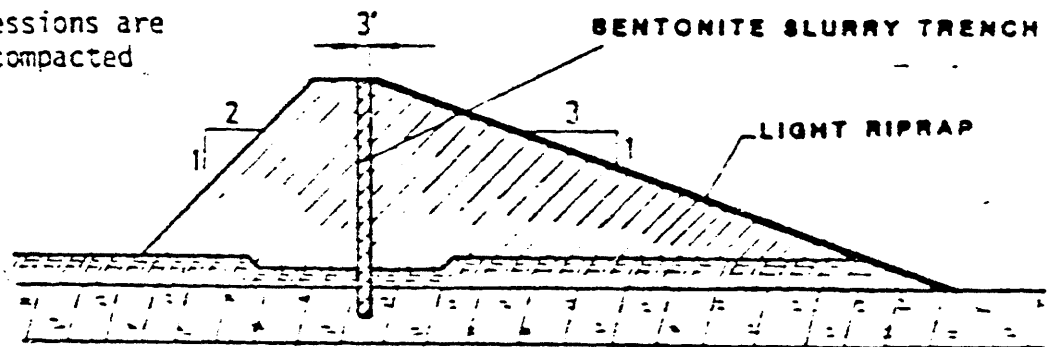


### b) COMPACTED NATIVE CLAY LINER



### c) BENTONITE SLURRY TRENCH

All depressions are cut and compacted.



**FIG.10.3: BRISTOL DRY LAKE DEMO 5MW SPPP**  
**TYPICAL DESIGN FEATURES BASED**  
**ON PERIMETER CUTOFF CONCEPT**

part of the dry depression which is flooded intermittently by storm water and is usually covered with a surface of white, crusted salts. The general layout of the 5 Mw pond is shown in Figure 4.1. Figure 4.2 shows the alternatives explored in the preliminary dike construction analysis.

From preliminary reports, Ormat concludes that it seems unlikely that adequate production of naturally occurring brine could be developed at the lake for initial filling of the pond especially in the case of a 50 Mw solar pond facility.

Furthermore, it seems that due to environmental conditions at the lake, it will be necessary to use a synthetic liner which would greatly add to the capital requirements for the facility. It also appears that on the basis of the water sources previously identified by Ormat, there would be insufficient water available in the Bristol Dry lake region to satisfy the requirements for initial pond filling and annual make up for the 50 MW commercial module. For these reasons the Bristol Dry Lake will not be further considered in this study.

#### 4.2.2.- The Salton Sea.

The Salton Sea is located in the Colorado desert of Southeastern California. The desert has a low inland elevation and is surrounded by mountains which provide a barrier to the

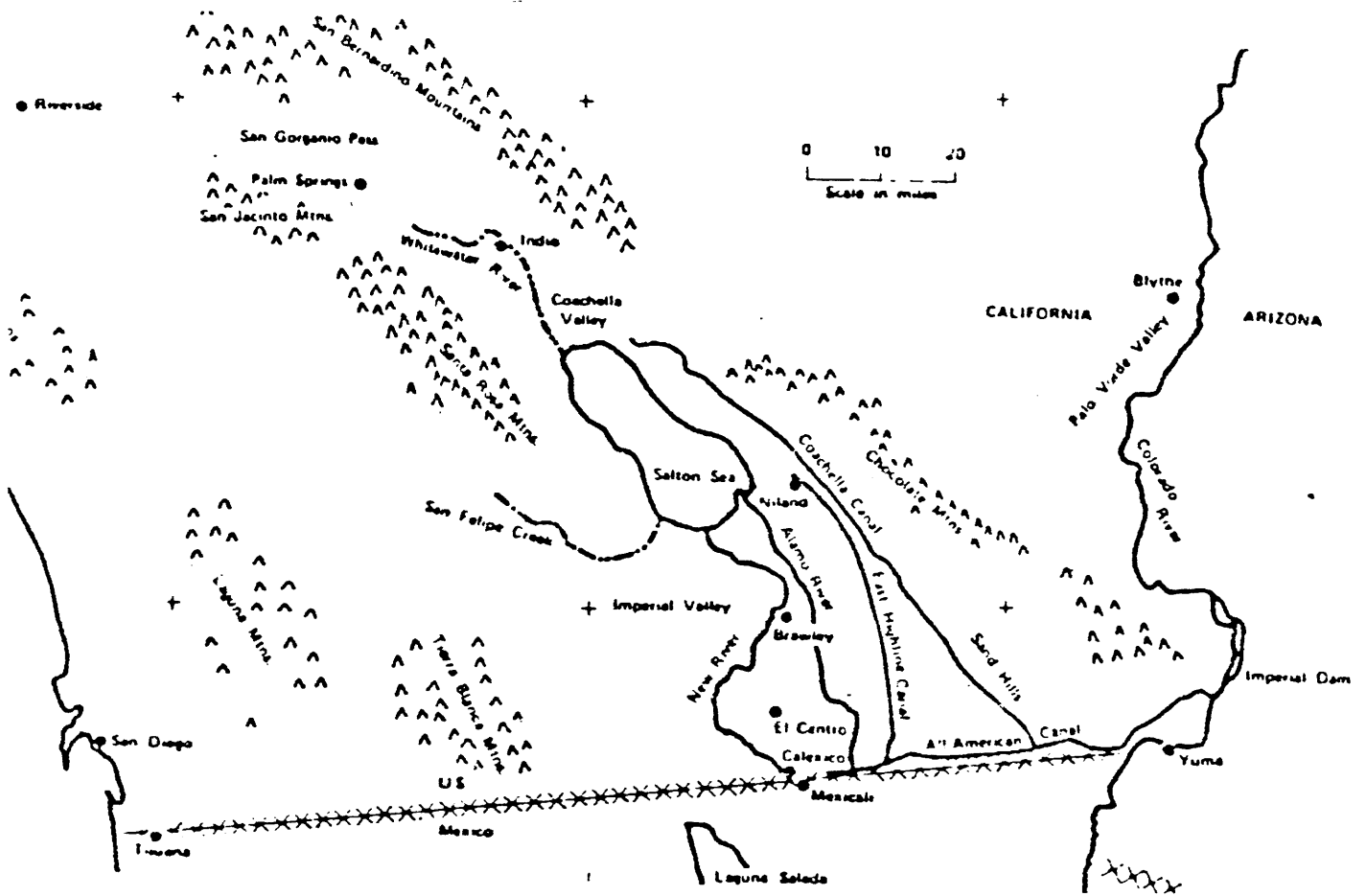
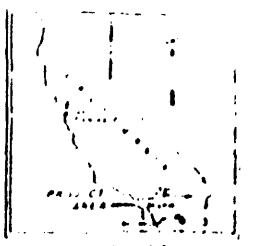
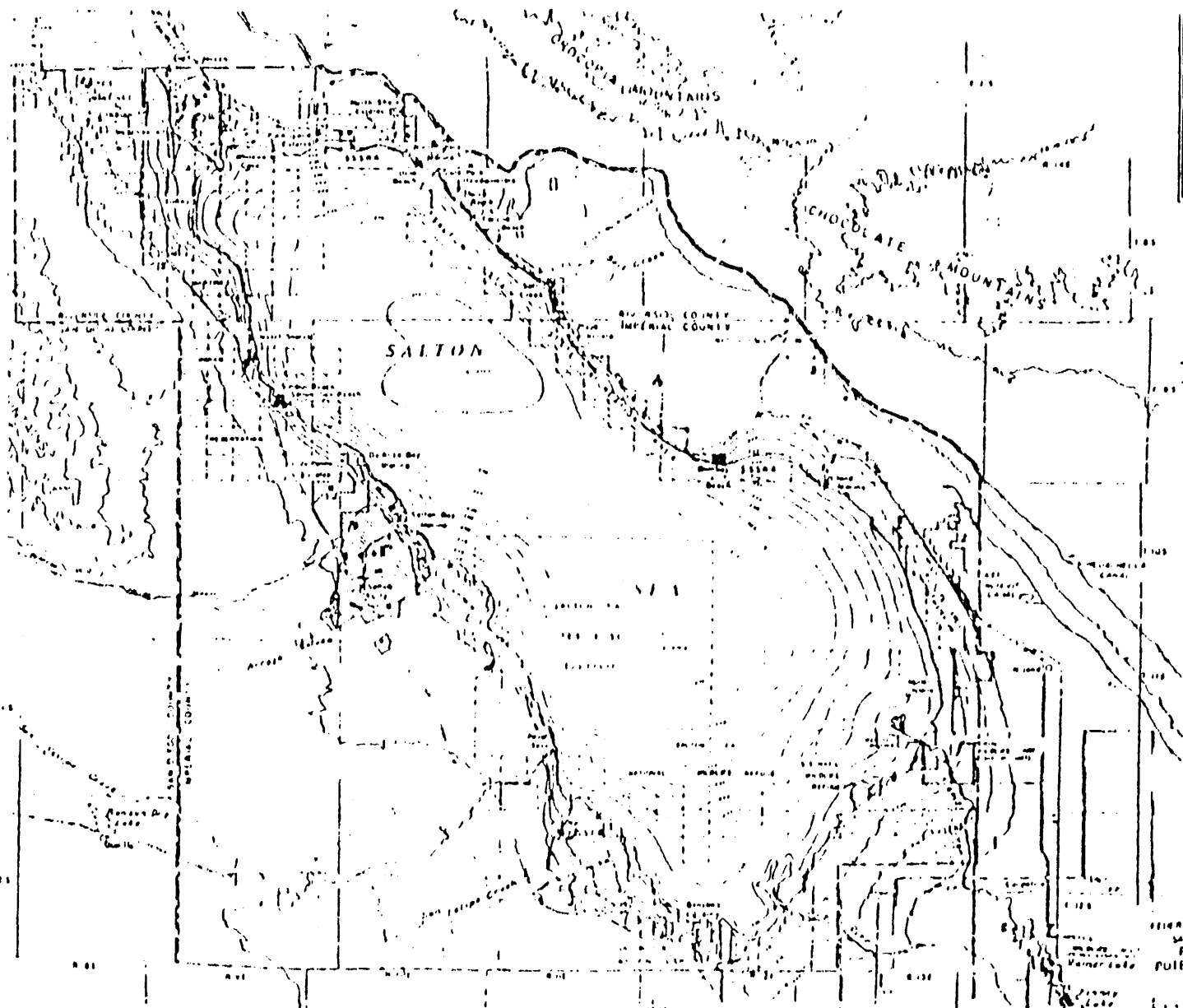


Figure 4.3 : Southeastern California  
( reproduced from Ormat, page 2-17)

Figure 4.4 : The Salton Sea.  
 (Reproduced from  
 Ormat, page 2-23)



- EXPLANATION**
- Project Study Area
  - - - - - Salton Sea Water Level
  - Geographical Mark
  - Agriculture
  - Urban Residential
  - Public Recreation
  - Urban Residential Subdiv. (Improved but still vacant)

FIG. 2.7

Reproduced from  
 Ref. (2-B) Map 7

**MILES**

NO. 100000 IN PRESENT  
 LAND USE AND POTENTIAL URBAN  
 DEVELOPMENT TRACED FROM  
 STATE OF CALIFORNIA DEPARTMENT  
 OF WATER RESOURCES MAP  
 THE CONTOUR INTERVAL IS 20 FEET  
 UNLESS OTHERWISE NOTED  
 UNLESS OTHERWISE NOTED



Pacific Coast. The general location of the lake is shown in figure 4.3 while figure 4.4 provides a more detailed geographical description of the site.

The lowest point of the desert is the lowest point of the Salton Sea at 278 ft below sea level. The surrounding mountains reach several thousand feet. The Salton Sea covers an area of 360 square miles. Its maximum length is 36 miles and its width varies from 9 to 15 miles.

The selected location for this base case study is the Salton Sea.

### .3.-Construction features.

The construction of the solar pond at the selected location includes:

- construction of dikes.
- dredging the layer of floor sediments and leveling it to obtain the required depth.
- protecting the dike slopes with boulders and riprap and constructing roads over them.

Several issues must be considered during the design phase before construction is given the go-ahead. They are the following:

- cost of construction on shore verses off shore.

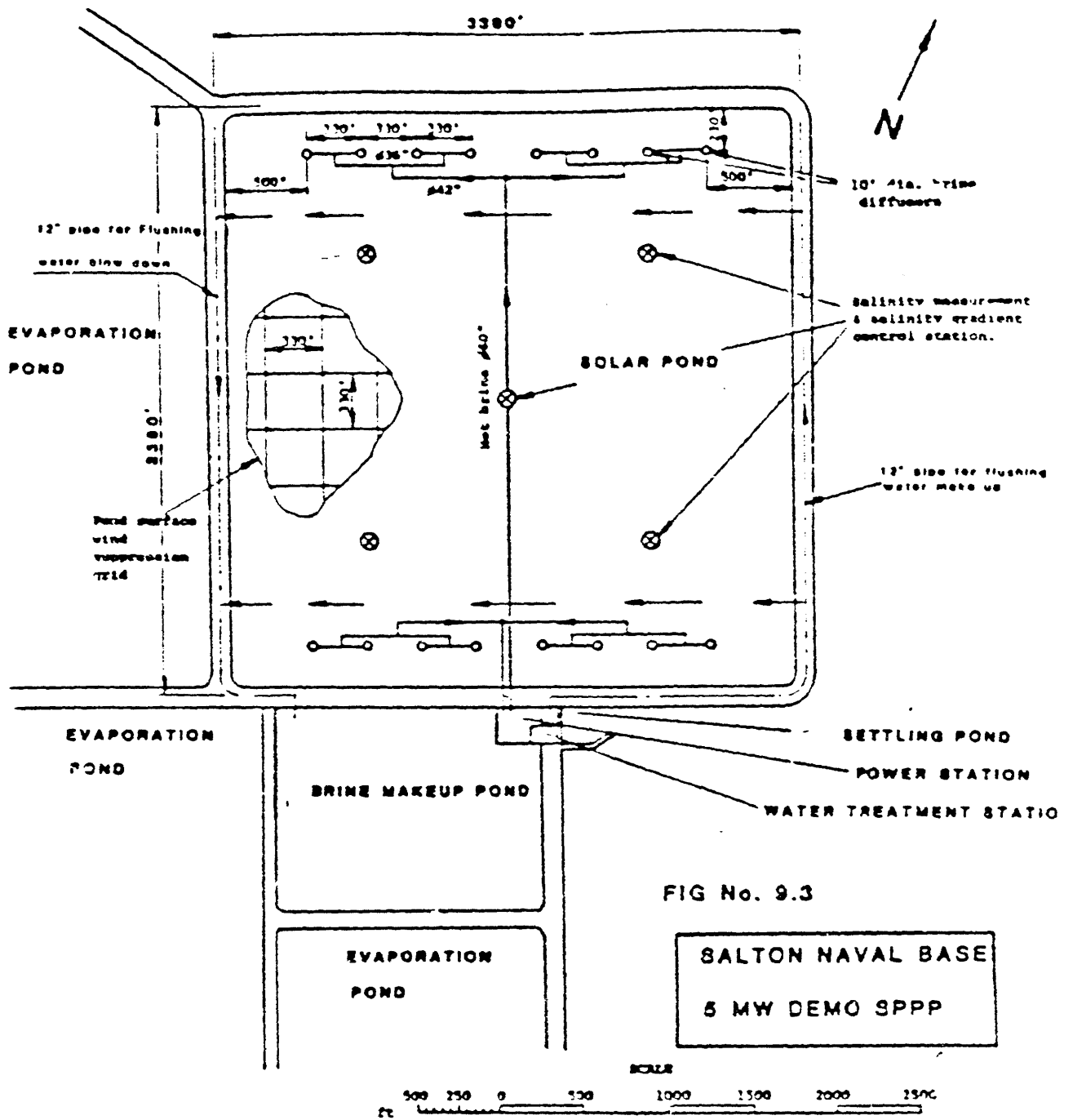


Figure 4.5 : General Layout of the 5 MW Salton Sea Solar pond. (Reproduced from Ormat, 9-16)

600 MW SPPP COMMERCIAL PLANT LAYOUT AT SALTON SEA

FIG. 19-1

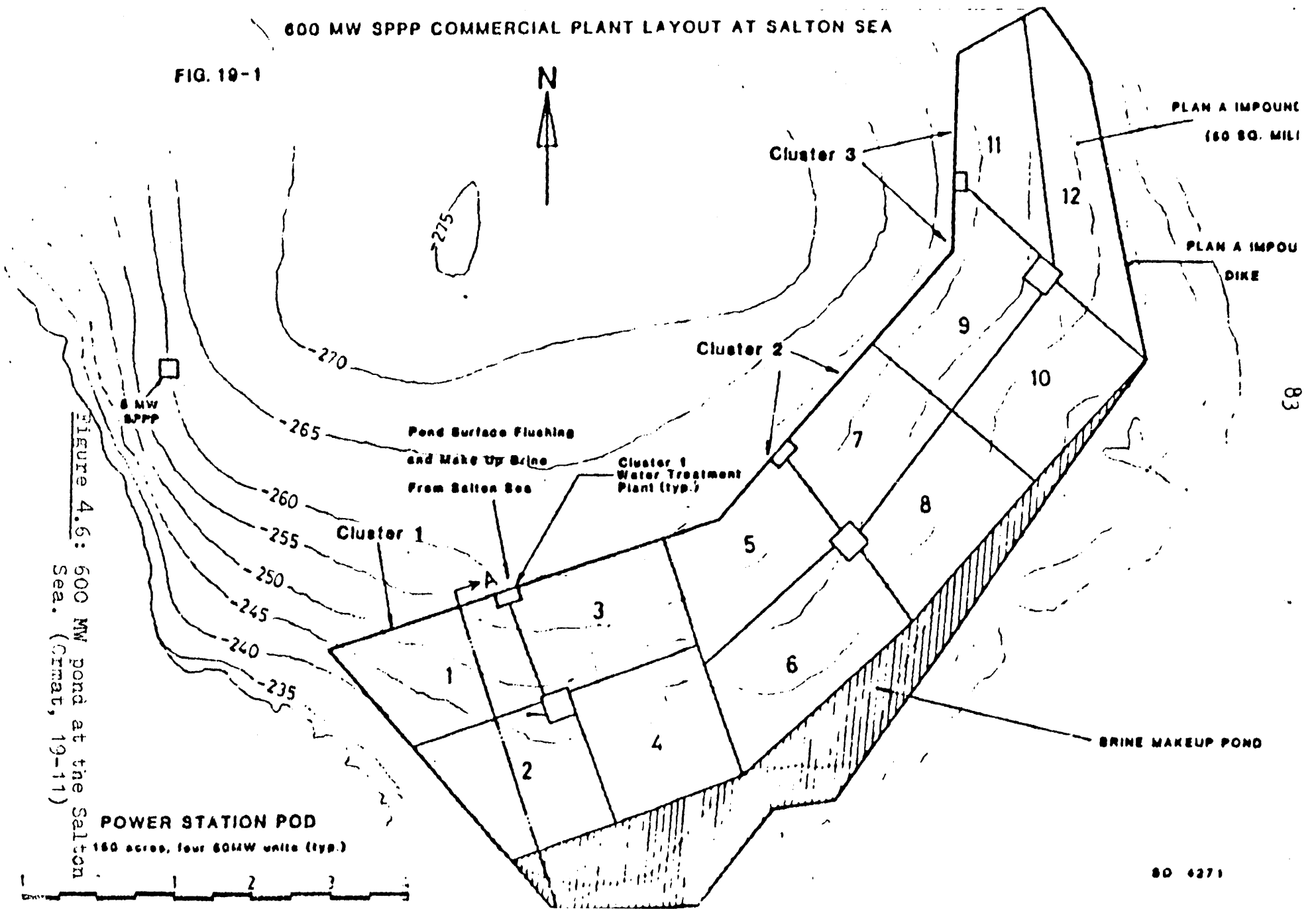


Figure 4.6: 600 MW pond at the Salton Sea. (Cimat, 19-11)

**POWER STATION POD**  
160 acres, four 60MW units (typ.)

PLAN A IMPOUND  
(60 SQ. MILE)

PLAN A IMPOUND  
DIKE

BRINE MAKEUP POND

83

80 6271

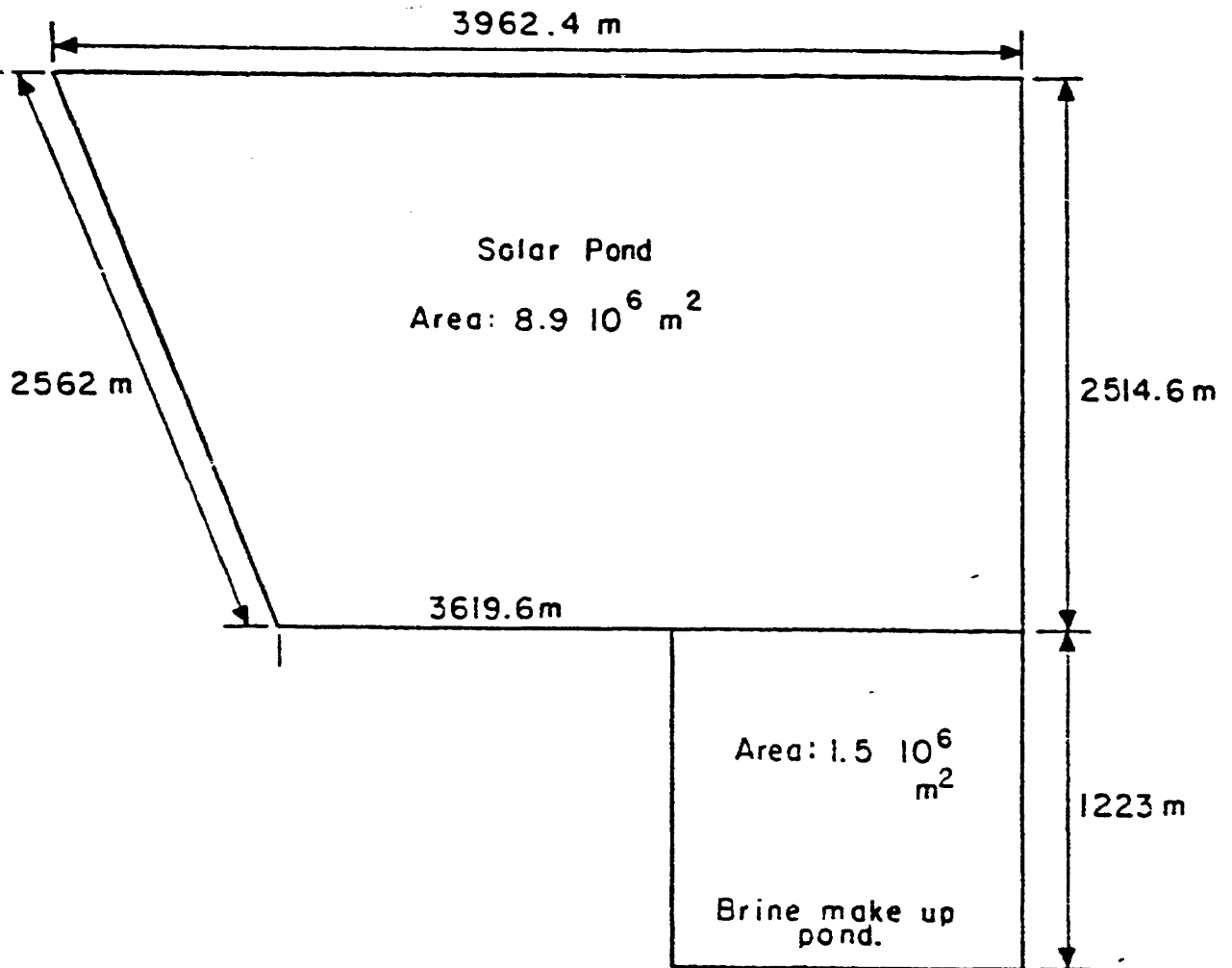
- area availability.
  
- compatibility of brine production with existing floor sediments and the cost of removing the top floor material if this proves to be incompatible.
  
- problems associated with dike construction in the sea for both evaporation and solar pond.

These aspects were considered in the Ormat report for the construction of the 5 Mw demonstration pond (figure 4.5 ) and the ultimate expansion to a commercial facility of 600 Mw made up of twelve 50 Mw volumes.(see figure 4.6). The Ormat report should be considered for an in-depth treatment of these aspects.

As was indicated before, the calculation of our base case 50 Mw estimate is based to a certain degree on Ormat for the technical data and some unit cost estimates but most calculations for the quantities and construction configurations had to be extrapolated after justified assumptions were made from the cost breakdowns available.

#### 4.3.1.- Pond sizing.

We generally followed the sequence of construction needed to build the 600 Mw commercial facility to site and size our 50 Mw pond. Pond number 1 was used to base our cost estimates (see figure 4.5). The rest of cluster 1 (i.e.,



LAYOUT OF 50 MW POND FOR  
SALTON SEA

Figure 4.7 : Layout of 50 MW pond for the Salton Sea.

ponds 2,3,4) would only be needed for the initial brine production (see figure 4.6) . They were not considered to be the required size for the steady state brine make up pond.

The brine make up pond size was estimated from the 50 Mw Bristol dry lake facility assuming that sizing characteristics for the two Southern California sites are closely related.

Figure 4.7 shows the layout of the 50 MW pond for the Salton Sea. The solar pond has an area of 8.9 million square meters which translates into a pond perimeter of 12,250 meters. The brine make up pond has an area of 1.5 million square meters and an assumed depth of 1 meter.

It is useful to relate the area of our 50 Mw pond to the 5Mw and 600 Mw facility. The following ratios will be used in our cost estimates:

$$\text{Area } 50\text{MW} = 8.9 * \text{Area of } 5 \text{ Mw.}$$

$$\text{Area } 600\text{MW} = 12 * \text{Area of } 50 \text{ Mw.}$$

#### 4.3.2.- Dike construction.

For the 50 Mw pond, it is intended by Ormat that the impoundment dike be constructed and designed using as many materials as are available on site. Due to the relatively large quantity of embankment material required for constuction, the subsea floor material should be used

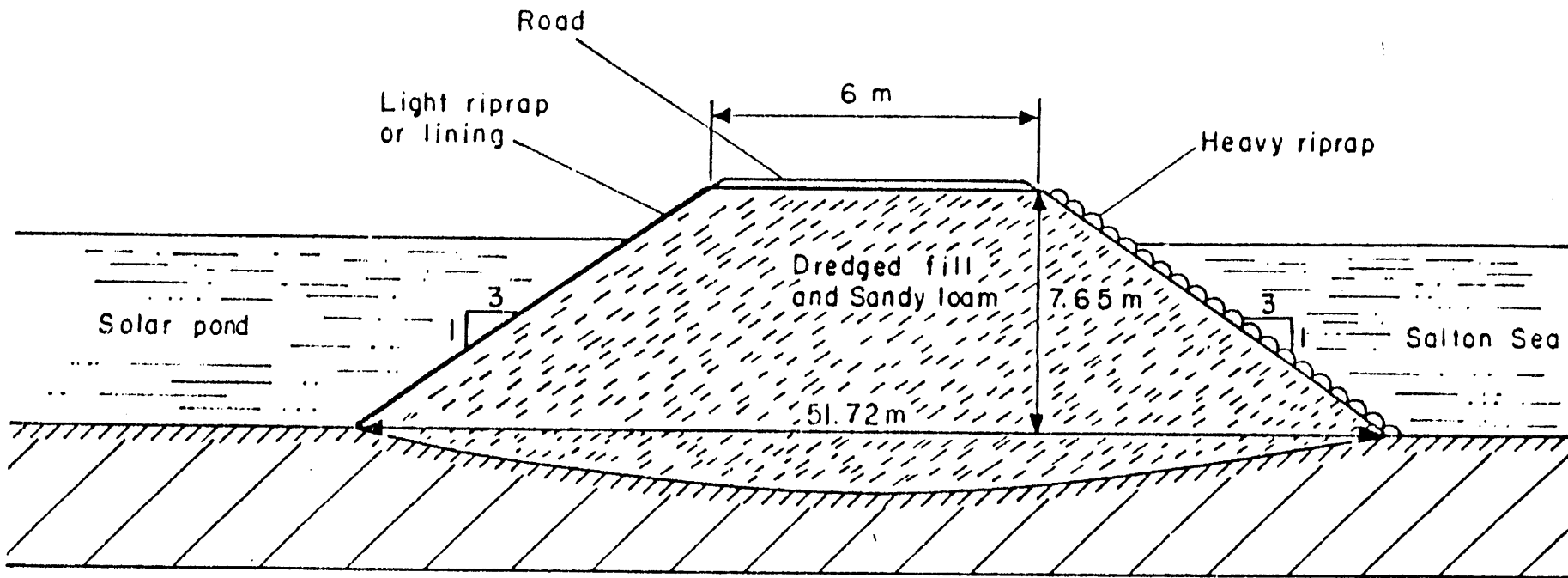


Figure 4.8 : Typical dike cross section for the 50 MW pond at the Salton Sea.

whenever practicable.

Due to the absence of a complete geotechnical review of the area of the pond, it is impossible at the present time to assess this approach with certainty although this would clearly reduce transportation cost of borrow materials to erect the dikes.

Dike cross-sectional design is based upon the Ormat report. The dike is made of dredged fill and sandy loam and has a slope of 1 in 3. The bottom width is 51.72m with a top width of 6 m. The dike is protected by heavy riprap on the Salton Sea side to protect it from wind effects and wave action as is shown in Figure 4.8 . On the pond side, a synthetic liner or a light riprap are used to prevent seepage of the higher concentration brine into the Salton Sea. A road was also placed on top of the berm for ease of maintenance.

#### 4.3.3.- Sea floor sediments.

The bottom top soil consists mainly of sea floor sediments. The sediment is a chemically reduced dark gray to black in color. It contains a heavy organic material and its consistency is like heavy grease. The observed thickness of the soft sediment ranges from less than 0.30 m to as high as 5 m.

This material will contaminate the bottom zone of the solar pond and brine turbidity will reduce the efficiency of



the pond. these sediments have to be dredged from the floor area for the solar pond.

#### 4.3.4.- Dredging.

A solar pond net depth of 5 meters is needed to provide the annual baseload service at the nominal power output. Figure 4.6 shows the 600 Mw commercial plant layout of the Salton Sea while figure 4.9 shows the region within the 600 Mw plant to be dredged to provide the requisite solar pond depth.

The maximum depth of material to be dredged is approximately 3.35 meters with an average dredging depth of about 1.5 meter. The dredged material can be placed in the deeper portion of the impoundment to reduce earthwork haul distance while maintaining depth requirements overall.

#### 4.3.5.- Liner.

Riprap is essential for a dike embankment constructed from dredged material. According to Ormat, this can be either a quarry run riprap or graded stone riprap placed over a crushed stone bedding material. The bedding material should provide adequate freeboard above the expected wave level plus a maximum wave height.

Protection of the interior slopes is less critical due to the effectiveness of the solar pond wind and wave

REGION TO BE DREDGED FOR 600 MW COMMERCIAL PLANT  
AT SALTON SEA

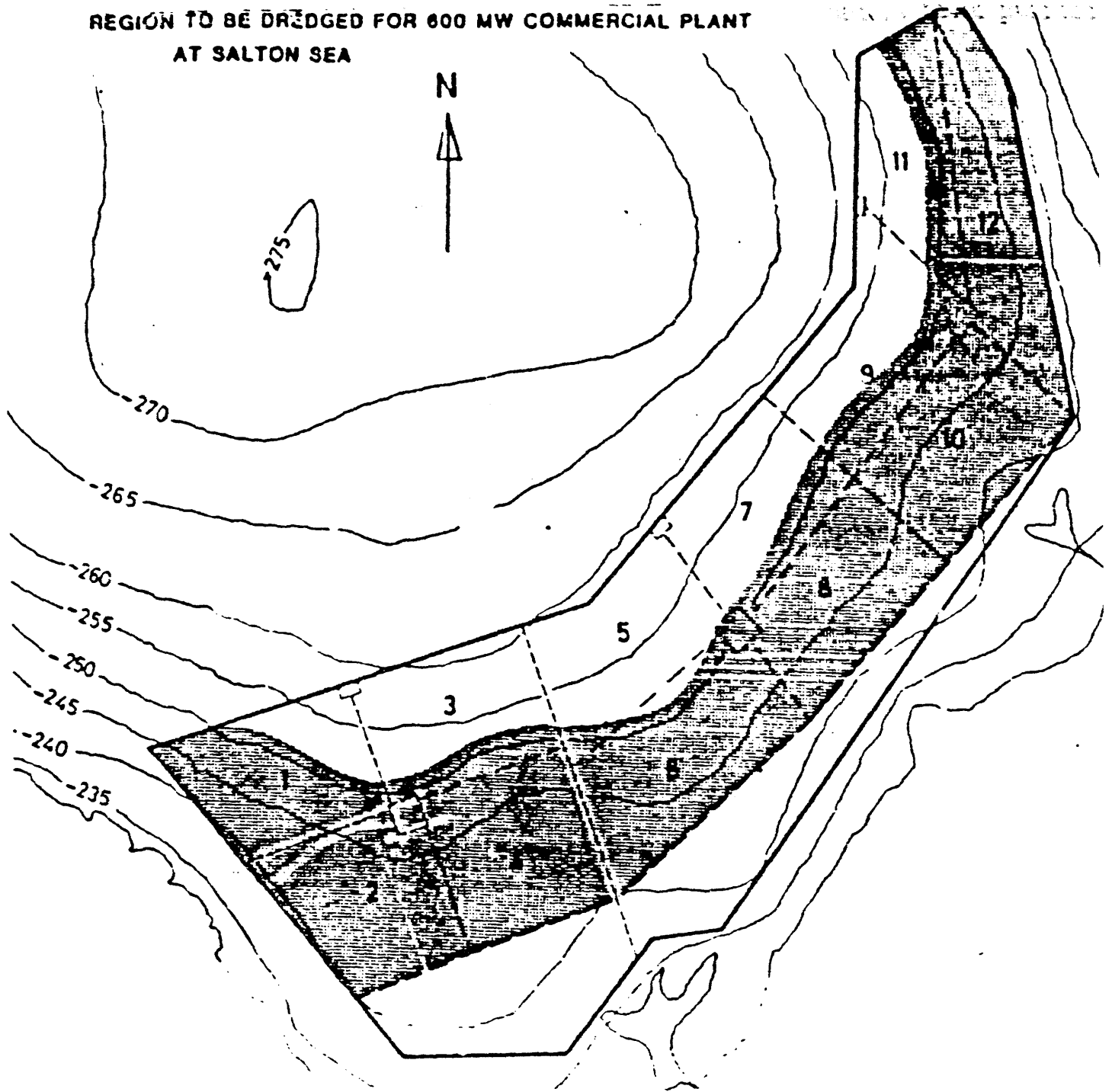


Figure 4.9 : Region to be dredged at the Salton Sea.  
(Reproduced from Ormat, page 19-12)

suppression netting. Use of a synthetic liner is recommended by Ormat.

#### 4.4.- Cost Estimation of the 50 Mw solar pond

No estimate was available for a 50 MW plant and no extrapolations could easily be made from the 5 MW and 600 MW pond cost breakdowns provided by Ormat since the correlation between these facilities is not linear. Furthermore the quantities computed are for illustration only and may not conform to the final quantities and cost at the Salton Sea. The estimates below include some assumptions on project configuration and site conditions. These assumptions will be detailed below.

A plan view of the facility was given in figure 4.7 . It assumes a solar pond collecting area of 8.9 million square meters, with a brine make up pond of 1 m depth having an area of 1.5 million square meters. In estimating construction quantities, the dike cross section showed in figure 4.8 was assumed as typical.

These cost estimates are specific to the Salton Sea location according to our estimates and to Ormat. They do not have the general nature of our estimates in Chapter 3. Inflation was treated in accordance to a Heavy Excavation Handbook index and was taken at 6% per year.

##### 4.4.1.- Total Dike Construction Costs.

The dike construction costs include the following items as described under account number 102 of tables 4.1 and 4.2 :

- dike construction;
- excavation cut-off;
- slurry trench compaction;
- gravel riprap;
- heavy riprap and;
- crushed rock road.

The volume of earthwork needed to construct the dike is equal to the cross sectional area of the dike times the perimeter of the pond.

volume= (220.7) \* ( 12,248.7)= 2.7 million cubic meters.

From Table 4.3, the 600 Mw cost for dike construction is \$199.4 millions. Reducing by a factor of 12 to the 50 Mw range gives a cost of \$16.61 millions.

From Table 4.1, the 5 Mw cost is \$1.44 millions. Increasing by a factor of 8.9 to the 50 Mw range, the cost is \$12.816 millions.

The price ranges given in 1981 dollars per cubic yard

TABLE A - SALTON NAVAL BASE 5 MW DEMONSTRATION SPPP - SOLAR POND SYSTEM  
BREAKDOWN OF COST ELEMENTS (US \$)

| Cost Acc. No | Item                                     | Unit | Quantity  | Unit Cost  | Amount                   |
|--------------|--|------|-----------|------------|--------------------------|
| 101          | Geotechnical survey                      |      |           |            |                          |
|              | bathymetry mapping                       | Acre | 1,000     | 70         | 70,000                   |
|              | Surveying incl. aerial                   | Acre | 1,000     | 20         | 20,000                   |
|              | See exploration program                  | Job  | 1         | 130,000    | 130,000                  |
|              | Sub-Total                                |      |           |            | \$ 220,000               |
| 102          | Solar pond construction                  |      |           |            |                          |
|              | dredging sea floor sediments             | CY   | 1,613,000 | .80        | 1 290,400                |
|              | Dredge of clayey loam and levelling      | CY   | 1,000,000 | 1.50       | 1,500,000                |
|              | Gravel toe                               | CY   | 60,000    | 10 - 15    | 500,000 - 900,000        |
|              | Dikes construction                       | CY   | 1,200,000 | 0.90 - 1.2 | 1,080,000 - 1,440,000    |
|              | Excavation cut off                       | CY   | 42,200    | 2.50       | 105,500                  |
|              | Slurry trench compaction                 | SF   | 370,000   | 2.00       | 740,000                  |
|              | Placement of filter gravel riprap (12°)  | CY   | 40,000    | 20         | 800,000                  |
|              | Riprap, heavy (18°)                      | CY   | 15,000    | 5          | 375,000                  |
|              | Crushed rock road (12°)                  | CY   | 7,500     | 15 - 25    | 112,500 - 187,500        |
|              | Inner slope protection                   | SF   | 270,000   | .60        | 162,000                  |
|              | Sub-Total                                |      |           |            | \$ 6,265,400 - 7,500,400 |
| 103          | Construction of evaporation ponds        |      |           |            |                          |
|              | Excavation, dikes foundation (stripping) | CY   | 380,000   | 1.20       | 456,000                  |
|              | Compacted borrow fill material           | CY   | 1,000,000 | 1.5-4.50   | 1,500,000 - 4,500,000    |
|              | Piping                                   | Job  | 1         |            | 50,000                   |
|              | Pumping station incl. installation       | each | 4         | 50,000     | 200,000                  |
|              | Sub-Total                                |      |           |            | 2,206,000 - 5,206,000    |
| 104          | Brine circulation sys.                   |      |           |            |                          |
|              | Piping                                   | Job  | 1         | 350,000    | 350,000                  |
|              | Diffusers                                | Unit | 16        | 7,000      | 112,000                  |
|              | Valves & Fittings                        | Job  | 1         | 50,000     | 50,000                   |
|              | Support & Anchoring                      | Job  | 1         | 80,000     | 80,000                   |
|              | Pumping station                          | Each | 1         | 160,000    | 160,000                  |
|              | Sub-Total                                |      |           |            | 752,000                  |

Table 4.1 : Cost Breakdown of the 5 MW pond at the Salton Sea. (Ormat, Appendix B-2)

| Cost Acc. No     | Item  | Unit   | Quantity | Unit Cost    | Amount         |
|------------------|---|--------|----------|--------------|----------------|
| 105              | Cooling system (once thru)  |        |          |              |                |
|                  | Construction of water inlet & outlet  | Job    | 1        | 300,000      | 300,000        |
|                  | Pumping station inc. installation   | Ea.    | 1        | 170,000      | 170,000        |
|                  | Piping  | Job    | 1        | 70,000       | 70,000         |
|                  | Valves & fittings   | Job    | 1        | 20,000       | <u>20,000</u>  |
|                  | Sub-Total   |        |          |              | 510,000        |
| 106              | Water flushing system   |        |          |              |                |
|                  | Piping  | Unit   | 1        | 60,000       | 60,000         |
|                  | Diffusers   | Unit   | 1        | 20,000       | 20,000         |
|                  | Valves & Fittings   | Unit   | 1        | 10,000       | 10,000         |
|                  | Pumping station   | Unit   | 1        | 50,000       | <u>50,000</u>  |
| Sub-Total        |   |        |          | 140,000      |                |
| 107              | Water treatment plant   | System | 1        | 1,000,000    | 1,000,000      |
| 108              | Gradient control system incl. control unit, netting, anchoring, pump & piping | Unit   | 1        | 650,000      | <u>650,000</u> |
|                  | Sub-Total   |        |          |              | 650,000        |
| 109              | Instrumentation & Controls  |        |          |              |                |
|                  | In-pond instrumentation   |        |          |              |                |
|                  | Temperature probes, measurement system (gradient)                             | Ea.    | 5        | 2,000        | 10,000         |
|                  | Soil temp. measurement system   | Ea.    | 5        | 1,000        | 5,000          |
|                  | Flowmeter & instrumentation   | Ea.    | 4        | 1,500        | 6,000          |
|                  | Salinity measurement  | Ea.    | 5        | 3,000        | 15,000         |
|                  | Transparency  | Ea.    | 5        | 1,000        | 5,000          |
|                  | Insolation  | Ea.    | 5        | 1,000        | 5,000          |
|                  | On-site instrumentation   |        |          |              |                |
|                  | Meteorological station  | Ea.    | 1        | 25,000       | 25,000         |
| Dust measurement | Ea.   | 1      | 1,000    | <u>1,000</u> |                |
| Sub-Total        |   |        |          | 72,000       |                |

Table 4.2 : Cost Breakdown for the 5 MW pond at the Salton Sea. (Ormat, Appendix B-3)

TABLE 16.1

PRELIMINARY COST ESTIMATE FOR 600MW SPPP

| COST ACCOUNT NO. | ITEM   | COST (1,000,000 \$)<br>(OCTOBER 1980 PRICE LEVEL) |
|------------------|--|---|
| <u>100</u>       | <u>Solar Pond System</u>   |   |
| 101              | Geotechnical Survey  | 1   |
| 102              | Dredging   | 100   |
| 103              | Dike Construction (including solar ponds, evaporation ponds and brine make-up ponds) | 199.4*  |
| 104              | Brine Circulation System   | 28.8  |
| 105              | Pond Surface Flushing and Cooling  | 68.4  |
| 106              | Water Treatment Plant  | 36  |
| 107              | Gradient Control System  | 70.2  |
| 108              | Instrumentation and Control  | 1.2   |
| 109              | Power Station Yard Development   | 2.4   |
| 110              | Engineering and Design   | 30.4  |
| 111              | Management, Supervision and Administration   | 20.2  |
|                  | Sub Total  | 538   |
| <u>200</u>       | <u>Power Generating Unit</u>   |   |
| 201              | Plant Equipment  | 311   |
| 202              | Construction Material  | 145   |
| 203              | Construction and Installation  | 60  |
| 204              | Engineering and Design   | 17  |
| 205              | Management, Supervision and Administration   | 7   |
|                  | Sub Total  | 540   |
|                  | TOTAL  | \$1,098   |

\* Includes the cost of impoundment dike construction for this 50 square mile region, \$108.4 million.

Table 4.3 : Cost Breakdown for the 600 MW pond at the Salton Sea. (Ormat, page 16-5)

in the same tables are from \$0.90 to \$1.20. Adjusting for inflation and converting to cubic meters, the range becomes \$1.30 to \$1.75 with a mean of \$1.55 per cubic meter. The other components of dike construction were discussed above. Totaling these items, a differential of \$1.00 to \$2.25 is found.

The total dike construction cost is obtained by adding the unit dike construction cost to the differential found for the other dike construction items. The total unit dike construction costs used for the purpose of this case study range from \$2.55 to \$4.85 per cubic meter.

The total dike construction costs range from \$6.885 millions to \$13.095 millions.

#### 4.4.2.- Dredging costs.

As is indicated by Ormat, the average quantity to be dredged is 1.5 meters. From figure 4.9, we assume that on half of the area of the pond is to be dredged due to its location.

Our independent calculation indicates that the volume to be dredged is equal to one half the area of the pond times the average depth.

Volume = 8.9 millions square meter \* 0.5 \* 1.5 meters  
= 6.675 million cubic meters.



The Ormat report on the 5 Mw pond separates dredging costs between the dredging of sea floor sediments and the dredging of the clayey loam. This distinction is not made for the 600 Mw pond where only a total dredging cost of \$100 millions is given. Taking a weighed cost of dredging to be \$1.05 per c.y. ( obtained from Table 4.1), the dredging volume of the 50 Mw pond when deduced from the 600 Mw plant can be obtained as follows:

$$(\$100 \text{ millions}/\$1.05 \text{ cy}) * (.765 \text{ c.m./c.y}) / 12 \text{ modules} = 6.07 \text{ million cubic meter.}$$

From the 5 Mw facility, the volume is:

$$(\$1 + \$1.6 \text{ millions}) * (.765 \text{ c.m./c.y}) * 8.9 = 17.8 \text{ million cubic meters.}$$

If we assume that the dredging volume of the sea sediments is 6.675 million cubic meters, then by direct line interpolation, the volume of clay dredging amounts to \$8.75 million cubic meters.

From the Excavation handbook, taking inflation at 6% for 4 years with correction for cubic meters, a dredging cost of \$1.80 per cubic meter was obtained.

From Table 4.1, the following cost range was obtained: \$1.18-\$2.20 . So, for sediment dredging, the cost range was assumed to be \$1.20-\$1.80 . For clay dredging, the cost was

assumed to be \$2.20

The overall dredging costs can now be calculated and are as follows:

- sediments: \$8.010- \$12.015 millions.
- clay: \$19.250 millions.

#### 4.4.3.- Liner costs.

Synthetic liner costs were applied to the construction of the solar pond for environmental reasons. Only the interior side of the dike is covered and not the whole area of the pond plus the interior sides of the dikes as is recommended by liner suppliers for truly effective seepage protection. The required width of the liner is therefore 24.1 meters and the total surface area of the liner is equal to the required width times the perimeter of the pond.

This area is equal to 0.295 millions square meters and appears to be conservative compared to the estimates prepared by Ormat.

The unit cost of the liner was obtained from suppliers and for such a surface area, is estimated \$9.5 .

#### 4.4.4.- Miscellaneous costs.

Estimates by Ormat for both the 5 Mw plant and the 600 Mw extension give miscellaneous costs of about 10 to 13 % of

the construction cost items discussed above ( earthwork, dredging, liner).

For purposes of this case, a value of 12 % of the construction costs has been assumed to cover miscellaneous costs.

#### 4.5.- Conclusion

The construction estimates are tabulized in Table 4.4. The total costs of the facility ranges from \$41.382 millions to \$52.823 millions.

The cost components of the 50 Mw plant are as follows:

- Dike construction    13.0% - 31.6% .
- Sediments dredging   15.1% - 29.0% .
- Clay dredging         36.4% - 46.5% .
- Liner costs            5.3% - 6.7% .

Table 4.4 and the above breakdown indicate that probably the most expensive additional costs, when compared with this 50 Mw base case, are at sites where salt has to be provided and where synthetic liners are an absolute neccessity not only to prevent seepage along the sides of the dikes but also on the bottom of the pond. On the other hand, the costs can be reduced at sites where no dredging is required.

The predicted energy costs are presented in Table 4.5 (Carmichael, MIT 1984). It has been assumed that dense brine

CONSTRUCTION COST ESTIMATE

| <u>Item</u>                       | <u>Unit</u>    | <u>Quantity</u>       | <u>Unit Cost</u><br><u>(Dollars per Unit, 1983)</u> | <u>Extension</u><br><u>(Millions of Dollars, 1983)</u> |
|-----------------------------------|----------------|-----------------------|---|--|
| 1. Dike Construction              | m <sup>3</sup> | 2.7x10 <sup>6</sup>   | 2.55-4.85   | 6.805-13.095   |
| 2. Dredging                       | m <sup>3</sup> |                       |   |  |
| a. Sediments                      |                | 6.675x10 <sup>6</sup> | 1.20-1.80   | 8.010-12.015   |
| b. Clay                           |                | 8.75x10 <sup>6</sup>  | 2.20  | 19.250   |
| 3. Liner                          | m <sup>3</sup> | 0.295x10 <sup>6</sup> | 9.50  | 2.803  |
| 4. Subtotal                       | --             | ---                   | ---   | 36.948-48.513  |
| 5. Engineering and Administration | --             | 12% of item 4.        |   | 4.435- 5.660   |
| 6. Total Construction Costs       | --             | ---                   | ---   | 41.382-52.823  |

Table 4.4 : Construction cost estimate for the 50 NW case study.

is available at the site, so that evaporation ponds are not required. The installed cost of the pond includes the pond construction costs and the power plant construction costs. The predicted value of the levelized busbar cost of energy is 148 mills/kwh. A figure which is similar to predictions for other renewable energy sources but not competitive with the conventional energy sources commonly used to produce baseload electricity. It would thus seem that the primary drawback of solar ponds is their high energy cost coupled with the remaining technical uncertainties usually encountered with a new technology.

Table 4.5. :

## BUSBAR COST OF ELECTRICITY FOR THE BASE CASE

(source Carmichael, MIT 1984)

## Installed Cost (1983 Dollars)

|   |                    |
|---|--------------------|
| Pond  | \$63.2 million     |
| Power Plant                                       | \$58.0 million     |
| Total   | \$121.2 million    |
| Power level                                       | 40 MW (Net)        |
| Unit Capital Cost                                 | 3030 \$/kW         |
| Capacity Factor<br>(Average Value First 10 Years) | 56%                |
| Operation and Maintenance Cost                    |                    |
| Pond (\$.57/square meter)                         | \$5.1 million/year |
| Power Plant (6%)                                  | \$3.5 million/year |

## Levelized (1983 Dollars):

|             |                 |
|-------------|-----------------|
| O&M         | 43.6 mills/kWh  |
| Capital     | 104.4 mills/kWh |
| Busbar Cost | 148.0 mills/kWh |

## Levelized Cost Factors:

(Source: EPRI (5))

|  |                |                            |          |
|--|----------------|----------------------------|----------|
| Debt                                     | 50%            | Inflation Rate             | 8.5%     |
| Preferred Stock                          | 15%            | Federal and State Tax Rate | 50.0%    |
| Common Stock                             | 35%            | Investment Tax Credit      | 10.0%    |
| Total Annual Return<br>(Current Dollars) | 12.5%          | Tax Recovery               | 10 years |
| Period                                   | First 10 years | Book Life                  | 30 years |
|  |                | Levelized Carrying Charge  | 16.9%    |

THE CLIMATE FOR UTILITY INVESTMENT IN SOLAR PONDS

5.1.- Approach.

The preceding chapters have shown that salt gradient solar ponds are highly capital intensive facilities whose energy cost will compare at best to that of other renewable energy sources. The advantage of non-intermittent energy production of solar ponds vis-a-vis other renewable energy sources will be hard to exploit for baseload production due to these high costs.

The purpose of this chapter is to show that, although the unattractiveness of solar ponds for electric power generation is primarily due to their cost, the present climate of the electric utility is very negative for investment in new and risky technologies. Even if the cost of these facilities was more favorable for investment, the institutional regulation in light of the Public Utilities Regulatory Policies Act (PURPA) and the financial condition of the utilities motivate them to assume a passive role in the development of new renewable technologies.

In evaluating incentives for investment into the solar ponds, it is important to consider the overall context which includes the following aspects:

- Regulatory environment for electric utilities;
- Utility perception of risk;
- The financial condition of the utility industry.

Before examining the Public Utilities Regulatory Policies Act, we will review the issues that made its enactment necessary such as electric utility rate regulation, the impact of solar systems on electric utilities, and the effects of rates on solar system economics. PURPA is extensively discussed concentrating on its effect on utility investment in new technologies. We then examine the financial condition of the electric utilities and see how the high risk associated with solar ponds distorts the capital budgeting decision.

#### 5.2.- Electric utility rate regulation.

Electric utility rate making is regulated by the states and by the federal government and receives the greatest attention in terms of public utility regulation. The reason why rates are regulated is because electric utilities are "natural monopolies" which cannot operate economically unless they enjoy a monopoly. Rate regulation is thus a substitute for competition in protecting utility customers.

In 1942, in the case of the Federal Public Commission v.s. Natural Gas Pipeline Company (315 U.S. 575 1942) , the



Supreme Court postulated a two step rate making process:

- adjust the utility's revenue level to the demands of a fair return. This means that the rate should generate enough revenue not only to cover operating expenses but also the capital costs.

- adjust the rate schedule to recover the necessary revenue while maintaining fairness.

Thus a desirable rate schedule should:

- obtain the revenue requirements;
- distribute the revenue requirements fairly among all customers.
- discourage waste and promote efficient use of energy (Bonbright, 1961).

The Federal Energy Regulatory Commission was established on October 1, 1977 under the Department of Energy Organization Act, taking over the responsibilities of the Federal Power Commission for electric utility regulation. Its function is to set rates according to the desirable rates schedule.

The federal government regulates the rates of interstate suppliers of electric power while the states regulate the retail utility rates. The power to regulate can

be exercised by the legislature or it can be delegated to a commission as was determined in 1933 in the case opposing the city of Seymour to the Texas Electric Service Company (66F. 2nd 814,816, 1933). The ratemaking function is legislative so it is not within the power of the courts to prescribe rates but as directed by the cases of Colorado Interstate Gas v.s. FPC, they determine whether the rates are just and reasonable. In general, Public Utility Commission are composed of from one to seven commissioners and have staffs of lawyers, engineers, rate analysts, and economists. Statutes generally define the regulatory authority of the Public Utility Commissions and provide guidelines under which they function.

Public Utility Commission jurisdiction does not extend to interstate sales of electric energy for resale and jurisdiction over municipal utilities vary from state to state. For example in the states of New York and Wisconsin they have that authority while in Colorado they do not (Anderson, 1976).

Public Utility status and public utility commission jurisdiction are very significant issues for an operator of a wind, photovoltaic, or solar pond energy conversion system able to supply excess electricity to a utility. Being subject to licensing, franchises, site regulations, and certification for public convenience and necessity may make operation as a

self generator impractical (Dean and Miller, 1977).

Public utility commission rate regulation may, however, be beneficial in that rates are generally required to be just and reasonable. Moreover, a public utility commission may be needed to compel electric utilities to purchase the solar pond energy or wind user's excess power.

In Hawaii, firms which produce or furnish power primarily from non fossil fuel sources for internal use but sell excess energy to local utilities have been exempted from public utility commission regulation and jurisdiction. Thus utilities would have to buy the excess power produced by solar ponds at rates to be set by the PUC, if necessary.

#### 5.3.- Impact of solar systems on electric utilities.

There are several problems associated with utilities and solar energy technology such as solar ponds. Two areas identified as research priorities are determining the impact of solar energy systems on electric utilities and identifying the impact of solar energy systems on electric utilities and identifying the impact of various utility rate structures on the commercialization of solar energy. Several studies are currently underway or have been completed including research, development, and demonstration projects. Although none of these studies considered solar ponds, similarities can be drawn.

The Office of Technology Assessment has studied by computer simulation the costs of providing backup power from an electric utility. The costs were found to depend on the following four factors (OTA, 1978):

- The number of solar buildings in the service area;
- local climatic conditions and their correlation with the utility's peak demand;
- the cost of equipment by region and the local cost of fuel;
- the type of solar design, including collector area and storage capacity.

The study compared the cost to the utility per kWh of providing electricity to the designated building with the cost of serving a similar building using an electric heat pump. A heat pump is a heat amplifier; through changes in its physical state , which takes a relatively small amount of energy to produce , a refrigerant fluid picks up heat outside a building and gives it up inside. The study showed that in general:

- costs to the utility are lower for conventional houses using electric resistance heating;
- a solar house costs the utility more per kWh than a conventional house.

It was also found that the utility's costs of supplying electricity to an all electric house with storage capacity for heating water and cooling are nearly 50% less than the costs of service to a similar house without storage capacity.

The nature of the conflict between solar applications and the utilities was addressed by the Energy Policy Project of the National Conference of State Legislatures. The conflict stems from two basic sources:

- reduction in net electric sales: any energy source which is utilized to displace electric sales exerts an adverse impact by reducing the utility's energy market share.

- reduction in load factor: to the extent utility pricing structures do not accurately reflect utility operating costs, lost sales may affect revenues differently than costs (Jones, 1978).

One computer simulation study showed that if solar devices become widespread, the electric utilities will suffer from two major effects:

- they will reduce electric utility revenues during periods when solar energy is being used and;

- they will either increase or decrease the electric utility's peak demand requirements depending upon the type of

load being displaced and the utilization pattern of the installed solar systems (Booz Allen & Hamilton, PB263371, 1976).

For both the summer and winter peaking utilities, it was shown that under rates based on average accounting costs, backup service to the solar building resulted in revenue deficiencies to the utility. Under the existing rate structure, the utility would not recover all the costs of serving solar customers (Felman, 1975). However the study concluded that no general statement can be made regarding the impact of solar heating and cooling upon the load curve of the electric utility industry. This analysis must be performed on an individual utility basis, since variations in the ambient weather conditions, load curves, and generation mixes of utilities will be the main determinants in the magnitude of the impact.

#### 5.4.- Effect of rates on solar system economics.

Since some form of conventionally fueled auxilliary system will be necessary to provide heating and cooling for buildings using solar energy, the type of rate structure will have a significant effect upon solar system economics and will usually be a factor that solar designers must take into account in new systems design. Because utility system loads can vary with solar demands, utilities may want to design a separate rate for solar backup service. Conversely, the type

of solar design used may govern the kind of rate structure the utility implements.

In a 1977 survey, each state public utility commission was asked what policy it had adopted to insure that electric rates did not discriminate against or discourage the use of solar or wind energy. Most commissions had no policy on rates for consumers using solar energy although most replied the rates were being studied. As of 1978, utilities under public utility commission in Illinois, Kansas, Michigan, New Hampshire, New York, North Carolina, South Carolina, Utah and Wisconsin had special solar rates; most favored the use of supplemental energy sources and had policies against higher rates for backup of solar systems. The California public utility commission believes that it is moving towards rates that will encourage utilities to purchase excess energy from solar users.

Most utilities do not have special rates for backup service to solar users. Some have tried to impose higher rates for the backup service, but they have mostly been withdrawn or overturned by regulatory commissions after protests. In five states, utilities have offered to a limited number of solar users lower than standard residential rates for backup service. Under the service, the solar customer's pattern of use and the characteristics of the solar energy and backup systems are monitored.

In October 1975, the Colorado public utility commission allowed the public service company of Colorado to put into effect a mandatory demand/energy rate for electric heating and for backup service. This rate would have made solar backup service more expensive for most solar customers than service under the general residential rate. The rate was designed in part to bring revenues to cover what the company claimed were extra costs of providing auxiliary electric service to solar equipped facilities. After protests and hearings, the commission changed the rate to make it optional.

Another solar backup rate which was rescinded after protests was the special service deposit in Columbia, Missouri. The electric utility, in september 1977, looking towards higher rates for solar beackup, instituted a requirement that customers taking backup service deposit \$200, in addition to the regular service deposit. The extra deposit was to be applied to the bill should a higher rate be adopted for standby service to solar equipped facilities.

Providing auxiliary service to customers using solar ponds, or wind generated power involves issues in addition to rates for backup services. The load factor of a small power producer will not be high because the systems are expected to result in a minimal auxiliary energy use, with intermittent demand. The concerns of the small power include whether an



electric utility is required to purchase excess electric energy and, if so, the rate at which the utility purchases the power.

A 1975 George Washington University study found that most utilities prohibit reverse power flows back into the utility grid (Mayo, 1977). Because this practice is contrary to the national goal of conservation of depletable energy resources, public utility commissions and legislature are beginning to fight that utility policy. The Energy Task Force, an organization which rehabilitated a tenement in New York City installed a solar system for the building's lighting (Finch, 1977). The Consolidated Edison Co. which supplies electricity in the city was unwilling to allow reverse flow from the windmill back to the utility. Its concerns were the windmill's effect on the utility transformers and computerized controls and possible hazards to line workers. The New York commission ordered Con Ed to buy excess power from the wind machine. The rate adopted contains an energy charge and a minimum monthly charge. The commission refused to let Con Ed include an indemnification clause which provided that "each customer shall agree in writing to hold the company harmless and indemnify it for any damages or injuries in any way resulting from the installation or operation of this equipment." If it had been approved, windmill operators would probably have needed liability insurance which would have been another cost

disincentive to windmill operations.

5.5.- Rates structures and solar system design.

Utility rate structures for backup service are likely to exert a strong influence on solar system design and commercialization. One study examined the potential impacts of four different rate schedules on utilities and solar commercialization. The inversion or flattening of traditional block rate structures would increase energy cost savings realized by solar users and thereby provide a marginal incentive for solar energy use. The financial effect of rate inversion on the utility was incapable of precise measurement but would depend heavily on the utility's individual characteristics.

Under time of day (TOD) rates, solar facilities could be designed optimally for the benefit of both the solar user and the electric utility by providing offpeak storage capacity. The economic impact of TOD rates upon the utility would depend upon its individual operating characteristics and the administrative and metering costs associated with this rate structure.

Another study found that the type of rate structure imposed by an electric utility for auxilliary service significantly affects the most cost effective design of the solar system. The effect is a financial barrier to the

purchase of a solar energy system. Where metering and associated and administrative costs are most prohibitive, the most desirable rate structure for auxilliary power to solar users appears to be a time differentiated scheme based on marginal cost pricing (Koger, 1978).

Theoretically the solar user would not be subject to any type of rate discrimination. TOD rates for solar auxilliaries are likely to promote national goals of energy conservation and environmental protection; to eliminate barriers to solar market penetration that any traditional rate structure imposes; and to improve utility load factor and more efficient system operation.

#### 5.6.- Electric rate discrimination law.

An important concern of solar users is whether a utility may impose higher or lower rates for backup service. The law prohibits public utilities from charging higher rates to some customers than to others for the same service under like conditions. As was determined in Hicks v.s. City of Monroe Utility Co., differences in rates are valid when there is a reasonable basis for distinguishing among the customers. A solar user subject to higher rates for auxilliary service may challenge the practice under state statutes prohibiting discrimination by public utilities or under less promising federal laws. Almost every state has a statute prohibiting utility pricing or sevic practices which favor one customer

over another. In 1952, in *City of Texarkana v.s. Wiggins*, the Texas Supreme Court said (264 S.W. 2nd 622, 1952):

The common law rule that one engaged in rendering a utility service...may not discriminate in charges or service as between persons similarly situated is of such long standing and is so well recognized that it needs no citation of authority to support it...The courts have imposed upon utilities...the duty to treat all alike unless there is some reasonable basis for a differentiation.

New York's electric utilities may not charge a customer higher or lower rates than any other customer pays for service under substantially similar conditions. Utilities may classify customers for ratemaking based upon quantity used, time of use, duration of use or any other reasonable consideration. However in *Lefkowitz v.s. Public Service Commission*, a temporary lower rate for electric space heating customers given at the expense of other customers was held to violate the New York Public Service Law. The New York Court of Appeals held that the separate classification of electric space heating customers was unreasonable and that the lower rate thus conferred an undue preference.

It is conceivable that solar customers (with low load factors and variable demands) may be classified separately from other residential or commercial customers and charged higher rates. Whether this would be an undue discrimination against solar customers depends on whether these differences result in higher costs of serving them. Due to a lack of

data, the answer is unlikely to be clear although utilities can project an answer that commissions may believe. The issue may be resolved by the solar costs of service experiments being conducted by the Federal Government and the public utilities.

A solar customer is more likely to face higher than lower rates. A challenge of rate discrimination generally must first be heard by the Public Utility Commission, and a court will not later substitute its judgment for that of the PUC on questions of fact unless it appears from the record that the PUC's findings are clearly unsupported by the evidence. Once in court, the solar user bears the burden of proving that the rates are discriminatory. Thus it would be difficult for individual solar users to challenge a discriminatory rate practice by invoking the federal antitrust laws. The solar user could maintain that high backup service rates are designed to slow solar commercialization and to preserve the utilities energy supply monopoly in violation of section 2 of the Sherman Act.

Unfortunately, this complex process is not a practical means of defense. An attack of charging denial of the equal protection of the laws under the fourteenth amendment might be made but is unlikely to succeed even if Public Utility Commission regulation renders the practice of rate discrimination "state action" since only governmental

actions or private actions supported by the state are subject to the fourteenth amendment. Success is unlikely because there may be rational as was shown in Allied Chemical Corp. v.s. Georgia Power Co., where the Supreme Court of Georgia stated (330 Ned 1, 1975):

Because ratemaking is a legislative act, our test under an equal protection analysis of this economic regulation matter is whether there was a rational basis for the differing rate treatment of the complaining industrial class vis-a-vis other classes, and the rate must be approved unless we find it to be without a rational basis.

5.7.- Electric utility rate making and the National Energy Act.

Perhaps the most telling argument against utility involvement in solar commercialization was that hinted by President Carter during his Sun day address in 1979-"no cartel controls the sun". President Carter obviously meant that the United States would be less at the mercy of OPEC if we moved to solar energy, but the implications of this statement for possible use of utility monopoly power over solar energy was not lost by solar advocates. This sentiment, plus the mandate in the Department of Energy Organization Act to foster and assure competition in the supply of energy and fuels has provided a formidable obstacle to utility involvement in solar energy. Utilities are notoriously poor at innovation, both in implementing new technologies and in developing them. Until the advent of the Electric Power

Research Institute, the bulk of research and development and process innovation in three electric utility industry was done not by the industry itself, but by its major suppliers such as General Electric and Westinghouse (Smith, 1978).

In defense of the utilities track record, it should be recognized that regulatory barriers may hinder the innovation process in utilities; many regulatory bodies have discouraged innovation in their rulemaking by refusing to allow R&D to be counted, either in the rate base or as an operating expense. Nonetheless, utility involvement with solar technologies has shown a dramatic increase. A survey of utilities conducted by EPRI shows that in 1980, there were 236 utilities involved in solar energy projects: an increase of 31% over the previous year. Although solar heating and cooling projects still represent the bulk of the utility solar projects, the survey reveals that utilities are shifting their emphasis away from passive to active solar systems. This increase represents the growing perception among utility managers that active solar systems can be used to reduce peak generating requirements, particularly those of residential customers.

#### 5.8.- PURPA.

The Public Utility Regulatory Policies Act of 1978, one of five statutes that comprise the National Energy Act, provides for the first time for national standards for public utility rates and practices settling the controversies

presented in the preceding sections.

Title 1, the regulatory policies portion of the act, is to encourage the conservation of electricity, the efficient use of resources and facilities by electric utilities, and equitable utility rates, all by means of rate reform. Solar users are assured that consideration will be given to standards potentially beneficial to them. Solar consumers wishing to advocate a particular standard are guaranteed a right to intervene in a regulatory proceeding. More important, the solar users, as a special interest group, could qualify for reimbursement of legal expenses of a regulatory proceeding if the tests are met.

Title 2 will affect service to and rates from electric producing solar devices. Utilities will have to sell electricity to nonutility small power producers and cogenerators and buy excess electricity from them at reasonable rates, under rules to be set by the Federal Energy Regulatory Commission. Sell back rates paid by the utility should not exceed the incremental cost to the utility of alternative energy; that is the cost at which the utility would generate the electricity or buy it from another source. Solar users who produce electricity are assured that utilities can no longer refuse to purchase excess energy from them and are assured fair backup and sellback rates.

The act was enacted to encourage the small scale



production of electric power using renewable energy sources. The act attempts to remove the following barriers for small power producers:

- the possibility that utilities would not buy the electricity generated by small power producers and pay a price for it that would make small power production profitable;

- the possibility that utilities would charge discriminatory rates for backup power.

To be qualified a small power producer, a facility must generate less than 80 Mw and be located at the same site. Fifty percent of the total energy input of the facility must be through renewable energy and no more than fifty percent of the equity interest in the facility can be held by an electric utility.

As a result of PURPA, the utilities are required to purchase all electric energy made available to them. PURPA requires that the rates be just and reasonable. The provisions of PURPA provide incentives that offer a unique investment opportunity for small power producers because PURPA guarantees the small power producers a market for the power they can produce and guarantees a price standard at the avoided cost to the utility that is very favorable.

Unfortunately as a result of PURPA, the electric

utilities are motivated to assume a passive role in renewable resources development. The utilities are required to purchase the power generated by solar ponds by others and are not given the incentive to invest in their own.

#### 5.9.- Utility financial condition.

In approaching a new technology investment like solar ponds, an electric utility takes a long view approach consistent with its ability to finance a project over a long time. This enables the utility to adopt project with long lead times. To do this with a feeling of confidence requires a stable economic and financial environment and the ability to project future conditions within reasonable limits.

The utility industry is very risk averse which is natural for an industry whose investments are being constantly regulated and for an industry whose performance is measured more by the reliability of its dividend payments and the dependability of its service.

Utilities now have little incentive to invest solar ponds for the following reasons:

- the effects of inflation on the cost of operation and on construction expenditures.
- the supply and high cost of capital.
- licensing and other delays affecting the

construction of new facilities.

We have just seen that solar ponds impose risks that must be carefully considered in making an investment decision. One of factors in the future of solar ponds investment is the financial condition of the electric utilities. For the last decade the financial condition has deteriorated.

The rapidly escalating costs of debt, together with the massive amount of debt sold by the utilities to meet load growth forecasts; while inflation, regulatory lag, and politics have combined to hold back rate increases and earnings growth making utility stocks very unattractive.

In this kind of climate , it is difficult for utilities to raise capital for any kind of major investment, let alone technologies like solar ponds considered risky.

## CHAPTER 6

## CONCLUSION

The preceding analysis of this thesis topic on utility investment in solar ponds has shown that the major barrier to solar ponds is the high cost of these facilities coupled with the uncertain financial regulatory environment of the electric utility industry. The energy cost of 145 mills/kwh does not compare favorably with the 50 mills/kwh figure generally taken as the avoided cost of energy generated by conventional coal and oil burning power plants.

The current policies that give incentives to third party power producers to invest in solar ponds, while exempting electric utilities, constitute a definite disincentive to the electric utility industry especially when the industry is in a state of general financial distress.

On the solar ponds themselves, additional research is needed to obtain better cost estimates to reduce uncertainty and risk and to improve the feasibility and adaptability at various sites throughout the United States concentrating on new construction technology to reduce technical costs and to meet the environmental requirements

of large scale solar ponds.

The framework presented to analyse the cost of these ponds can be adapted to other facilities such as wastewater reservoirs, storage reservoirs in the oil and gas industry, and most land intensive reservoir construction facilities. The section on site conditions and economies of scale provides a new approach in estimating the size, depth, and costing of solar ponds and reservoirs. It shows that these facilities are highly site specific cases where the actual construction of these ponds will have to be reduced to a minimum to minimize the costs.

It seems that at the present time, utility interest in solar ponds will be limited to agreements where a utility could operate a small power production facility that it did not own and still have the facility qualify for the incentives provided under PURPA.

This is illustrated by the recent agreement between the Government of Israel and Southern California Edison Co. to build a 40 MW solar pond at Danby Lake. The agreement calls for SCE to buy the power from the solar pond at the avoided cost. This agreement results in the first large scale pond to be built in the US and will be the true testing ground for large scale solar pond technology.

## BIBLIOGRAPHY

Fynn, R.P. and T.H. Short. "Solar Ponds - A Basic Manual" Special Circular 106. Wooster, Ohio: The Ohio State University, Ohio Agricultural Research and Development Center, Feb. 1983.

Tabor, H. "Non-Convecting Solar Ponds" Phil. Trans. R. Soc. London. A, Vol. 295, 1980, pp. 423-433.

Tabor, H. "Review Article Solar Ponds" Solar Energy. Vol. 27, No. 3, 1981, pp. 181-194.

Harris, M.J. and L.J. Wittenberg. "Construction and Startup Performance of the Miamisburg Salt Gradient Solar Pond" Journal of Solar Energy Engineering. Vol. 103, Feb. 1981, pp. 11-16.

Hull, J.R. et al. "Construction and First Year's Operational Results of the ANL Research Salt Gradient Solar Pond" Proc. AS/ISES. Houston, June 1-5, 1982.

Hull, J.R., Y.S. Cha and W.T. Sha. "Major Design, Construction and Operational Considerations of Salt Gradient Solar Ponds" Proc. of Pan American Congress on Energy Alternatives and National Congress on Renewable Energy Technologies.

Nielson, C.E. "Experience with a Prototype Solar Pond for Space Heating" Sharing the Sun, Vol. 5, Proc. Joint Conf. of American and Canadian Solar Energy Soc. Winnipeg, Canada, 1976.

Nielson, Carl E. "Salt Gradient Solar Pond Development" Proc. Annual DOE Active Solar Heating and Cooling Contractors Review Meeting. The Ohio State University Research Foundation, March 1980.

Tabor, H. and Z. Weinberger. "Non-Convecting Solar Ponds" Solar Energy Handbook. New York: Kreider McGraw Hill, 1980.

Zangrando, F. and M.C. Bryant. "Heat Extraction from a Salt-Gradient Solar Pond" Proc. International Conference on Alternative Energy Sources. Washington, D.C. Vol. 6, 1977, pp. 2935-2967.

Engineering News Record, Bid Abstracts, various issues, 1983.

Markow, M.J. and P. Dintrans. Solar Pond Construction, Maintenance, and Costing. Cambridge, MA: Center for Construction Research and Education, Massachusetts Institute of Technology, February 1984.

A Study of the Feasibility of a Solar Salt Pond Generating Facility in the State of California, USA, Vols. I and II. Prepared for Southern California Edison Company. Yavne, Israel: ORMAT Turbines, May 1981.

Church, H.K., Excavation Handbook. New York: McGraw-Hill, 1981.

Private Communication with Salt Institute, 206 N. Washington Street,  
Alexandria, VA 22314.

Private Communication, Burke Rubber Company.

Private Communication, Shelter Rite Company.

Jet Propulsion Laboratory. Regional Applicability and Potential of Salt  
Gradient Solar Ponds in the United States, Volume II. Prepared for U.S.  
Department of Energy. DOE/JPL-1060-50, Vol. 2, March 1982.

California Energy Commission. A Study of the Feasibility of a Solar Salt  
Pond Generating Facility in the State of California, USA. Final Report,  
Vols. I and II, May 1981.

Monbright, J, Principles of Public Utility Rates, Columbia  
University Press, NY, 1961

Public Utility Regulatory Policies Act of 1978, Public Law  
95-617, November 1978.

Jean & Miller, utilities at the dawn of a solar age, N.D.L.  
review, 1977

Anderson, Bruce, The public utility and solar energy  
interface, Wash ERDA, Dec 1976

Jones, Judicial determination of public utility rates, Boston  
U. Law review 873, 1974

Booz, Allen & Hamilton, The effectiveness of solar energy  
incentives at the state and local level, Wash D.C. P-B 263  
371, March 1976

Felman, S, Utility pricing & solar energy design, prepared  
for NSF, grant APR 75 16006

Koger, Regulatory restraints on solar energy, Public Utility  
Fort. Jan 19, 1978

Mayo, L, Legal- Institutional implications of solar systems,  
prepared for the program of policy studies, George  
Washington University, 1977, NSF

Finch, T, Wind & Solar at East 11 St. Wind power digest,  
summer 1977.