Salton Sea Project
Phase 1

Final Report

M.L. Peelgren

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ABSTRACT

A feasibility study was made for a salt gradient solar pond power plant in or near the Salton Sea of California. The conclusions are very supportive of continuing the project into the next phase; design and construction of a 5-MWe proof-of-concept experiment, and ultimate construction by an electric utility company of a 600-MWe plant. The Solar Pond concept will provide an environmental benefit to the Salton Sea by reversing the increasing salinity trend that, if unchecked, will eventually kill all life in the sea. The greatest cost drivers determined for the 5-MWe plant are the lake dike construction and pond sealing. Problems remaining to be resolved include method of brine production from Salton Sea water for the first unit (which will require evaporation pond area and time), the high turbidity and color content of the Salton Sea water (which will require pre-treatment), and other questions related to pond permeability, bio-activity and soil/brine chemical reactions. All technical and environmental problems appear solvable and/or manageable if care is taken in mitigating impacts.

ACKNOWLEDGMENT

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EXECUTIVE SUMMARY

INTRODUCTION

This report presents the results of a feasibility study made for a salt gradient solar pond power plant in or near the Salton Sea of California. The conclusions drawn from this effort are very supportive of continuing the project into a 5-MWe (megawatt electric) proof-of-concept experiment to provide the baseline data and experience required for utility implementation of a 600-MWe plant at the Salton Sea and the development of the technology for use throughout the United States.

The project, as currently planned, has multiple phases and multiple sponsors. Phase 1, a feasibility study, is now complete. The next phases are: Phase 1a, Conceptual Design; Phase 2, 5-MWe Design and Construction of a Proof-of-Concept Experiment; and Phase 3, 600-MWe Commercialization. The project sponsors for Phase 1 are the Department of Energy (DOE), the California Energy Commission (CEC), Southern California Edison Company (SCE), the Department of Defense (DOD), and Ormat Turbines Ltd. of Israel (Ormat). The total funding level for the Phase 1 study was $650K, made up of the following contributors: DOE, $300K; CEC, $100K; SCE, $100K; DOD, $50K; and Ormat, $100K.

The sponsors and funding participation level for Phases 1a and 2 will be DOE at 50%, CEC at 25% and SCE at 25%. Phase 3 will be strictly a utility function, funded at 100% by SCE.

The feasibility study was performed by a team composed of SCE, the Jet Propulsion Laboratory (JPL), Ormat, and WESTEC Services, Inc. (WESTEC). Overall project management was provided by SCE and technical management provided by JPL. This report presents the results of the entire team. Ormat and WESTEC reports have been included as attachments.

The basic ground rules for the feasibility study were to gather and organize existing data and to conduct a study addressing the questions of technical, economic and environmental feasibility. Ormat conducted site and system analyses, JPL provided technical management and addressed important site-specific technical issues, and WESTEC evaluated the environmental implications of constructing and operating a solar pond plant on the Salton Sea. Effort has been expended to inform private and governmental institutions and to share information and plans.

The DOD's involvement in the project broadened the study to include an evaluation of the potential of solar pond power plants in other areas of the United States. An additional JPL effort, therefore, has been a survey to estimate that potential.

OBJECTIVES AND PERFORMANCE

Two candidate sites were evaluated for a 5-MWe proof-of-concept experiment. The primary site is located on the Salton Sea within the U.S. Navy test range on the western shore. This site is called the "wet" site. A

secondary site, called the "dry" site, is located at Bristol Lake (a dry inland desert lake). The initial major requirements of the 5-MWe concept were to produce 5-MWe gross baseload power 12 months of the year utilizing the energy derived from a salt gradient solar pond. Performance estimates at both the wet and dry sites are similar. A 250-acre solar pond will support year-round baseload operation and achieve a 66% load factor and a power profile that lies within a 5-MWe +15% band. The difficulty (and consequently the cost) of constructing a solar pond in the lake at the wet site is greater than at the dry site. However, because the real commercial potential (abundant water supply) is at the wet site, the primary focus remained at the Salton Sea site.

During the study, cost estimates of $35,000,000 began emerging for a 250-acre solar pond power plant within the Salton Sea. To reduce costs, a re-examination of the requirements of the proof-of-concept experiment were made, and options that retained the 5-MWe capacity but reduced solar pond acreage were evaluated. Comparable cost estimates of $20,000,000 to $25,000,000 were made.

The economics of a 600-MWe plant are very promising. Early cost estimates by Ormat are 1.1 billion (1981) dollars, which translates to an installed cost of $1830/gross kWe or $2290/net kWe. The corresponding busbar energy costs for a commerical operation initiated in 1990 is 85 mills/kWh in 1981$.

The commercial plant will be constructed of modules. Each module will consist of a 50-MWe power conversion unit coupled to a 2200-acre solar pond. A 600-MWe plant will therefore be composed of twelve modules.

One of the important factors influencing performance at the Salton Sea is upper zone water clarity. The Salton Sea water has high turbidity and color, which must be reduced or removed. Activated charcoal treatment has been found to be effective.

Solar pond brine will be created from the evaporation of Salton Sea water. For the initial plant, brine production becomes an important cost, space and time issue. For a 250-acre solar pond, 625 acres of evaporation ponds and 5 years are required to produce a full (11.5-ft) solar pond storage zone. Fortunately, power plant operation can begin with a partially filled storage zone after 2 years of brine production.

In the long term, the relatively low salinity of the Salton Sea (3.8%) is more a benefit than a liability. After a pond has been established, direct use of the Salton Sea water as the pond surface flushing water is practical. At some locations, like the Great Salt Lake or the Dead Sea in Israel where heavy brine is abundantly available, a source of low saline surface flushing water is a major factor, perhaps even a limitation, on the deployment of solar ponds. In the commercial concept at the Salton Sea, the sequential installation of modular units is most compatible with brine production, as one of the products of pond operation is an output stream containing an increased level of salinity. Thus, the first module helps to produce brine for subsequent modules, and large dedicated evaporation ponds will not be required.

Environmentally, the benefits of a large solar pond complex in the Salton Sea are significant. Operating ponds will take saline water from the lake. This process, together with a low salinity level inflow to the lake, will

produce a gradual salt concentration reduction. The current salt concentration in the Salton Sea is about 38,000 ppm (parts per million) and increasing. In a few years, plant and fish life will begin to disappear unless some means is initiated to reverse the salinity trend.

The major environmental concerns relative to a solar pond involve disposal of dredge bottom surplus, temporary stirring of lake bottom muds and settled debris, displacement of possible fish spawning grounds, and disposal of long-term salt and brine byproducts of solar pond operation. All of these concerns appear manageable at this time.

CONCLUSIONS

The major conclusions from the Phase 1 feasibility study are as follows:

(1)   Solar pond power plants in the Salton Sea are judged to be technically, environmentally and economically viable.

(2)   Baseload electric power generation is achievable from solar ponds.

(3)   The greatest cost drivers for the 5-MWe proof-of-concept experiment are the lake dike construction and pond sealing.

(4)   Salton Sea water has high turbidity and color content and must be treated before use in a solar pond.

(5)   Production of brine from Salton Sea water for the first solar pond unit will require space (evaporation ponds) and time.

(6)   All environmental problems appear to be manageable.

RECOMMENDATIONS

It is recommended that the project should be continued into the next phase, Phase 1a. The focus of the study should be along the following lines:

(1)   Develop a system concept design for the wet site.

(2)   Conduct a comprehensive geotechnical investigation.

(3)   Conduct dike design option studies to determine the lowest cost configuration.

(4)   Continue experiments to resolve questions related to brine compatibility, pond bio-activity and soil/brine chemical reactions.

When these are completed, reliable cost/schedule information can be issued. These data will be useful in making the decision to proceed to Phase 2, the final design and construction of the proof-of-concept experiment.

SECTION I

INTRODUCTION

A.   PROJECT DESCRIPTION

The idea of converting a portion of the Salton Sea into salt gradient solar ponds for the dual purpose of generating commercial electric power and controlling the salinity of the lake was suggested in 1978. By November 1979, a project concept was formulated and a feasibility study initiated. The project as proposed has multiple phases. These phases are: Phase 1, Feasibility; Phase 1a, Conceptual Design; Phase 2, 5-MW Proof-of-Concept Design and Test; and Phase 3, 600-MW Commercialization. This report presents the results of the Phase 1 Feasibility Study.

B.   OBJECTIVES

The broad objectives of Phase 1 were to determine the technical, economic and environmental feasibility of constructing and testing a 5-MWe solar pond power plant in or near the Salton Sea as a proof-of-concept experiment and to assess the potential for a commercial installation. The study was conducted under multiple sponsorship with multiple participants.

C.   PROJECT ORGANIZATION

For Phase 1, the multiple sponsors are the U.S. Department of Energy (DOE), the U.S. Department of Defense (DOD), Southern California Edison Company (SCE), the State of California Energy Commission (CEC) and Ormat Turbines, Ltd., of Israel. The total funding level was $650K, made up as follows: DOE, $300K; DOD, $50K; SCE, $100K; CEC, $100K; and Ormat Turbines, $100K. The DOD participated through the Office of Civil Preparedness, with a specific objective of identifying other potential solar pond power plant sites.

The funding support for Phases 1a and 2 will be shared; 50% by DOE, 25% by SCE, and 25% by CEC. Phase 3, Commercialization, will be wholly a utility function without CEC or DOE participation.

The project was conducted within the organizational structure presented in Figure 1-1. Project management was provided by SCE and technical management provided by JPL. Ormat collected and organized the data base and conducted conceptual plant design, performance and cost analyses. JPL conducted site-specific studies related to solar pond chemistry, soil biological activity, and dike design and construction. WESTEC Services, Inc. of San Diego, California, conducted environmental investigation studies and performed an environmental assessment. SCE provided planning support for licensing and permitting and technical evaluations of the system design and cost estimate.

Actual project contracting and money transfers differed from Figure 1-1. The CEC funding support was channeled through SCE and SCE contracted directly with Ormat. The DOE and DOD dollars flowed through JPL to support the JPL

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                    │   PROJECT    │
                    │  DIRECTOR    │
                    │    SCE       │
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                    │   PROJECT    │
                    │  TECHNICAL   │
                    │  MANAGEMENT  │
                    │    JPL       │
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```

JPL
- WESTEC CONTRACT
- SOLAR POND OPERATION
- SUPPORT ORMAT
  CONCEPT STUDIES
- SITE SURVEY
- PHASE 2 MANAGEMENT
  PLAN

SCE
- ENSURE PRACTICALITY
  OF STUDY
- REVIEW DESIGN AND
  COST ESTIMATES
- SITE SELECTION
- UTILITY REQUIREMENTS

ORMAT
- POND CHARACTERISTICS
- 5-MWe CONCEPT DESIGN
- OPTIMIZE MODULE SIZE
- COST ESTIMATES
  (5- AND 600-MWe PLANTS)

WESTEC
- ENVIRONMENTAL
  - SENSITIVITY MAPS
  - SETTING DATA, 5 MWe
  - IMPACT, 5 MWe
  - FEASIBILITY, 600 MWe

Figure 1-1. Solar Ponds Project Organization

management and technical activities and the contract award to WESTEC. The
project organization, as reflected in Figure 1-1, worked congenially and
effectively due, in large measure, to the commitment and dedication of all
participants.

D.   SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The results of the Feasibility study are positive. A 5-MWe baseload
proof-of-concept solar pond power plant can be constructed within the Salton
Sea or at Bristol Lake, a nearby dry lake site. For baseload operation, the
solar pond will be 250 acres in size and 15-ft deep. Electrical output can be
sustained throughout the year at a 5-MWe +15% gross power output level. The
estimated cost of building this plant is $35 to $40 million (1980 dollars).
The plant could be constructed and made operational by 1985.

Preliminary cost estimates made by Ormat for a 600-MWe commercial
installation are $1830/kW (gross output) installed (1981 dollars). The
corresponding busbar energy costs for a commerical operation initiated in 1990
is 85 mills/kWh, in 1981$. A commercial plant will be constructed from 50-MWe
modules and is readily adaptable to a multi-year phased construction strategy.

The net environmental benefit of a commercial installation in the Salton
Sea is very positive because such a plant will reverse the increasing salinity
level of the Salton Sea. Currently, the salinity of the Salton Sea is
increasing toward 40,000 ppm and life in the lake is being threatened. The
withdrawing of lake water into large-area solar ponds will provide a salt
outflow and after many years will stabilize the salt concentration near
30,000 ppm. During construction of the 5-MWe plant, some local disruption of
the lake ecology will occur. This, however, will be temporary and no sustained
environmental degradation is anticipated.

Important issues and design considerations which must be resolved in the
next phase of work have been identified. These items include (1) cost and
method of dike construction in the lake, (2) brine production prior to system
startup, and (3) water treatment plant design.

SECTION II

TECHNICAL APPROACH

A.   INTRODUCTION

The goal of the Salton Sea Solar Pond Project is to conduct a proof-of-concept experiment to provide the technology base and experience to facilitate implementation of the technology throughout the United States. The development of solar ponds in the Salton Sea for the purpose of generating commercial electric power would then be used as a baseline by other utilities. Phase 1 of this effort, Feasibility Studies, included assessments of both the "wet site" (Salton Sea) and the "dry site" (Bristol Lake). This work was done by Ormat Turbines, Ltd. An environmental assessment was performed by WESTEC Services Inc. Specific site studies were performed by JPL and SCE.

As the feasibility study progressed, several factors became apparent and influenced the direction of the study, placing additional emphasis on certain aspects of the study and involving some basic changes to the plant configuration. These factors are discussed in detail below and are reflected in the direction of the sections following. Stated briefly, these factors are:

(1)   The desire to start operation of the plant before a full inventory of brine could be produced led to evaluations of pond depth, pond area and brine production methods.

(2)   As early estimates of total project cost were made, it became apparent that projected costs were increasing. Decreasing solar pond size to reduce overall project costs was considered a reasonable option to pursue. Another significant cost factor was dike construction, and alternate methods of construction were studied. Ponds required for brine production were also studied to determine the lowest cost commensurate with delivery of required inventory when needed by the project.

(3)   The water treatment procedures necessary to attain the quality needed were somewhat different than what originally had been anticipated.

(4)   A project decision was made to institute an additional phase in the project (Phase 1a) to generate realistic cost and schedule estimates.

The interaction of these factors resulted in some reallocation of resources in order to initiate studies that would answer the questions presented.

B.   SYSTEMS DESIGN (ORMAT)

1.   Description

This section presents the work performed by Ormat Turbines, Ltd. to study the feasibility of a solar salt pond electric power generating facility

in Southern California. Ormat was under contract to SCE to perform the work.
The work performed by Ormat included the following:

> (1) Site data acquisition and analysis.
>
> (2) Potential site evaluation.
>
> (3) Proof-of-concept (5 MWe) optimization.
>
> (4) Cost estimate and schedule of the 5-MWe proof-of-concept facility.
>
> (5) Commercial plant (20 MWe to 600 MWe) feasibility evaluation.

2. Summary

The climatological, hydrological and physio-chemical boundaries and constraints were determined within which a 5-MWe proof-of-concept solar pond power plant (SPPP) and 50-MWe modules generating up to 600 MWe of power are feasible at the Salton Sea and at an inland "dry site" (Bristol Lake). Existing climatic, geotechnical and solar pond characteristics were compiled and, on the basis of analyses of solar pond response as well as design and operational conditions, an optimized 5-MWe SPPP plan is presented, including physical and construction features of both sites, major equipment description, and mass flow and energy balances. Equipment arrangements are proposed and a preliminary system reliability estimate is provided. Estimates of cost and construction schedule for the 5-MWe proof-of-concept SPPP were given for both sites. A preliminary cost estimate for a commercial plant using 50-MWe scaled-up SPPP modules for generating power in the 600-MWe range is also given.

Evaluation of the feasibility of the commercial SPPP includes determination of the optimum unit module size (50 MWe) and description of the physical and construction features of a possible area of the Salton Sea to be used for the commercial 600-MWe facility. Optimization studies were performed to define the solar ponds and power-generating equipment for baseload operation based on the minimum installed cost of electricity per kilowatt. In support of the Ormat activity, JPL conducted an economic analysis to estimate the busbar energy cost (BBEC) for the SPPP. Delivered energy costs can be expressed as BBEC, which is the minimum price that solar pond energy users would have to pay in order for investors to cover solar pond system costs. The BBEC are basically the present value of the annualized life cycle costs divided by the annual energy output. The BBEC for the 600-MW electric power plant at the Salton Sea, in mills/kWh, 1981$, are estimated as:

	1985	1990	1995	2000
BBEC	84	85	86	87

Each year represents an initial year of commercial operation. The estimates are based on installing a 600-MW plant each time, as opposed to accounting for the interdependencies which will accrue from installing twelve 50-MW modules.

Busbar energy cost estimates vary widely depending on the assumptions made. The base case assumptions for these estimates are as follows:

Capital cost (kW installed)	$ 1,830
Operations & maintenance (10^3 $/yr.)	14,230
Net electrical power output (W_e/m^2)	3.11
System lifetime (years)	20
Depreciation method	Sum-of-years-digits
Construction time (years)	2
Discount rate (nominal)	11%
General inflation rate	7.2%
O&M escalation rate (nominal)	9.3%
Capital escalation rate (nominal)	7.2%
Miscellaneous expense rate	2.25%
Investment tax credit	10%
Tax rate	51%

For a discussion on the methodology used to calculate the $\overline{BBEC}$ and a brief discussion on the sensitivities of the cost estimates to the various assumptions, please see Appendix C.

3.   Conclusions

The Salton Sea site was determined to be technically feasible for both a 5-MWe proof-of-concept SPPP and a 600-MWe commercial facility composed of 12 50-MWe modules (operation of such a facility at the Salton Sea provides a unique opportunity to combine commercial electric power generation while simultaneously improving the environmental state of the Sea by absorbing its excess salinity). The Bristol Lake site was found to be suitable for a 5-MWe Proof-of-Concept SPPP, but not for a 20- to 50-MWe unit nor for a 600-MWe commercial facility. Evaluation of the potential performance of a 5-MWe SPPP located at the two sites shows that a solar pond area of approximately 250 acres can sustain an SPPP with a gross power output of 5 MWe. The installed cost of electricity for a 600-MWe SPPP at the Salton Sea is estimated by Ormat to be approximately $1830/kW (gross output, 1981 dollars), and the baseload factor is 0.63. The corresponding busbar energy costs for a commercial operation initiated in 1990 is 85 mills/kWh, in 1981 $.

4.   Reference

The Final Report by Ormat (in two volumes) to SCE is included in this report as Attachments A & B. Detailed discussion of Ormat's analyses, evaluations, optimizations, and computations are presented.

C. ENVIRONMENTAL ASSESSMENT (WESTEC)

1. Description

The environmental assessment for the proposed site at the Salton Sea was performed by WESTEC Services under contract to JPL. In the performance of this contract, WESTEC efforts included the following:

(1) Assembled available site data.

(2) Performed an environmental screening of selected sites at Salton Sea.

(3) Prepared an environmental setting report.

(4) Prepared an environmental impact assessment for the proof-of-concept 5-MWe plant.

(5) Prepared an environmental feasibility report of the 600-MWe commercial plant.

2. Summary

The WESTEC effort was directed toward a number of studies aimed at determining the environmental feasibility of implementing a solar pond power plant at the Salton Sea. The results of WESTEC's environmental studies for the 5-MWe proof-of-concept plant can be grouped into three categories:

(1) Anticipated impacts which have been reasonably well defined.

(2) Identified data gaps involving the design, construction, or operation of the 5-MWe proof-of-concept.

(3) Areas of potential impact that cannot be fully defined until the data gaps identified in Item (2) above have been resolved, until further fieldwork has been accomplished, or, in some cases, until the 5-MWe proof-of-concept plant is actually operating.

Based on these results, and despite the fact that a lack of data in some areas precludes a full and detailed analysis of all impacts at this time, it currently appears that the 5-MWe proof-of-concept plant could be constructed and operated without incurring significant adverse environmental effects. This conclusion is based on the assumption that final resolution of the project data gaps will not result in an unacceptable set of related impacts and that adequate mitigation of certain identified impacts can be accomplished.

3. Conclusions

Based on the results of the environmental impact analysis conducted by WESTEC in the 5-MWe proof-of-concept plant and the feasibility analysis on the larger 600-MWe commercial facility, the following statements can be made:

(1)   The 5-MWe project appears to be completely feasible, and following receipt of the necessary permits can be constructed and operated as an experimental project with little or no adverse effect on the environment.

(2)   The feasibility of the 600-MWe facility will depend in part on the results of operating the smaller experimental pond. Considerable additional data regarding the project itself plus further environmental baseline studies appear to be necessary in order to complete a full evaluation of the 600-MWe project. To date, a number of potentially adverse environmental effects have been identified for the larger commercial facility; however, most of these can be effectively mitigated through appropriate project design, construction and operation. The others can probably be resolved through a careful and sensitive location and siting effort within the Salton Sea. None of the impacts identified so far would make the project totally infeasible, provided that the aforementioned mitigation and siting efforts are carried out.

4.   Reference

The Final Report (draft copy) by WESTEC to JPL is included in this report as Attachment C. Detailed discussion of WESTEC's work is presented there.

D.   WATER AND SOIL CHEMISTRY STUDIES (JPL)

1.   Introduction

This section reports on the Phase 1 investigation of the chemical[1] aspects of the Salton Sea as a site for solar pond electric power production. A number of site-specific chemical factors have been identified by the participants (Ormat, WESTEC, and JPL) that can affect essential characteristics of solar pond power plants (SPPPs) and thus can influence the question of feasibility.

In the year ending March 1981, three of the five characteristics critical to feasibility of the Salton Sea site were investigated intensively. Work on these characteristics is continuing; however, the results obtained are complete enough to indicate that these characteristics, suitable water and brines, adequate light transmission, and a stable gradient, can be provided. The remaining two critical characteristics, ingredient conservation and environmental protection, will be investigated when candidate local clays for pond sealing have been identified and sampled. In this work, some potential problems were encountered. However, practical solutions to those problems were developed.

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[1]In this work, chemical aspects of solar ponds include elements of microbiology, metallurgy, physics, and chemical engineering.

Thus far in the investigation, all measures that have been found necessary for the construction and operation of a solar pond system at the Salton Sea are based on established industrial technology. It appears that this will also be true for the characteristics which have not yet been investigated. Therefore, the study team remains confident that a solar pond electric power plant at the Salton Sea is feasible.

This report has a second purpose. While investigating the feasibility of solar ponds at the Salton Sea, JPL has been developing a comprehensive methodology for site-specific evaluations in general. The methodology development is not finished; however, it has reached the stage where it is possible to lay out, in a cohesive, organized array, all of the work that has been done in the Salton Sea investigation and most of the work that should be done. For this reason, the remaining discussion in this section is divided into two coordinated parts:

(1)   Required solar pond characteristics and site-specific factors affecting them.

(2)   Investigations and results.

In certain instances, the latter discussion is supported by items in the Appendix, one of which is a published paper describing work done at JPL.

2.   Required Solar Pond System Characteristics and Site-Specific Factors Affecting Them

Table 2-1 shows seven essential characteristics of SPPPs which have been identified in the present stage of this work that can be affected by site-specific chemical (and biological, etc.) factors. These factors must be investigated for each proposed site-system combination to find out if all of the essential characteristics can be provided economically. To illustrate the application of these concerns to solar ponds at the Salton Sea, the major elements of a solar pond system are displayed in Figure 2-1. For a SPPP to be feasible, the following conditions must exist:

(1)   Water and brine having appropriate compositions must be provided at required rates.

(2)   A significant fraction of the incident solar radiation must be transmitted through the upper convecting layer and the gradient layer to the storage zone.

(3)   The gradient zone must be maintained and controlled to ensure a stable, nonconvecting operation.

(4)   Design heat-transfer coefficients must be maintained in the boiler and the condenser.

(5)   All materials in contact with waters and brines must be durable in that environment.

(6)   Essential ingredients (chiefly water and brine) must be conserved.

Table 2-1. Factors Affecting Solar Pond Feasibility and Approaches to Evaluation and Treatment

Laboratory Investigations

Solar Pond Characteristics/Affecting Factors

	A Brine Chemistry	B Light Transmission	C Soil Bio-Activity	D Soil Properties	E Pond Bio-Activity	F Diffusion	G Heat Transfer	H Corrosion
1. Water/Brine Preparation								
1.1. Process Definition	■							
1.2. Saturated Salts	■							
2. Light Transmission								
2.1. Inherent Turbidity		■						
2.2. Inherent Color		■						
2.3. Wind-Borne Dirt	□							
2.4. In-Pond Precipitation	■	■	■					
2.5. Suspensions From Bottom			■					
2.6. Color From Bottom				□				
2.7. In-Pond Organic Growth					□			
3. Gradient Stability								
3.1. Gradient Control		■						
3.2. Diffusion			■			□		
3.3. Liner Failure				□				
3.4. Gas From Bottom			■	■				
4. Heat Transmission								
4.1. Mineral Scale	■						□	□
4.2. Bio-Fouling					□		□	
5. Materials Durability								
5.1. Corrosion								□
5.2. Liner Degradation				□				
6. Ingredient Conservation								
6.1. Evaporation	□							
6.2. Leaks, Seepage				□				
6.3. Additive Recovery	□							
7. Environmental Quality								
7.1. Earthwork				■				
7.2. Brine Loss, Disposal	■			□				

Legend

■ Laboratory Investigations Reported Here

□ Investigations Identified But Not Pursued
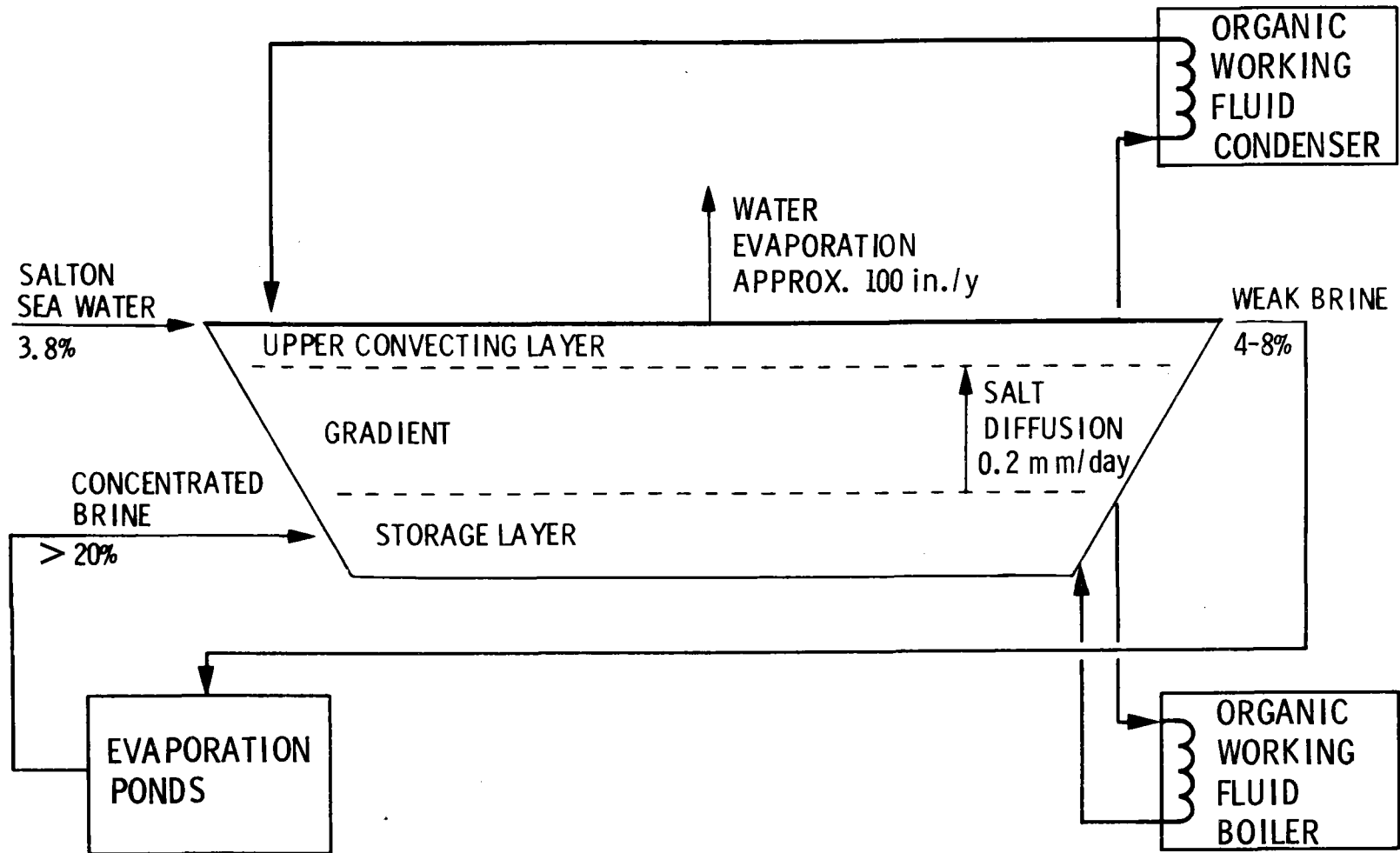
Figure 2-1.   Generalized Schematic Diagram for a Solar Pond Electric Power System at the Salton Sea

(7)   The environmental impact of construction and operation of the
system must be acceptable.

All of the seven essential characteristics are listed in Table 2-1.
Under each are the chemical factors that have been identified as having
potential for affecting them. Coordinated with these factors in the grid
arrangement, are the titles of the investigations being conducted to evaluate
the factors. Because of limited resources, all of the investigations have not
been made. In the following two subsections, only those factors and
investigations in which work has been carried out will be discussed.

a.   Water and Brine Preparation. A fundamental part of the plan
for the Salton Sea Solar Pond Project is the use of Salton Sea water as the
only source for both water and brine. The total dissolved salt concentration
of Salton Sea water is approximately 3.8%, by weight. This concentration is
appropriate for surface flushing of solar ponds. To provide the brines for the
storage and gradient layers, a process which will concentrate Salton Sea water
is required. Solar evaporation is the anticipated process with potential
enhancement with sprays.

The laboratory investigation of brine preparation included evaporation
and blending experiments, chemical analyses, and density measurements. These
experiments are discussed under Investigation A in the latter part of this
section.

Salton Sea water is saturated in calcium sulfate and calcium carbonate.
When this water is concentrated to make brine, precipitation of these salts is
to be expected. This occurred consistently in the evaporation experiments
conducted for the investigation. Calculations based on the resulting data
indicated that approximately 9% more water will have to be removed in
evaporation to make 20% brine than would be the case if no salts precipitated.

b.   Light Transmission. Only that fraction of solar radiation
which penetrates both the upper convecting layer and the nonconvecting gradient
is recoverable for the production of power. Recent solar pond computer model
calculations at JPL indicate that continuous, net solar pond electric power at
the Salton Sea should range from 2.5 to 4.5 Wm^{-2}, depending upon light
transmission of 20% to 35% to the storage zone.

Laboratory measurements of Salton Sea water and brines and computer
modeling of an assumed gradient predicted a transmission of only 8%. Similar
treatment of distilled water (which, of course, could not insulate a solar pond
storage zone) yielded a prediction of maximum possible transmission to the same
depth of 45%. Subsequent investigation demonstrated that Salton Sea water and
brines could be improved by conventional water treatment processes, yielding a
prediction of approximately 24% transmission.

These results highlighted the importance to solar ponds of a
comprehensive approach to light transmission, in terms of both assessment of
quality and methods for improving quality. As far as the methodology has been
developed, the main elements are organized in Table 2-1. Seven factors
affecting light transmission are listed in coordination with appropriate

laboratory approaches for studying them. Each of these will be discussed briefly below.

Of the seven classes of light-transmission-inhibiting contaminants listed in Table 2-1, potential sources for the first three (2.1 to 2.3) are external to the pond. The remaining four classes (2.4 to 2.7) can be generated within the pond. Although the first two classes of contaminants can be removed in advance of introduction into the pond by treatment of water and brines, the last four types must be prevented or, if not prevented, eliminated from the pond itself. The third class, wind-borne dirt, is special. It cannot be removed in advance, and it probably cannot be prevented. In certain instances, removal of wind-borne dirt from solar ponds has been demonstrated by other solar pond applications.

Inherent Turbidity and Color. Salton Sea water contains suspended matter and dissolved light-absorbing substances. The investigation demonstrated that the suspensions could be removed by settling and filtration and that a major fraction of the color could be removed by contact with activated carbon. These treatments produced the three-fold increase in predicted light transmission cited above. Fundamental in the methodology used in this work are two techniques developed at JPL, one chemical, the other mathematical. In the chemical technique, the attenuating effect of both dissolved and suspended contaminants on light transmission is measured as a function of wavelength in a spectrophotometer. The mathematical technique, which is computerized, uses these data first to estimate the fraction of given insolation (also in a spectral distribution) that will reach the storage layer of the solar pond. Through a one-dimensional model, the technique then estimates the real performance of a solar pond under the given conditions. In general, transmissions of light energy to the storage zone of 20% predicted in this way are considered to be acceptable. The laboratory and mathematical modeling studies are described under Investigation B in the latter part of this section.

It is the belief of the study team that the predictions of solar pond light transmission cited above are conservative. However, the degree of error is not presently known. The present method of measurement excludes wide-angle forward scattering. Further uncertainty exists because of unavoidable mathematical amplification of instrument error. These problems are being studied with the aims of improving the method and of developing methods for quantitatively estimating error. Verification of predictions in model ponds is also planned.

Wind-Borne Dirt. The key questions about dirt that will be blown into a solar pond are:

(1) Is the density of a significant fraction low enough for the material to become suspended in the gradient?

(2) Although dense enough to settle, is there a significant fraction that will settle at a slow rate?

(3) How frequently are such events likely to occur?

(4)   How can such problems be treated economically, if they exist?

The first two questions can be answered in the laboratory, providing adequate sampling has been done. Performing adequate sampling and determining the frequency of wind-borne dirt events will require regular, periodic site visits. Work on this factor has been deferred until such a schedule is possible.

In-Pond Precipitation. A phenomenon unique to certain salt-gradient solar ponds was discovered in the Salton Sea evaluation. If flushing water and brines come from the same source (the latter being derived by evaporation), and if the source is saturated in a given salt (calcium sulfate and carbonate in this case), then a tendency exists for continual precipitation of that salt in the gradient zone. This phenomenon was predicted from chemical analysis data (Investigation A) and was observed in laboratory gradient columns (Investigation C). Observation and qualitative transmission measurements (Investigation B) indicate a probability that the settling rate of the precipitate exceeds the rate of precipitation. This needs to be verified in model pond experiments.

Suspensions Arising from the Pond Bottom. Essentially, the same questions about wind-borne dirt must be posed about suspensions arising from a pond bottom. However, in this case, it was possible to do a limited laboratory investigation (Investigation C). During this study, one of four gradient columns, each with Salton Sea subsoil in the bottom, exhibited one transient band of turbidity which could have originated in the soil. Its source was not determined. No other evidence of this phenomenon was observed. Future tests for this potential problem will be made with materials that are planned for use in the upper layers of actual pond bottoms.

Color Arising from the Pond Bottom. There has been no specific testing of Salton Sea materials for this potential problem. However, no added color has been observed in other studies where, if it occurs, it should be evident. Tests with non-Salton Sea soils and clays have warned that extraction of soluble, colored substances from the soil liner is a possibility that must be investigated. Although extraction in a pond will occur chiefly in the storage zone, the color will migrate by diffusion into the upper layers. Here again, this will be investigated with materials that are planned for use in the upper layers of pond bottoms.

In-Pond Organic Growth. Previous investigators have encountered a problem with the growth of organisms in solar ponds generating sufficient populations to cause significant inhibition of light transmission. General identifications included green and red algae and bacteria. Appropriate application of biocides has been found effective. Although this phenomenon has not been actively studied, some incidental observations are worth noting. Algal colonies have been observed in shoreline ponds at the site. Suspended and dissolved organic matter in Salton Sea water is biological in origin. On the other hand, in-situ turbidity development which could be interpreted as being organic has not been observed in any of the laboratory experiments. All of the requirements for photosynthetic activity are available at the Salton

Sea, including nutrients from agricultural run-off. Therefore, this potential problem requires further study.

   c.   Gradient Stability. The heart of a solar pond is the gradient layer, which is a radiant energy trap. It allows sunlight to enter the pond and insulates the pond from the air and sky above it. The light-transmitting properties of a solar pond salt-gradient layer were discussed above; the insulating properties will be discussed here. Because the gradient layer is nonconvecting and infrared-absorbing, the controlling mechanism for heat loss to the air and the sky is simple thermal conduction through that layer. In the Salton Sea region, the net energy flow through the surface of a solar pond is estimated to be 80% to 85% into the pond. Convection is avoided in the gradient layer by the maintenance of a density gradient high enough to withstand the thermal gradient. This is done by initiating and maintaining a sufficiently high compositional gradient. Control, or management, of a gradient is required to offset the tendency for reduction in compositional gradient by natural ion diffusion. Thus, gradient control and diffusion are two of the factors that affect gradient stability. Two other factors which are destructive and must be avoided or prevented are (1) liner failure leading to vertical flow in the pond and (2) generation of gas at the bottom of the pond, which causes mixing.

   Gradient Control. In the Salton Sea ponds, brine upwelling (at a rate which matches diffusion) and surface flushing are the planned measures for gradient management. The required compositional range for providing these two streams is readily available using Salton Sea water as the single source. Sea water has an appropriate composition (3.8% salts) for surface flushing. By evaporation of Salton Sea water, brines containing as high as 28% salts can be obtained (see Investigation A).

   Diffusion. In their report, Ormat predicted an approximate average rate of salt diffusion up the pond to be 0.060 kg $m^{-2}day^{-1}$ (0.0123 lb ft^{-2} day^{-1}). This is equivalent to an upwelling rate of 0.18-mm day^{-1} of concentrated brine. A limited study of published diffusion data indicated this estimate to be correct for ambient temperature, but low for the temperatures expected in the bottom of a solar pond. No diffusion measurements have yet been made. However, gradient formation and durability were demonstrated in the laboratory gradient columns (see Investigation C).

   Liner Failure. The chief purpose of a liner in a solar pond is to prevent leakage or excessive seepage; this is needed to prevent loss of salt (and water) and to prevent contamination of ground water. In the Salton Sea Project, local materials (clays) are the planned application for lining. If a liner fails in an operating pond, not only are the above hazards possible, but there is the possibility of a third hazard – the gradient can become destroyed or damaged by the downflow at the leak. This form of gradient damage has been encountered in experimental solar ponds. Probably, the major measures which should be taken to avoid this problem are reliable compaction of the subsoil and reliable application of a liner with suitable properties. This factor has not been investigated for this project.

Gas Generated in the Pond Bottom. Gas evolution from the subsoil severe enough to destroy gradients has been encountered in experimental solar ponds. It was deduced from these experiences that the rate of anaerobic microbial activity native to the soil was increased by the higher temperature existing in the pond, generating gaseous metabolic products at a rate faster than the pond could absorb them. Clearly, it is imperative to evaluate all soil materials that are expected to be in the thermally affected zone of the pond container for this tendency.

Although pond construction can confidently be predicted to be feasible, two reasons remain why the work done at JPL thus far must be considered to be preliminary. Very limited soil sampling was done. Many parameters of the phenomenon have not been investigated. The tests showed: gas-producing bacteria exist in at least one of four soil samples; the rate and total amount of gas were too low to be disruptive; no measurable gas was produced at predicted pond bottom conditions. This work is described in Investigation C.

Investigation of this soil gas-production factor is continuing with several objectives. More representative soil sampling will be done. Research will be conducted to determine the conditions of salinity and temperature which will promote biological activity and those which will suppress it. These results will be verified by demonstration with systems which will gas vigorously under appropriate conditions. The temperature range will include not only the range of the soil-brine interface of a hot, fully-developed pond, but also the range of a heating, new pond and of the sub-soil below the interface.

d.   Environmental Quality. Two chemical factors which can have an effect on the environment have been identified: (1) earthwork in building the pond and its dikes will disperse material into the sea; (2) solar pond systems at the Salton Sea will require a net inflow of sea water and will produce a net outflow of brine, which must be disposed of safely. Any possible potential for leakage from the pond may also affect the environment.

With regard to the earthwork question, WESTEC asked for chemical analyses of soil samples for heavy metal and toxic organics concentrations. These analyses were done in Investigation D. Chemical analysis of brines (Investigation A) are provided to aid in the assessment of questions of brine disposal and potential pollution.

3.   Investigations and Results

a.   Salton Sea Site Samples. The Salton Sea Naval Base was visited in the middle of May 1980. Seven 10-lb samples of soil were taken. Six-hundred gallons of sea water were pumped and transported to JPL.

At JPL, the water was stored out-of-doors in its shipping containers: one 400-gal fiberglass-plastic tank and four 55-gal stainless-steel drums. At the site, the soil samples were placed into plastic bags in 1-gal paint tins; the bags were tied, and the tins were closed. At JPL, the tins were placed in a freezer for storage.

Because of a lack of adequate roads on the base for the water transporter, the water was pumped from the sea at a point approximately three miles south of the planned location of the 5-MWe solar pond pilot plant. The pump intake was placed approximately 50 ft from shore, one ft below the water surface. The sea was about 3 to 4 ft deep at that point. Locations and descriptions of the soil samples are given in Table 2-2.

       b.   INVESTIGATION A: Water and Brine Compositions and Physical Chemistry. The composition of Salton Sea water is given in Table 2-3. JPL measured the concentrations of the principal ions (Column 3). These are compared with values measured at a different location and at a different time (Column 4). The largest differences are in the analyses for calcium and for sulfate. However, the fact that one increases as the other decreases is compatible with our finding that the sea is saturated in $CaSO_4$ (calcium sulfate). Probably, the other differences are due to the difference in samples and to accuracy of the methods.

JPL-measured values give a reasonable picture of the composition. However, there is a gross error, which as yet has not been located. A charge balance calculation based on the values in Table 2-1 gives 17% excess negative ions for the JPL analyses. The same calculation for the same species using the Lawrence Berkeley analyses gives 0.11% excess negative. Including the other species does not change the balance materially. Problems with charge balance have occurred in brine analyses also.

Simultaneously, open pan evaporation was used to produce brines for the other investigations, and the process of evaporation was studied to obtain data

Table 2-2. Soil Sampling Data

Sample Number	Location			Description
	General Location	Feet from Shore (Sea = + Land = -)	Feet from Soil Surface	
1	At 5-MWe plant site	+50	0	Black mud
2	At 5-MWe plant site	0	+2	Coarse sand
3	At 5-MWe plant site	+7	0	Black mud
4	At 5-MWe plant site	+7	+3	Black mud
A	3 mi. so. of site	+10	0	Black mud
B	3 mi. so. of site	+10	1	Clay
C	3 mi. so. of site	-1	0	Shell fragments

Table 2-3. Salton Sea Water Ion Concentrations

Species		Concentration, ppm	
Positive Ions	Negative Ions	JPL	Lawrence Berkeley[a]
	Cl (Chloride)	15600	15000
	SO$_4$ (Sulphate)	11400	8146
Na (Sodium)		10500	10500
Mg (Magnesium)		1100	1077
Ca (Calcium)		460	945
	CO$_3$ (Carbonate)	220	146
K (Potassium)		200	172
	NO$_3$ (Nitrate)		14
Sr (Strontium)			11
B (Boron)			9.2
Li (Lithium)			3.2
	F (Fluoride)		3.2
Fe (Iron)			0.1
Zn (Zinc)			0.062
Mn (Manganese)			0.01
Cu (Copper)			0.005

[a]Geothermal Resources and Reservoir Investigations of U.S. Bureau of
Reclamation Leaseholds at East Mesa, Imperial Valley, California, J.H. Howard
et al, Report # LBL-7094 (UC-66a), Earth Science Division, Lawrence Berkeley
Laboratory, UCB, Calif.

useful for plant design. Bulk evaporation was accomplished in a reclaimed
vessel which was formerly a metal parts cleaning bath. This evaporator, which
was placed out-of-doors, is illustrated in Figure 2-2. With 3-kW power applied
to the heater, the unit ran at temperatures ranging around 75°C and
evaporated water at an approximate rate of one gal/h.

Three evaporation experiments were made to determine the characteristics
of the process and of the brines that could be made. Careful accounts of
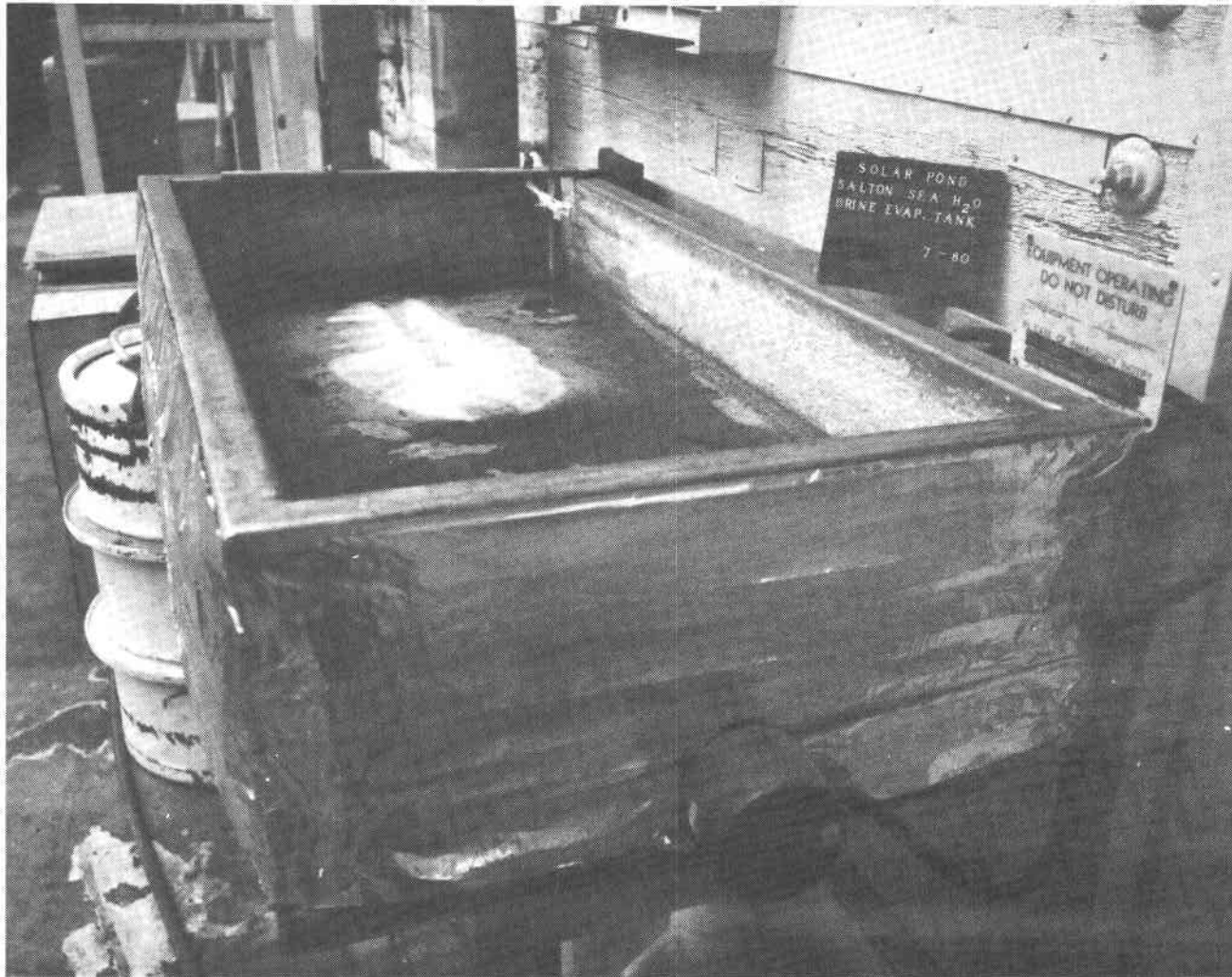
Figure 2-2. Laboratory Bulk Evaporator (White patch is precipitate floating over the heater)

weights were kept, chemical analyses were made, and densities were measured. The conditions were:

(1)   Heated, open in the laboratory (about 75°C).

(2)   Room temperature, under vacuum.

(3)   Solar heated, open out-of-doors.

In all three experiments, the following qualitative observations were made. From the beginning, precipitate was seen to accumulate on the bottom and sides of the vessel; some floated, but dropped to the bottom if agitated. As evaporation progressed, turbidity natural to the Salton Sea water disappeared; the solutions became clearer. On the other hand, the very slight yellow hue of the sea water became progressively stronger.

Chemical analyses of the final brines of the three evaporation experiments are given in Table 2-4. In the heated, open experiment, analyses were made of seven brines stepwise through the process. These data are presented in Table 2-5. The density of Salton Sea brines is seen to follow that of sodium chloride solution in Figure 2-3.

The fate of the major ionic species when Salton Sea water is evaporated can be seen in Figure 2-4. Here, the concentration of each ion is expressed as a ratio of its concentration in a given brine to its concentration in the original solution. The four ions, sodium, potassium, magnesium, and chloride (Na, K, Mg, and Cl), remain entirely in solution. The other three ions, calcium, sulfate, and bicarbonate, do not. This is indirect proof that the precipitated material is a mixture of calcium sulfate and calcium carbonate ($CaSO_4$ and $CaCO_3$). Direct proof is in chemical analysis of precipitate; calcium was 90% of the cationic species. Aluminum, copper, iron, and magnesium were also found in very low concentrations.

The above results are interpreted to answer questions about some of the factors listed in Table 2-1. The process for making brines by evaporation will be required to remove 9% more water than would be the case if no salts precipitated (Table 2-1, 1.1 and 1.2). Appropriate brines for solar pond gradient management can be obtained from the single source, Salton Sea water (3.1). Mineral scale can be expected to be a factor to deal with in heat transmission (4.1). Chemical data are given for environmental considerations relating to brine disposition (7.2).

This investigation yielded a most interesting result (2.4). Salton Sea solar ponds will naturally and perpetually manufacture precipitating salts at a very slow rate in the gradient zone. This phenomenon is to be expected in all solar ponds which will depend on a single brackish or saline water source, which also is saturated in one of its component salts. The analysis which follows explains why this is so.

In referring again to Figure 2-4, it can be seen that the concentrations of sulfate and carbonate increase with evaporation even though fractions of them leave the solution. On the other hand, the concentration of calcium decreases with evaporation. This will always happen to the ion whose molar concentration in the original solution is lowest - a result of conservation of

Table 2-4. Characteristics of Concentrated Salton Sea Brines Made by Three Methods

Evaporation Method	Ion Concentrations, wt %									Total Solids, wt%		Specific Gravity	pH
	K+	Na+	Ca++	Mg++	SO$_4$	Cl-	PO$_4$	HCO$_3$-	CO$_3$	Ion Sum	Residue		
Open, Heated 75°C	0.16	8.29	0.01	0.87	5.61	11.63	1.5 x 10	0.05	---	26.62	28.30	1.23	8.2
Vacuum Ambient Temp.	0.15	7.89	0.04	0.80	5.79	11.14	---	0.11	0.01	25.92	27.23	1.23	7.3
Solar	0.19	9.44	0.02	0.98	6.18	13.92	---	0.06	0.02	30.82	31.82	1.25	7.5

Table 2-5. Characteristics of Successively Stronger Brines

Concentration Sequence	Ion Concentrations, wt %								Total Solids, wt%		Specific Gravity	pH
	K+	Na+	Ca++	Mg++	SO$_4$	Cl$^-$	PO$_4$	HCO$_3$	Ion Sum	Residue		
Salton Sea Water	0.020	1.05	0.046	0.1	1.14	1.56	---	0.022	3.95	3.63	1.018	7.5
1	0.041	2.05	0.045	0.22	1.51	3.18	---	0.025	7.07	7.00	1.056	8.0
2	0.060	3.04	0.038	0.32	2.96	4.61	---	0.026	11.05	10.23	1.076	8.0
3	0.075	3.99	0.036	0.42	3.17	6.04	---	0.029	13.76	13.58	1.103	7.9
4	0.097	5.12	0.030	0.53	3.09	7.31	---	0.030	16.81	16.99	1.138	8.0
5	0.11	6.11	0.025	0.65	4.80	8.95	---	0.035	20.69	20.49	1.162	8.1
6	0.14	7.07	0.020	0.76	5.32	10.22	---	0.044	23.46	24.57	1.184	8.2
7	0.16	8.26	0.011	0.87	5.59	11.59	1.5 x 10^{-5}	0.052	26.53	28.20	1.234	8.2
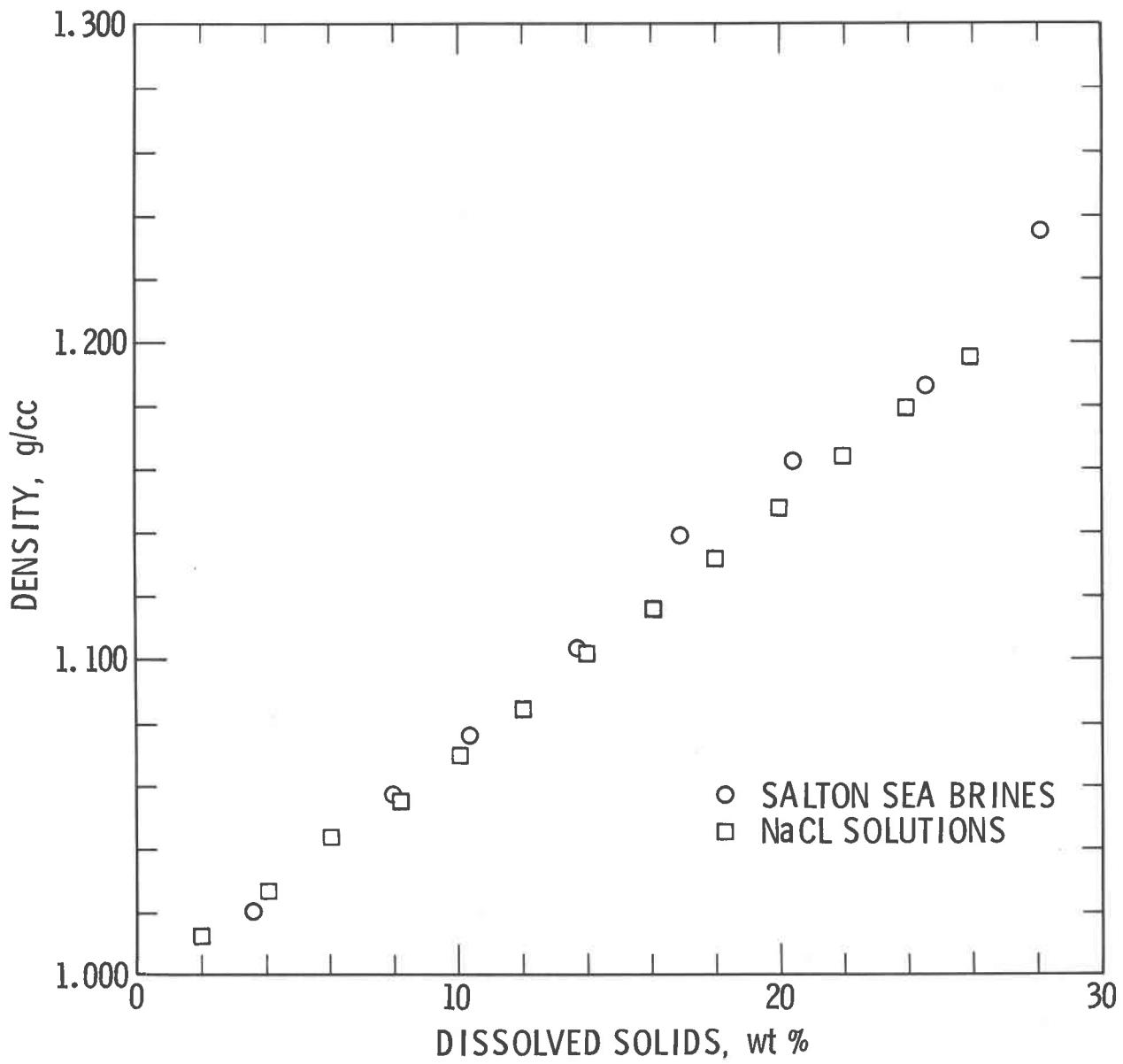
Figure 2-3. Density versus Composition of Salton Sea Brines

COMPOSITION: MAJOR CONSTITUENTS
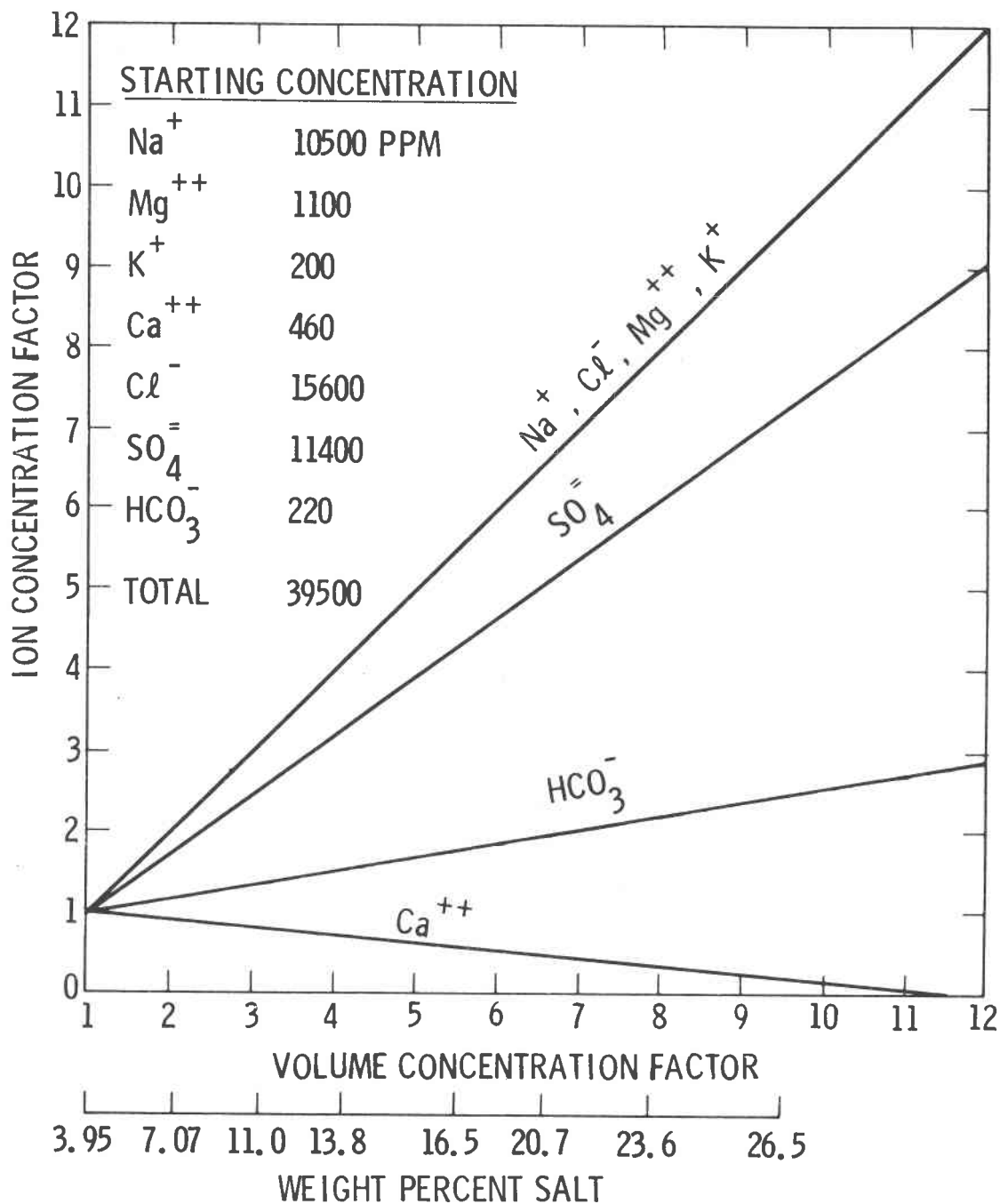
Figure 2-4. The Fate of Ionic Species During the Evaporation of
Salton Sea Water (Both volumes and concentrations are
relative values based on original values)

matter in a chemical reaction. The practical result is this: in contrast to all of the other ions, calcium will have lower concentration in the storage layer of a solar pond than it will in the upper convecting layer. Through the gradient layer, the concentration gradient of calcium will be in the opposite direction of all of the other ions. This is illustrated in Figure 2-5. Because of its reverse gradient, calcium will diffuse in a direction opposite from that of the other ions. Counter-current diffusion of the cation calcium and the anions sulfate and carbonate from boundaries that are saturated will produce higher than saturated salt concentrations (of both $CaSO_4$ and $CaCO_3$) in the gradient. This can be expected to lead to precipitation. This phenomenon was observed in all of the gradient columns run in Investigation C. An example is illustrated in Figure 2-6. Optical measurement of gradient sampled at various levels showed minimal turbidity. The precipitate either settled to the bottom (see Figure 2-7) or clung to the walls of the vessel. The predicted negligible optical effect of this phenomenon must be verified in a model pond.

It is estimated that the rate of sediment deposit at the pond bottom will be approximately one-half inch per year.

c.   INVESTIGATION B: Light Transmission, Evaluation and Treatment. The work on light transmission will be summarized briefly in this subsection. Optical effects of in-pond precipitation (Table 2-1, 2.4) were discussed in Investigation A. A detailed discussion of turbidity and color inherent in Salton Sea water (2.1 and 2.2) and its brines is given in Appendix A, (a JPL paper presented at the August 1980 IECEC meeting in Atlanta). Confirmatory studies are reported in Appendix B (a report written by JPL consultant, Professor James Giulianelli of the Colorado School of Mines).

A chemical analysis instrument, the Cary Model 14 Spectrophotometer, was used to measure light absorption spectrally with small samples of water and brines. The effect of color (dissolved light-absorbing substances) is illustrated in Figure 2-8. The absorption curves show absorption versus wavelength for filtered Salton Sea water and the seven brines described in Investigation A. A typical air mass 1 solar spectrum and the absorption curve for distilled water are shown for reference.

In Figure 2-8, it is seen that the absorption in the red end of the spectrum (about 700 nm and higher) is a characteristic of the water alone. The dissolved substances, which give the yellow color to the sea water, absorb in the blue end of the spectrum. When turbidity is present, its effect appears to be independent of wavelength.

As can be seen in Figure 2-9, most of the turbidity and a large fraction of the apparent absorption can be eliminated from Salton Sea water by allowing it to settle. Filtration through a very fine-pored membrane removes a little more. Further improvement in light transmission was obtained by treating the filtered water with activated carbon. Activated carbon treatment is used to remove odor and taste from municipal water and as a tertiary treatment of sewage effluent. The mechanism of the process is non-selective adsorption of organic solutes. In this instance, it is the light-absorbing characteristic of the organic solutes which is undesirable.

2-21
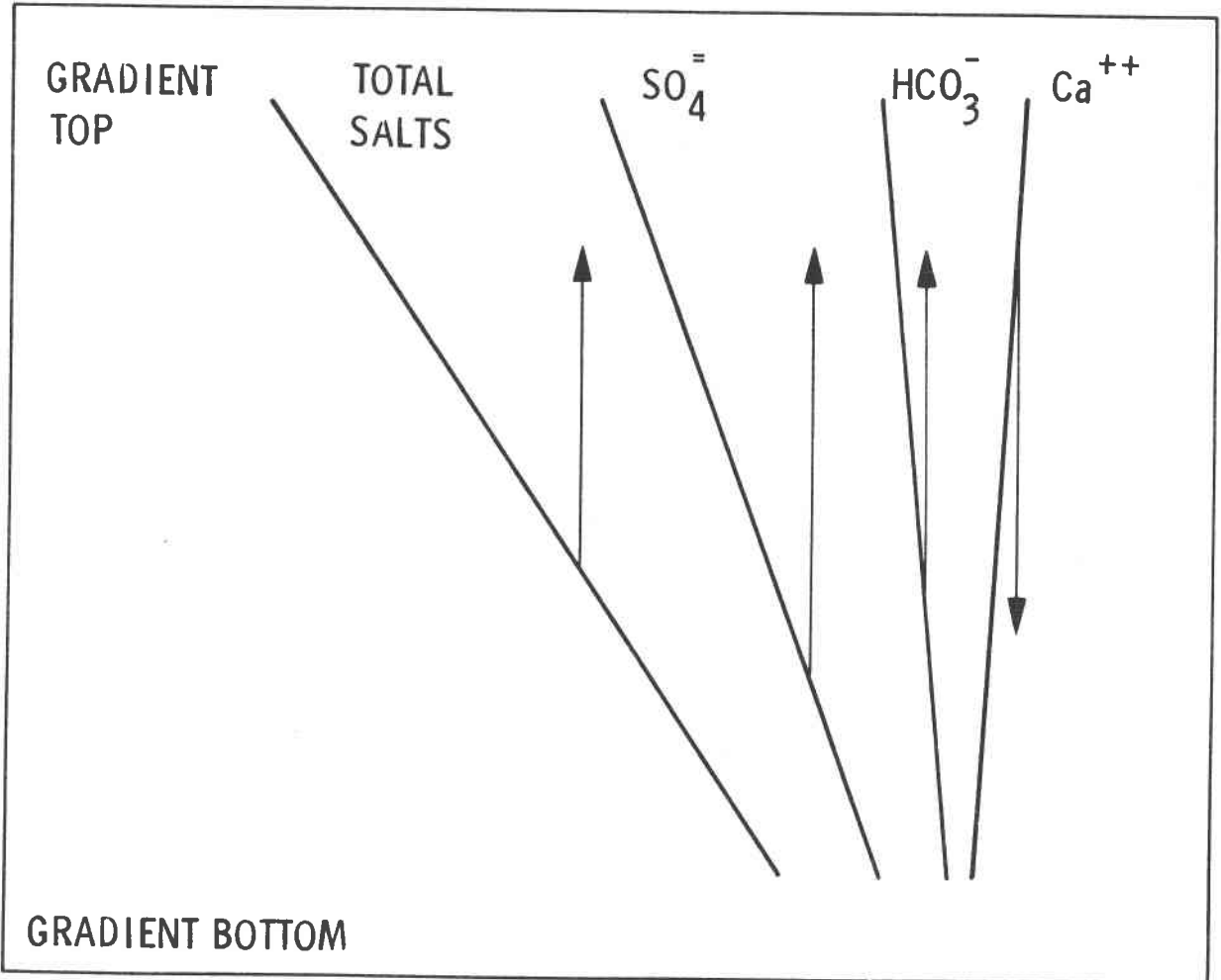
Figure 2-5. Representation of Ion Gradients in a Salton Sea Solar Pond
Showing Counter-Current Diffusion of Calcium with Respect to
the Other Ions
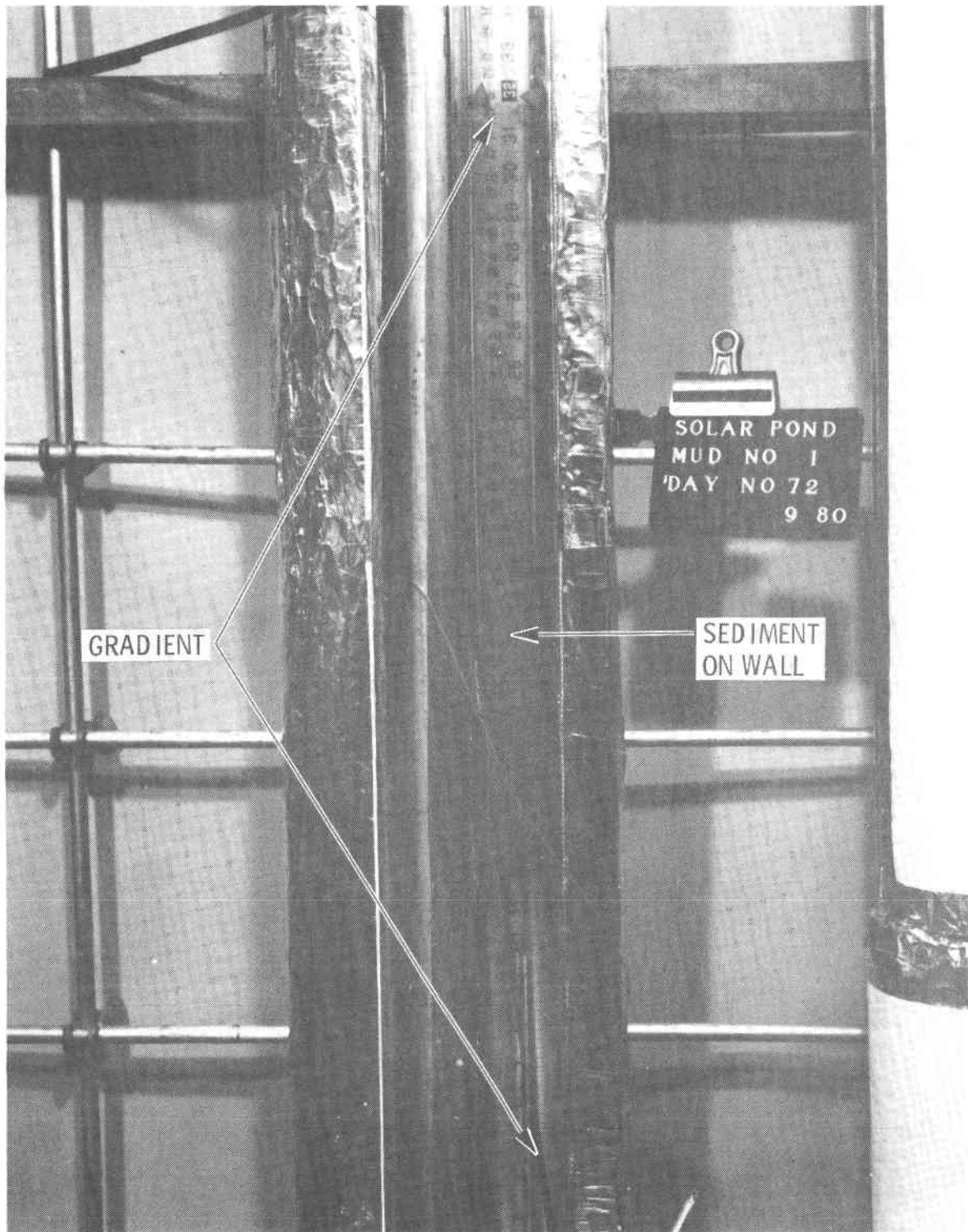
Figure 2-6. Gradient Column Showing Accumulated In-Pond Precipitation
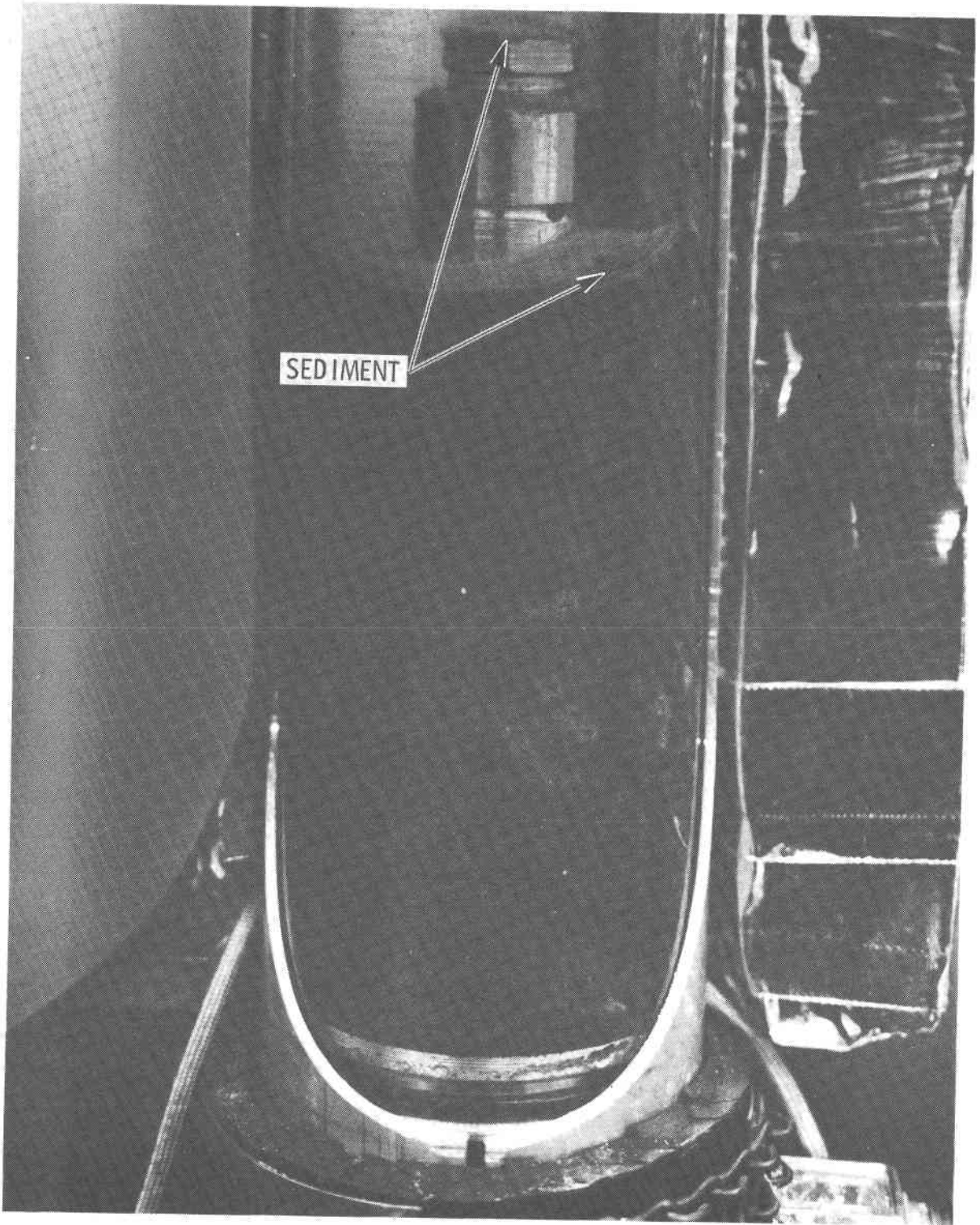
Figure 2-7. Sediment on the Bottom of a Gradient Column, (Source was precipitation of calcium salts in the gradient)
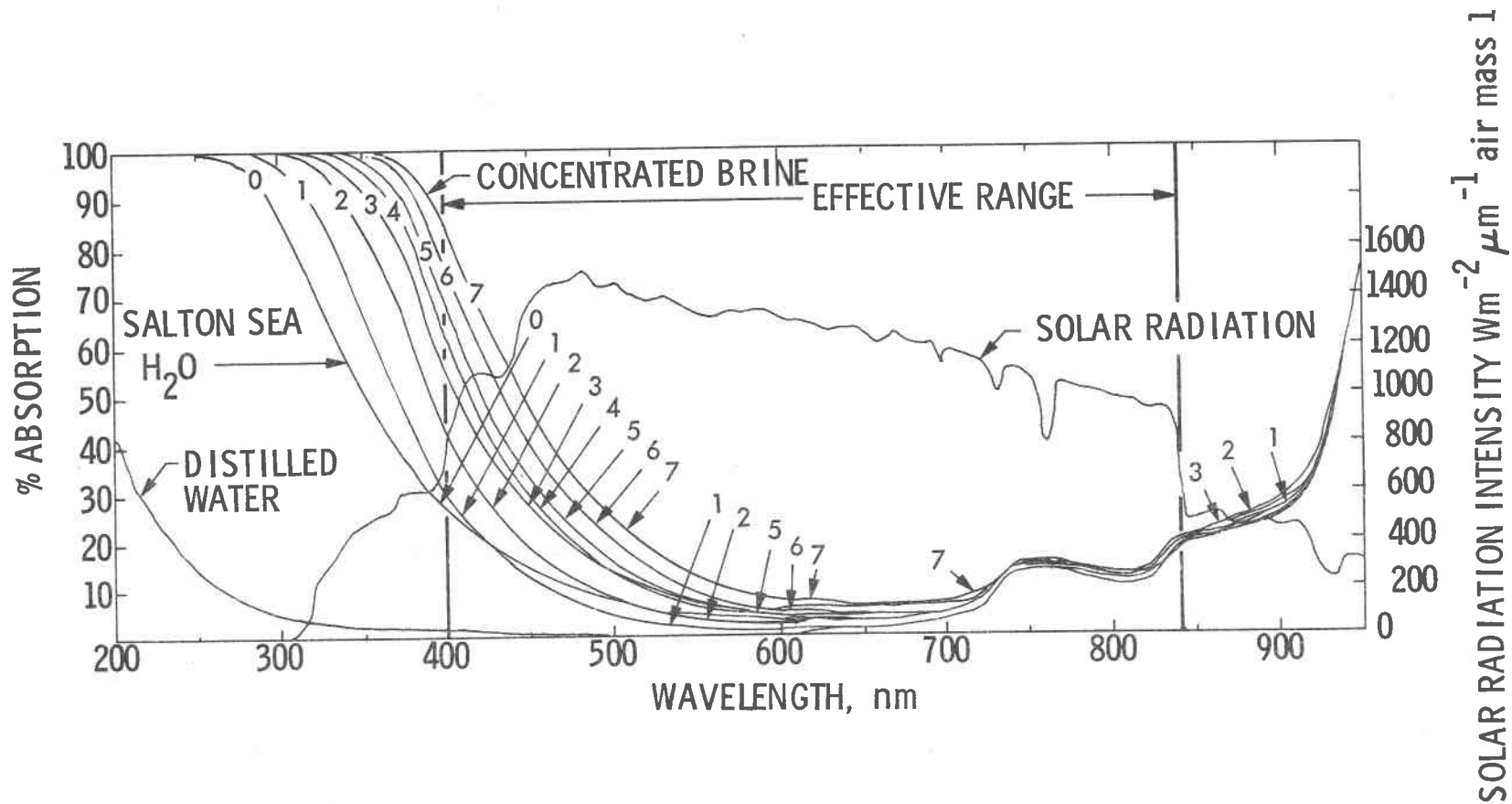
Figure 2-8. Light Absorption versus Wavelength, Salton Sea Water and Brines 5-cm Path Length
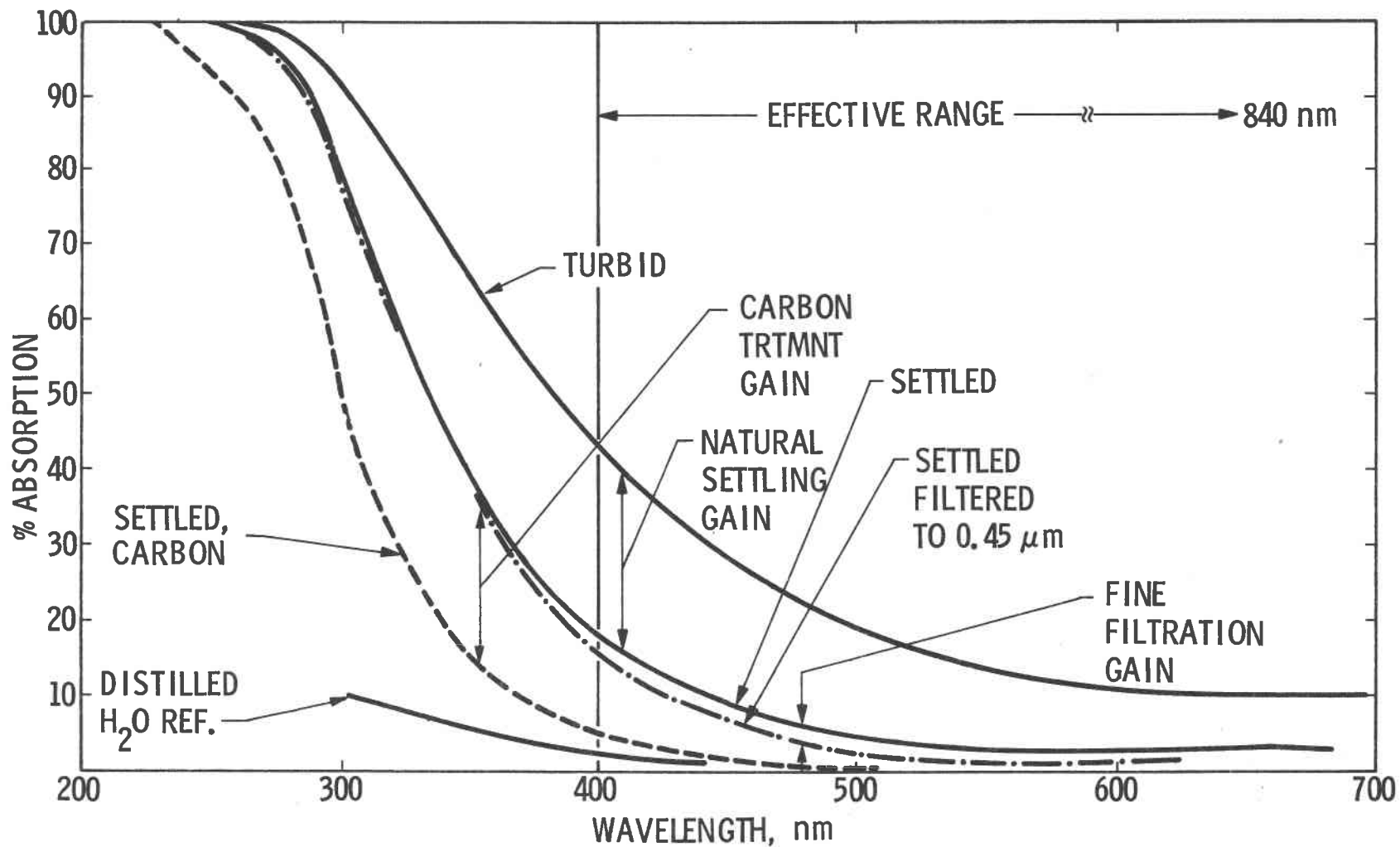
Figure 2-9. Improvements in the Light-Transmitting Capacity of Salton Sea Water by the Settling, Filtration, and Activated-Carbon Treatments, 5-cm Path Length

Figure 2-10 shows the effect of carbon treatment on strong Salton Sea brine. No treatment is necessary for turbidity because that material is removed in the concentrating process. The degree of improvement is independent of process sequence; i.e., decolorization either before or after evaporation.

Mathematical treatment of these data to estimate solar pond performance is described in Appendix A. However, a qualitative description can be given by referring back to Figure 2-9. Take, for example, the absorption at 750 nm, which should be the same for any nonturbid water. Five centimeters of solution absorb about 12% at this wavelength. If the path length is increased to 100-150 cm, the absorption would be nearly 100%. Thus, a gradient formed from undecolorized brines will transmit only in the narrow range of about 550 to 700 nm, a small fraction of the total incident energy, and even that will be reduced by the increased path length. Results of the computer model calculations for untreated and treated Salton Sea brines are compared in Figure 2-11 with values calculated for distilled water and the four typical natural waters identified by Ormat in their proposal and report.

Work is continuing in both water treatment and light-transmission measurement. Besides settling, filtration, and activated carbon, treatment with flocculents and with ozone will be tried.

The concerns in optical measurement are instrumentation error and a question of the contribution of forward scattering. Spectrophotometers used in this work are chemical analysis instruments; although their accuracies are suitable for the designed measurements, these instruments have shortcomings for the present problem. Any error in a short-path measurement will be multiplied in the mathematical treatment. All forward scattering leaving the sample tube in these instruments that falls outside of a 6° cone is not measured. Ultimately, the predictions made by this approach will have to be verified in model ponds.

      d.   INVESTIGATION C: Soil Bio-Activity Evaluation. A group of five exploratory tests were made to determine the possibility of thermally-induced, solar pond damaging, biological activity in Salton Sea subsoils (Table 2-1, 2.5 and 3.4). These tests showed that the offensive microbes exist in at least one of the four soil samples tested, but that they are not active at pond brine-soil interface conditions.

A general arrangement of the tests is shown in Figures 2-12 and 2-13. In each of the columns 2, 3, 4, and 5, the essential components are a sample of soil placed under a one-meter gradient of Salton Sea brine. The columns were heated at the bottom. The sides were insulated and heated to a lesser degree. Generally, the bottom temperatures were held at about 75°C . Columns 2 and 3 were 2 1/2 in. in diameter; columns 4 and 5 were 4 in. Figure 2-14 shows details of the bottom of each test: provision was made for withdrawing samples of brine and adding new brine; both soil and bottom liquid temperatures were monitored. Test number 1 did not contain a gradient. Instead, the supernatent liquid was unconcentrated Salton Sea water. In all cases, the waters and brines were deoxegenated by boiling. Tests were run for a period of 4 mo each.

Advised by Ormat representatives to look for activity of sulfate-breathing organisms, the JPL study team analyzed periodically samples withdrawn from the bottom brines for sulfide content. In Tests #2 through 4, no sulfide was
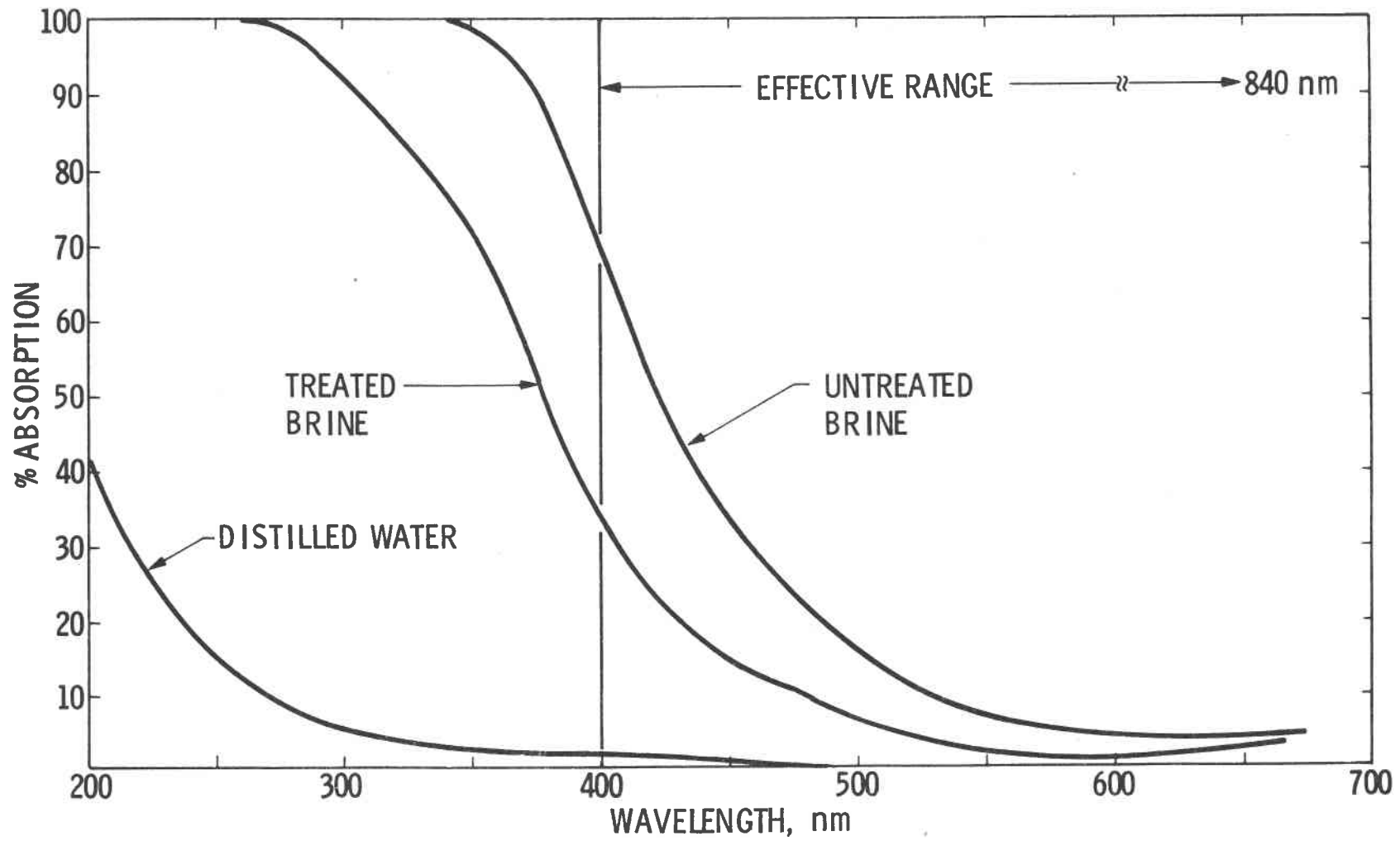
Figure 2-10. Light Absorption versus Wavelength - Effect of Carbon on 20% Salton Sea Brine, 5-cm Path Length

Figure 2-11. Annual Average Fraction of Total Insolation Reaching Storage Zone
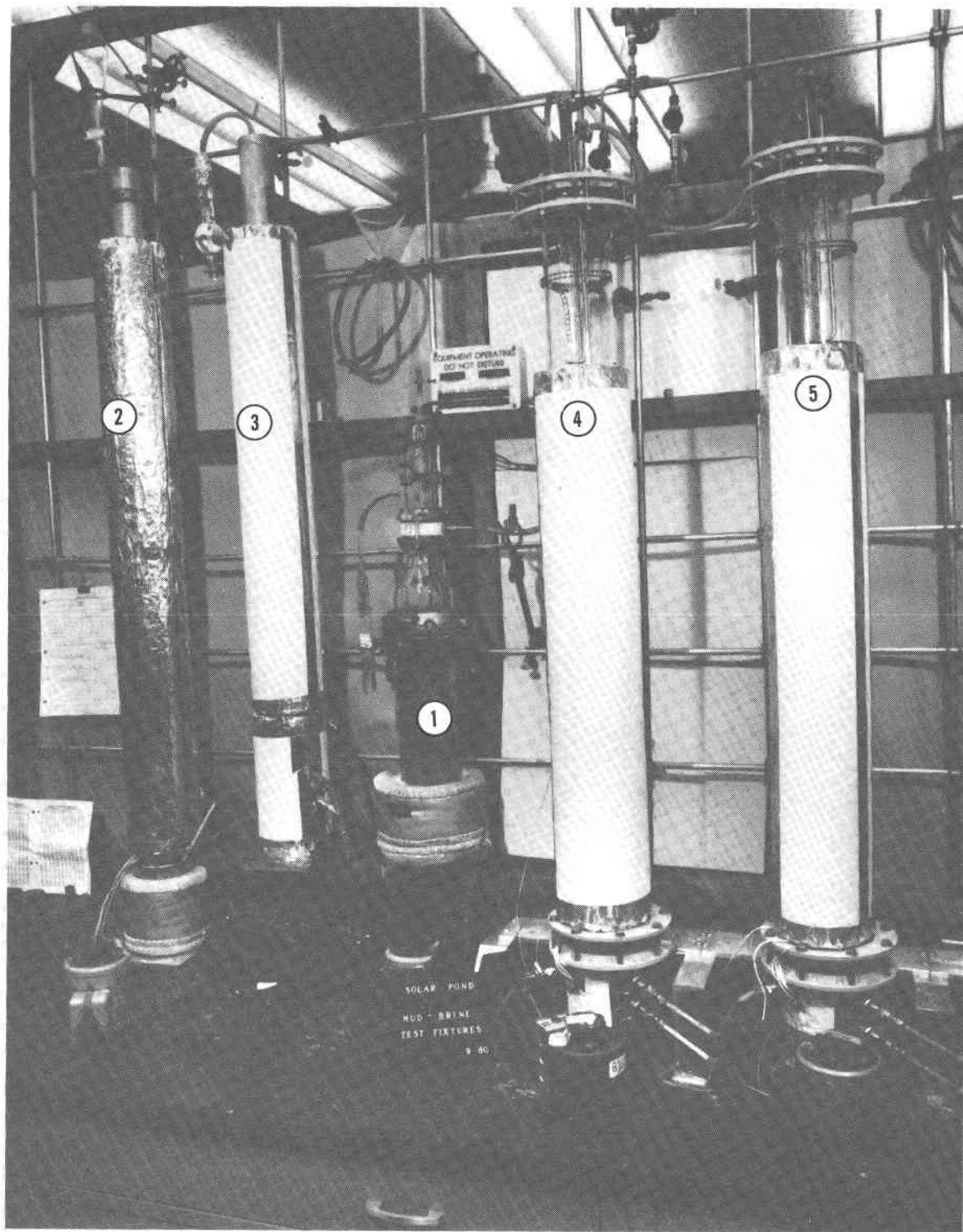
Figure 2-12. Soil Bio-Activity Tests - Units 2 to 5 have Gradients;
Unit 1 (Center) has Salton Sea Water
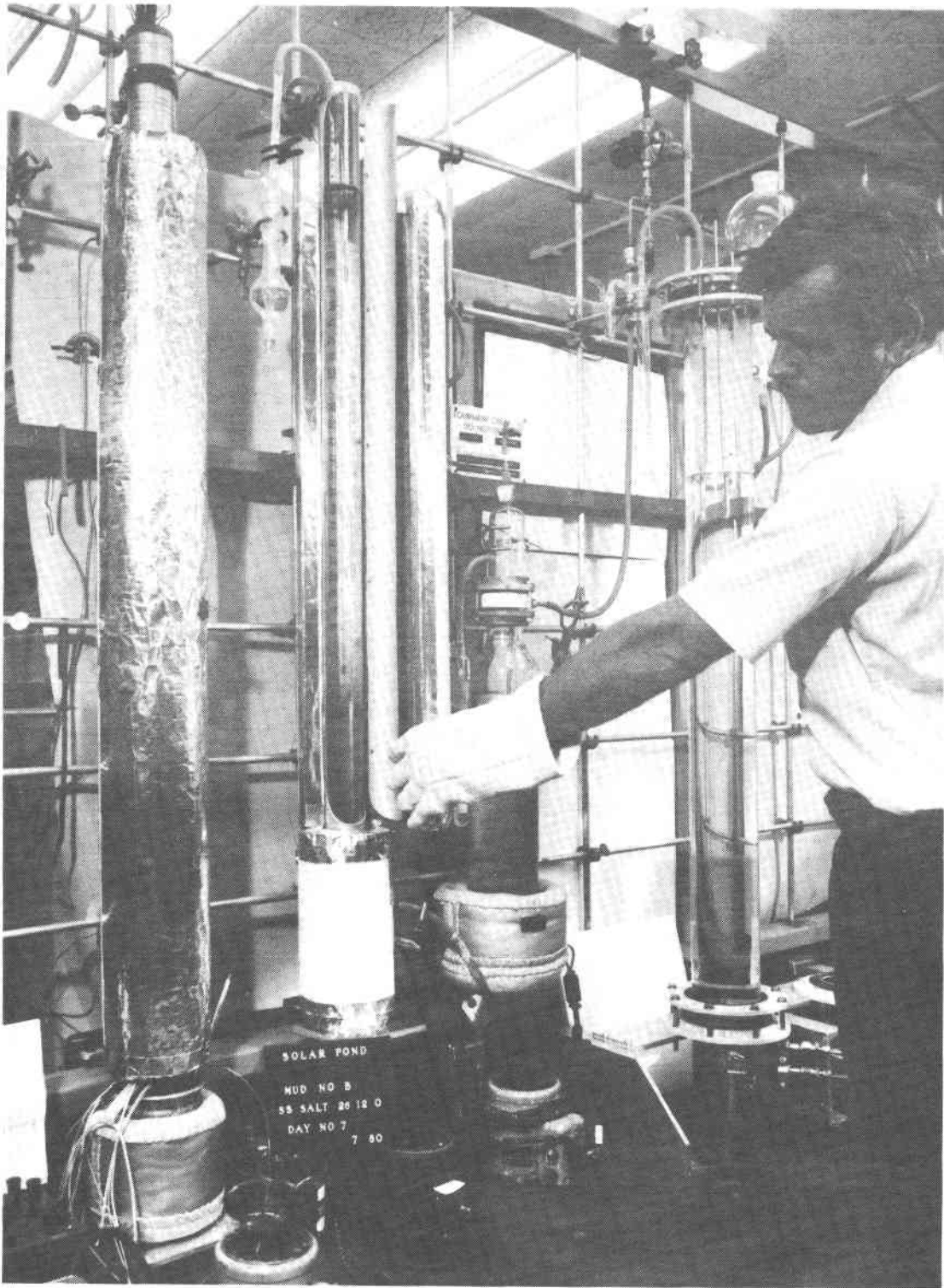
Figure 2-13. Soil Bio-Activity Test Gradient Column Showing Inspection
Access through Insulation
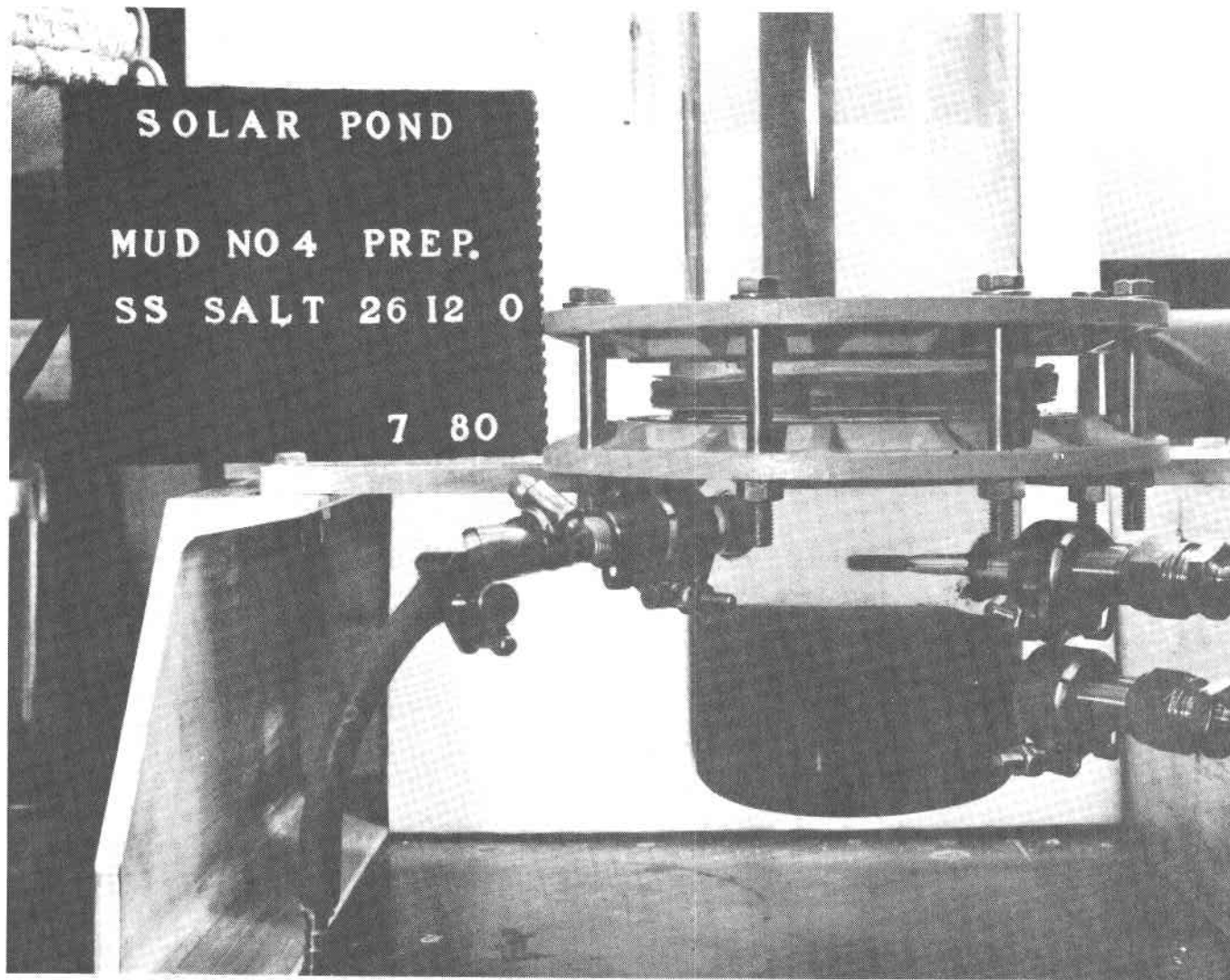
Figure 2-14. Bottom Details of Bio-Activity Test Gradient Column Assembly Showing Three Ports: Brine Inlet/Outlet, Brine Temperature, and Soil Temperature

measured. In Test #1, sulfide was measured. The time pattern for sulfide generation is shown in Figure 2-15.

Sulfide measurement was done first by a colorometric method on a liquid sample (circles in Figure 2-15). The lower limit of measurement of this method is approximately 0.1 ppm. In order to follow the progress of the reaction beyond that point, a method involving the measurement of H_2S in the gas phase was adopted (squares in the figure).

As far as this test goes, it can be concluded that sulfate-breathing bacteria were present in soil sample #1. These organisms appeared to be able to metabolize at 75°C when the liquid in contact had low salt content. However, at higher salt content, metabolism did not appear. Nothing can be said about the other samples tested except that, if any bacteria were present, they did not metabolize at 75°C and high salt concentration. The possibility of methane formation was searched for in one of the tests, but none appeared. None of the tests showed any bubbling. In one case, a band of black suspension appeared (see Figure 2-16); however, it dispersed or disappeared in a few days. The source of this suspension was not determined.

There is some concern that the temperature chosen for this set of tests was too high. Many bacteria are known to metabolize best at lower temperatures, such as 55°C. This could be important in solar pond construction and operation. During the heating-up phase of a new pond, the soil-brine interface will slowly pass through that range. In an established pond, soil at some distance below the interface will reach and remain in the lower temperature range. Future test development will examine the effect of temperature and of salt concentration as well.

In tests described, the columns were not started with established gradients. Instead, each column was started with from two to four brine layers. Density floats were made to monitor the progress of gradient formation. The floats were composed of ABS plastic with varying proportions of stainless steel embedded.

One of the gradients was disassembled carefully, layer-by-layer, and the individual densities were measured. Figure 2-17 shows a 4-month transformation of a step-wise configuration to a gradient. This demonstrates the slow process of diffusion (Table 2-1, 3.2).

4.   Conclusions

Seven essential solar pond characteristics have been identified which can be affected by site-system chemical (biological, etc.) factors. Four of those characteristics have been investigated, to varying degrees, in the laboratory. As far as the work has gone, no problem has been encountered which appears to stand in the way of the feasibility of solar pond electric power production at the Salton Sea. All measures that have been found necessary to accommodate site-specific factors would employ no new technology; conventional industrial practice can be applied. A side-product of this work is the partial development of a general methodology that will be applicable to the evaluation and chemical factor adaptation of future site-system combinations. Further work is needed to (1) complete the evaluation of the Salton Sea system, and
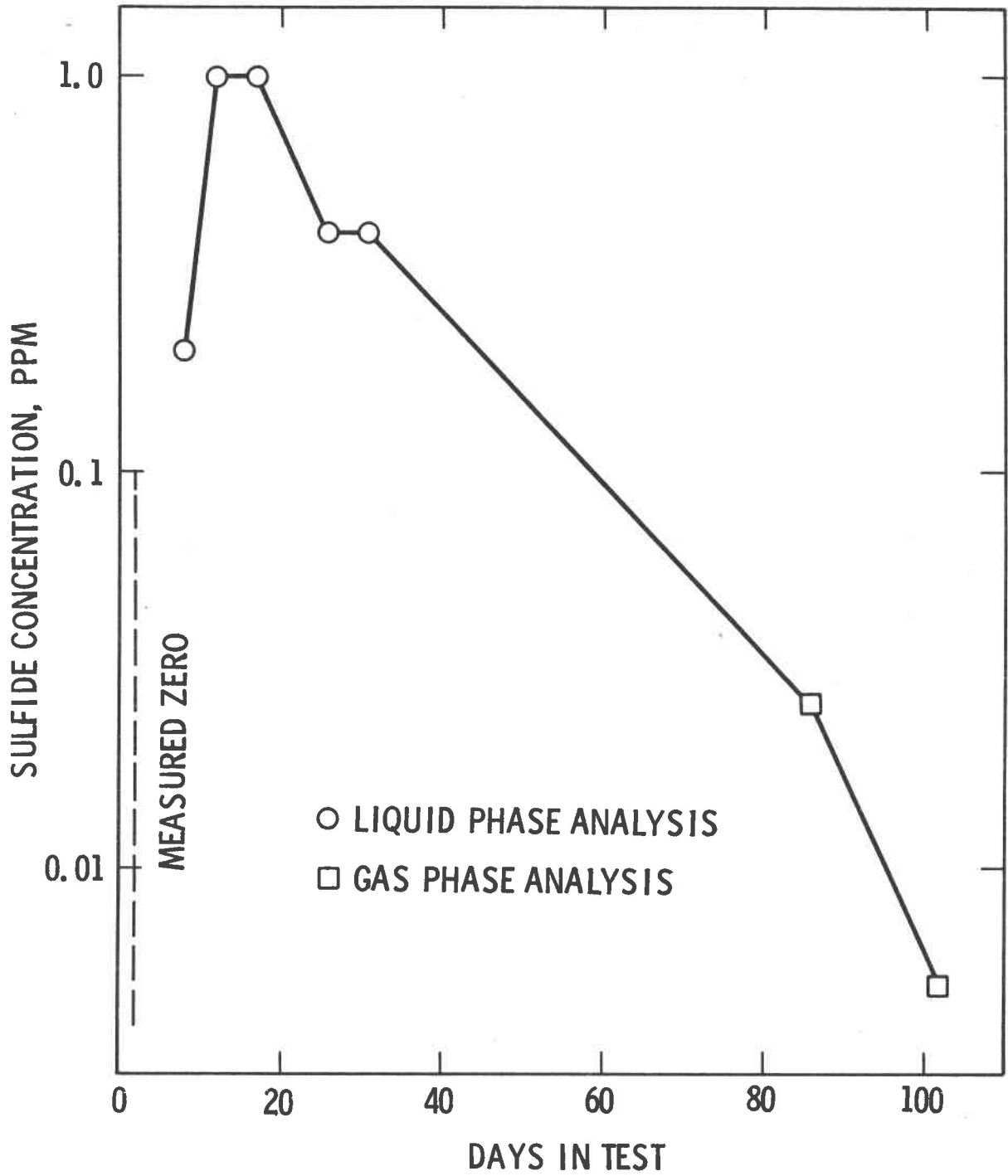
Figure 2-15. Sulfide Generation History Test #1 (Mud #1 Submerged in Salton Sea Water, Temperature 70°C)
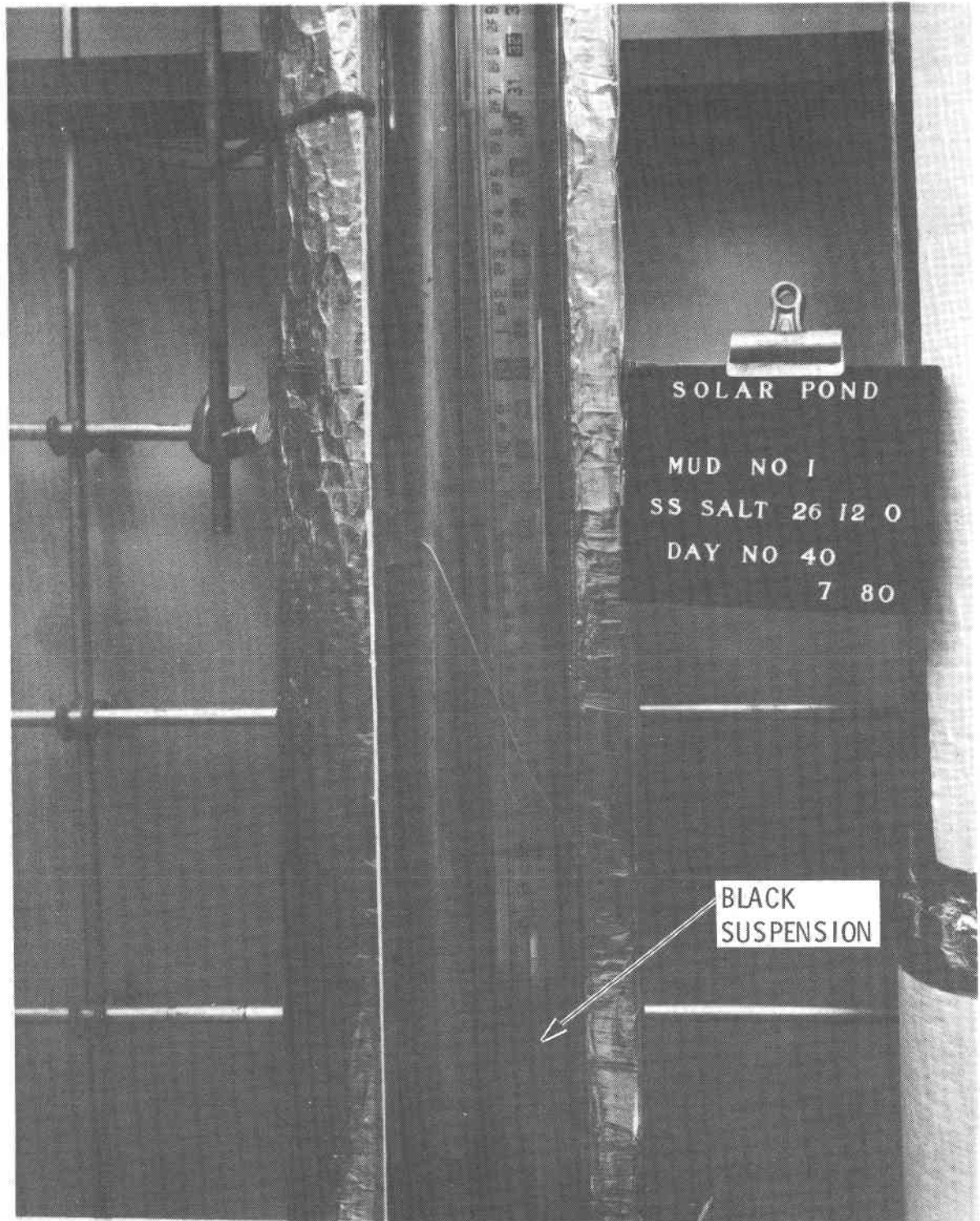
Figure 2-16. Transient Turbidity in a Bio-Activity Test Gradient Column
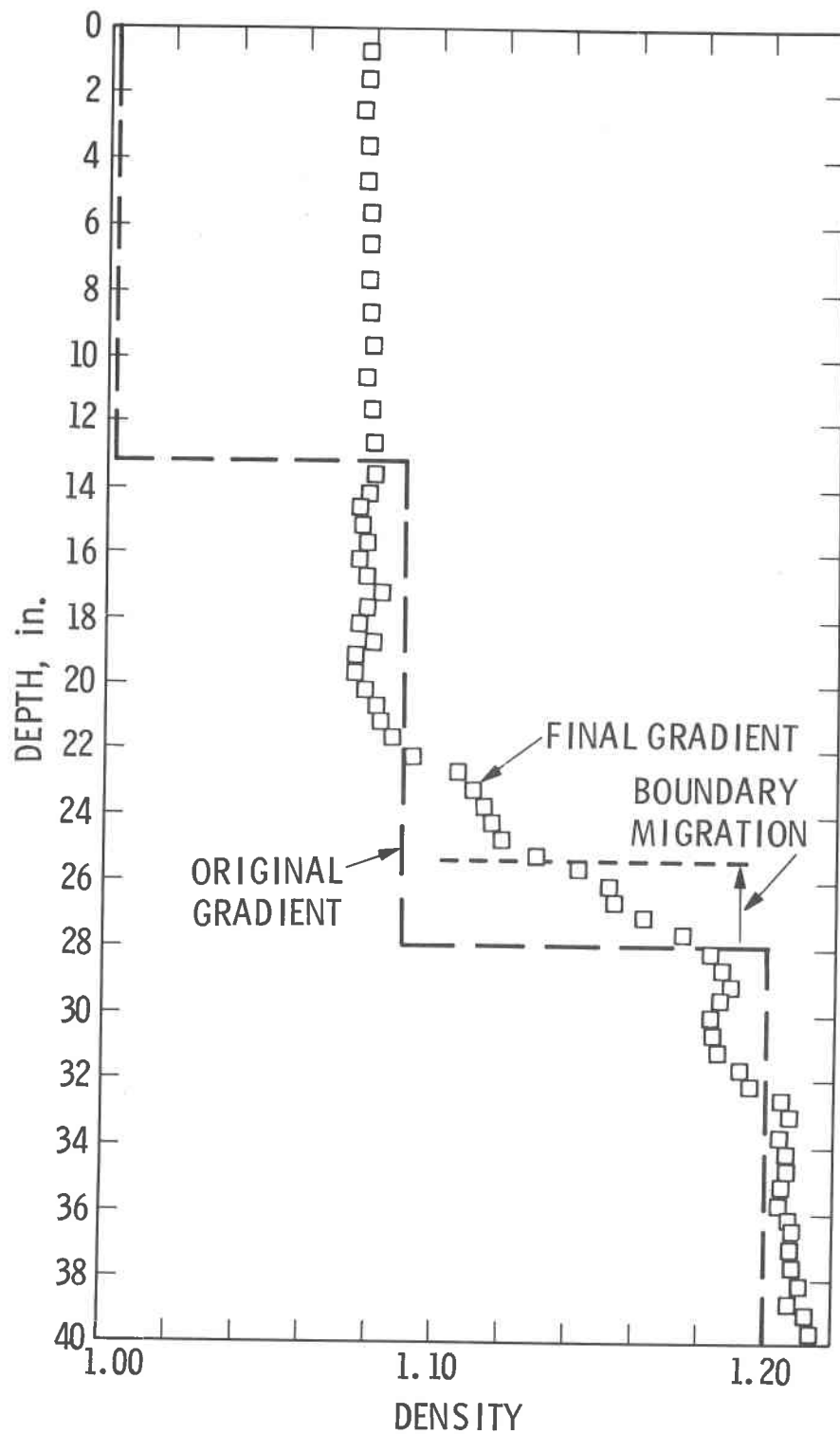
Figure 2-17. Natural Generation of a Concentration Gradient from Original Stepped Load (0%, 13%, 26%, top to bottom) in Four Months (One step boundary was still visible and had moved up the column)

(2) complete the development of the methodology. Specific recommendations are outlined below.

        a.   Water and Brine Production. The Salton Sea water is a suitable source for all water and brine requirements. Evaporation, or some alternate concentrating process, will be required to make brine. Design of the concentrating process will have to take into account the loss of precipitating calcium salts.

        b.   Light Transmission. It is predicted that Salton Sea water will have to be filtered and decolorized before use in the solar ponds in order to obtain acceptable transmission of solar radiation to the storage volume of the ponds. During normal operation, the gradient layer of solar ponds based on Salton Sea water will manufacture sedimenting calcium salts at a slow rate. Tests indicate that the sedimentation rate is fast enough to obviate any significant light transmission interference.

    More work is required to confirm the above predictions, and verification in model ponds will be necessary. Other factors that can affect light transmission and should be investigated are: suspensions and color arising from the bottom, biological activity in the pond, and wind-borne dirt.

        c.   Gradient Stability. Very preliminary tests indicate that, although gas-producing micro-organisms exist in a limited sampling of local soil, they are not likely to be active at operating pond bottom conditions.

    A wider representation of local soils must be tested. The test method needs more development. Another factor which needs study is the properties of candidate local clays for pond lining, specifically, in this case, resistance to leak formation.

        d.   Environmental Quality. Chemical analyses were made of a local soil sample specifically for heavy metals and toxic organic wastes. These results were transmitted to WESTEC.

        e.   Other Characteristics. The following solar pond characteristics have not been studied; it is the opinion of the JPL study team that they should be: heat transmission (fouling), material durability (corrosion and liner properties), and ingredient conservation (liner properties).

E.   DIKE CONSTRUCTION EVALUATION

    1.   Introduction

    From the outset of project planning, the power plant and its associated ponds were conceptually placed near the sea shore to benefit from the sea and the land. Initially, siting was distinctly offshore, and the solar pond constructions were tied to land by dikes, which were placed to form

concentrating pans. As planning progressed and greater appreciation for the site and its characteristics evolved, the entire layout was moved landward. A series of compromises involving capability pond area, service areas and economics resulting in trade-off designs. The terrain and the native soil influenced these significantly.

Onshore, the available site consists of the terminus of a long alluvial fan which originates in the west from the Santa Rosa Mountains and terminates in the Salton Sea. The land form and its topography are prototypical of the "desert fan" phenomena of the southwestern desert region. In this instance, the Salton Sea serves as catchbasin for the finer detritus and the clastics washed from the high ground. The land slopes to the Sea at about 5% ruling grade.

Superficially, the ground consists of loose, fine silt which here and there has been cemented into slabs or accretions with limonite, silica or gypsum as the binder. The surface is dissected thoroughly with run-off channels which are seldom deep near the Sea (say, 5-feet maximum) but are everyplace. Low-profile sand dunes form from the loose silt, and nearby, have crept over roads and power lines.

Offshore, the land slope continues to deepen, perhaps at an angle somewhat more gentle. The shoreline is temporary because the Sea rises or falls from year to year and sometimes during a year's span.

The ground characteristics that caused concern to the JPL study team were:

(1)   The native earth on the section reserved for construction consists of loose, ultra-fine silt, clearly representing material deposited near the lower end of the "fan." Macroscopically, the silt appears 100% minus 100 mesh (Tyler). The occasional concretions were scattered and apparently shallow.

(2)   Offshore, the same material persists, but is overlain by a deposit of marine ooze that is thick, fine, black and possibly of marine origin. Reconnaissance proved the layer was most often 2 feet thick, but occasionally more (not surveyed).

(3)   No rock or balanced soil-rock mixture appears in the region. Sound rock is known to be in the Chocolate Mountains on the east shore of the Sea, and in the area west of El Centro. No exhaustive exploration was conducted by the JPL team, but superficial scanning suggests that suitable dike construction materials are not available nearby.

(4)   Considering the nature of the alluvial fan and the geologic history of the Sea, it had to be considered that more than a few hundred feet of sediment underlay the construction site, and that the silt found at the surface might persist through the zone of interest for construction. This possibility threatened the porosity and permeability goals sought for the pond system.

With these unknowns and concerns, the JPL study team was cautious about the technical and economic feasibility of the designated site.

2. Exploration (Preliminary)

An exploration was conducted of the site's subsurface makeup to:

(1)   Determine the nature of the subsurface earths.

(2)   Obtain samples of the native earth types for examination and any testing desired.

(3)   Measure the water table as a factor in onshore construction planning.

A drilling contract was negotiated, and three exploration holes were completed across the project site and inland from the shoreline (Figure 2-18). No floating equipment was available on which offshore exploration might have been made. The exploration established that the alluvial silt continued, indeed, to (at least) 30 ft, and established that the silt mass carried frequent, thin (2-inches to 4-feet thick) lenses or streaks of heavy marine clay. These findings provided some positive encouragement and permitted JPL to consider that:

(1)   The clay presences offered some likelihood that impermeable pond bottoms might be engineered on the basis of the native materials.

(2)   While the clean, fine, barren silt was incompetent for dike refill in the Sea, an admixture of silt with clay in about the proportions found in the exploration might provide competence. The silt might be bound with clay mixed in excavation and in placement.

(3)   The onshore material, certainly, and the offshore material, probably, could be excavated by floating hydraulic dredge.

With these outlooks, JPL considered that the site was potentially viable and decided that a formal geotechnical engineering investigation was required.

3. Dike Construction

If the premises of native material acceptability could be confirmed, the means and procedures for dike construction remained uncertain. The demands of the construction approach, of course, varied with the positioning of the SSP, the evaporation ponds and the service modules, and their respective sizes and interfaces.

It was determined to be desirable that some, if not all, of the earthworks program be positioned offshore, so that valuable design and construction experience might be gained toward expansion of solar pond building in the Salton Sea. Simultaneously, it became evident that the farther offshore the SPPP might be sited, the deeper the sea became, necessitating higher and wider dikes and placing more demands on all of the construction. Accordingly, compromises moved the layout astride the shoreline where at least part of the ponding dikes would be positioned in the sea and where economy could be expected in the earthwork. Notwithstanding, handling the silt or the silt-clay mix posed problems in placement, stability and competence. JPL investigated
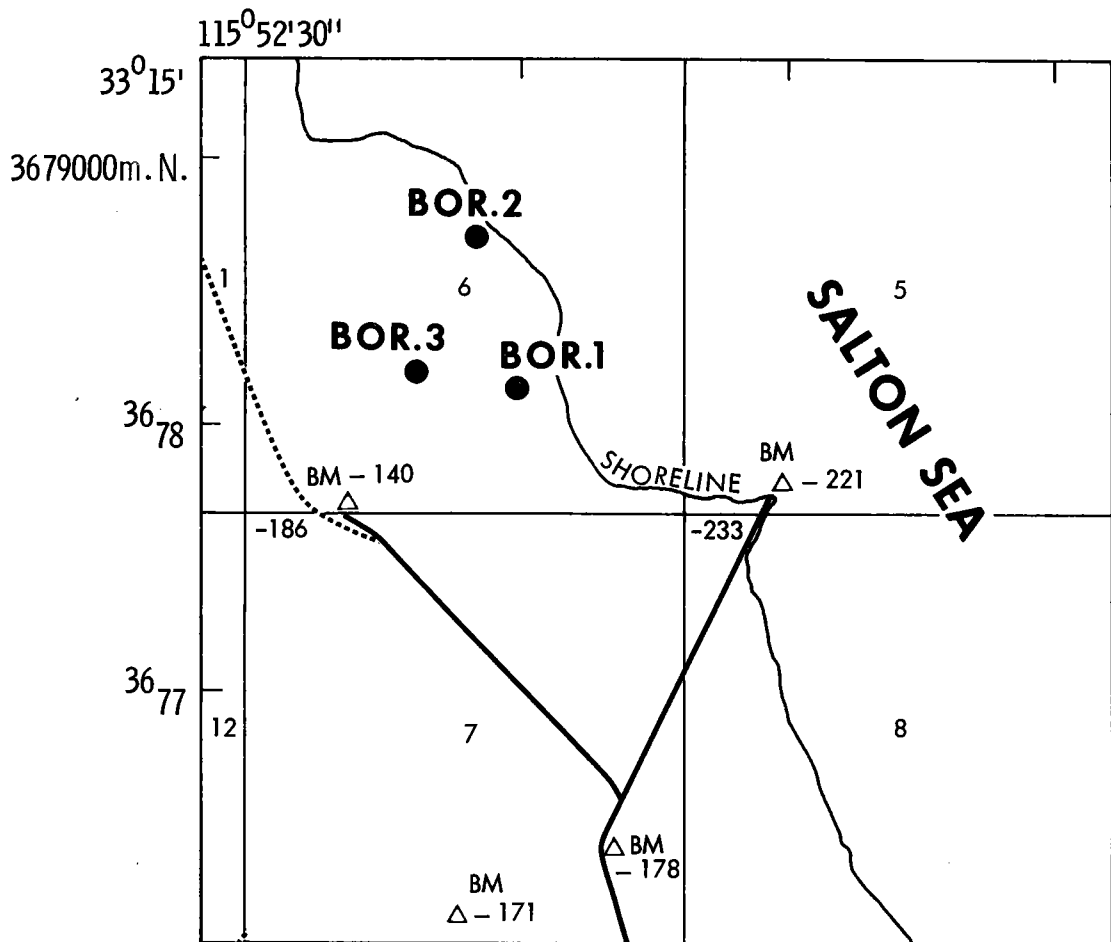
Figure 2-18. Location of Exploration Bore Holes

PLOT   PLAN

SCALE   1" = 2000'

numerous techniques to identify a method that might match the conditions. Several possible approaches were evaluated:

(1) The classic end-dump and extension using rear-dump trucks was considered and rejected because the new fill could not support the traffic, especially offshore.

(2) Importing coarse rock, or rock-in-soil was evaluated for end-dump fill extending gradually on the pond perimeters. An acceptable source of supply was not found in the locality, so this alternative construction procedure was rejected.

(3) Clamshell-on-barge cutting from the sea-bottom and dumping on the dike formations was considered. It too was rejected because the method was judged exorbitant in cost, not quite practical, and slow.

(4) Double rows of sheet-pile were considered together with a procedure that would fill the space between with dredged spoil. The accumulated load would then be dewatered, the temporary walls pulled (and leap-frogged ahead) and the heap shaped to form the dike profile. This alternative was evaluated, and found feasible but overwhelmed by engineering concerns.

(It should be noted that JPL had decided favorably upon using a hydraulic suction cutter dredge to excavate the pond bottom. Wherever the dredged spoil might contribute to dike build-up, economies of time, effort and resources would follow. Dredge spoil that emerged surplus to dike-fill requirements, would probably be placed ashore for storage.)

None of the conventional dike building techniques satisfactorily met the demands imposed by poor materials and lack of substitutes. The extraordinarily fine, clean silt, even with mixed clays, was not amenable to the usual procedures. The JPL team decided to seek advice and identified an earth and rock handling expert who was engaged to propose a practical solution. After his study, recommendations were:

(1) Use of a hydraulic suction cutter dredge to excavate and to prepare by blending the native silts with clay.

(2) Formation of the dikes by placing dredge spoil within suspended turbidity curtains, whose purpose was to provide a confined settling zone where the spoil solids would drop and settle.

(3) As deposited earth fill broke the water line in buildup, a fill to increase the freeboard would be delivered from land by rubber-tired equipment.

The approach defined above, while adequate in its resolution of certain problem aspects, has not been accepted as a failsafe, proven technique. During exploration of the turbidity curtain possibility, the JPL team encountered the range of products offered by the curtain manufacturers. Among those was a woven plastic fabric bag which had successfully been applied in wave erosion and marine embankment problem areas. After investigation, the JPL team formed the opinion that a bag technique seemed to resolve the Salton materials problem while offering a means to establish large, stable earthern constructions. The

method uses polyethylene bags (usable in the hot, concentrated brine environment) fabricated to accept and hold dredge spoil in a round, "cigar" shape having a diameter of about 30 in. and a length of 12 ft. Stacking the filled bags in orderly pyramids on a clean sea-bottom and raising the structure above water level to establish freeboard and roadway provided sound constructions that were assumed impermeable. The bags in the JPL concept would be filled on barge, hoisted, then lowered into nestled position with the aid of sonar guidance.

Recent JPL planning and estimating for dike constructions has proceeded on the assumption that the "bag technique" and the means of application will satisfactorily provide competent dike formations.

4. Cost Estimates

Dike, pond, roadway and onshore earthwork costs vary according to the geometry, sizes and architecture of the SPPP system and its layout. Numerous arrangements and construction layouts have been studied and estimated, all varying as dimensions and interfaces change.

Key unit costs, however, have been used consistently throughout the layout and estimating process in order to establish valid comparison and tradeoffs. Over the period of examination, minor adjustment has been made for escalation and inflation, but a consistent pattern has been retained.

Examples of key construction cost estimating components are:

(1) Hydraulic suction cutter, dredge excavation and spoil: $0.85/yd^3 (bank) discharge at 4,000 feet or less.

(2) Excavation, onshore, cut and fill: $1.33/yd^3 (bank)

(3) Crushed rock, base; $15.00/ton, supply
$10.00/ton, place

(4) Concrete, ready-mix, delivered: $200/yd^3

(5) Bag cost: $64.00 ea.

(6) Equipment application cost: according to Southern California Contractors Association.

(7) Labor cost: according to the Master Labor Agreement for 1980-1981 issued by the International Union of Operating Engineers (IUOE) Local 12 of Southern California.

Because dikes, as linear constructions, and any of the ponds, as real constructions, vary severely with positioning and relation to the shoreline (thus varying the depth of construction), no running cost per unit of construction type has been practical. Each system variation has required individual costing. System costs in the aggregate may be reviewed in the Tradeoff Studies Section of this report.

5. Conclusions

The effort being reported is entirely in the engineering concept design. In order to convert SPPP installation concepts to the site, the site materials, and their usefulness in earthworks, construction methods and costing evaluations have been required. These requirements have been satisfied, but only in a very preliminary sense. Each of the construction elements has been explored, and even though preliminary, satisfaction has been established so that recommendations could be made to the program sponsors.

The JPL team has consistently recognized the need for a full, formal and in-depth engineering investigation of the SPPP site, its materials, the best construction approaches, and cost evaluation. The conclusions reached in the preliminary phase favor proceeding upon that formal evaluation phase.

The JPL study team has not satisfactorily addressed or resolved certain questions that must be raised about the seismic performances expected of the system and its construction. The position has been taken that the seismic evaluation requires a very formal analysis and extensive capability that is beyond the scope of Phase 1.

6. Recommendations

Regarding the evaluation of the SPPP dike construction, the JPL study team recommends that more thorough regional exploration be undertaken to determine whether competent earthwork construction materials might be available in a still uninvestigated locality, possibly in the watershed area west of the considered site.

F. COMPUTER MODELING

1. Introduction

a. Background. The Ormat Turbines feasibility study report (Ref. 1) includes a description and some results of a one-dimensional computer model of solar pond thermal behavior. The present work details efforts at JPL to replicate the Ormat model. The JPL code has been used to corroborate Ormat's performance predictions for the Salton Sea Solar Pond and to provide performance estimates for other locations as part of the Regional Applicability Study (Ref. 2).

b. Solar Pond Model Capabilities. The JPL solar pond computer code is a design tool that calculates pond thermal performance for a given set of specified design and operating conditions. The code is a finite-difference solution of the one-dimensional heat conduction equation with a source term representing absorption of insolation as a function of depth. The code is applicable to large ponds where edge effects are insignificant.

The specified design parameters include:

(1) Thicknesses of the solar pond upper convecting zone, middle non-convecting zone and lower convecting zone.

(2)   Surface area.

(3)   Monthly values for total insolation and ambient temperature.

(4)   Site latitude.

(5)   Water clarity data in terms of transmittance of insolation as a
       function of salinity and wavelength.

(6)   Upper convecting and lower convecting zone salinity.

The specified operating conditions include either (1) a lower convecting
zone temperature for constant temperature thermal extraction, (2) an annual
temperature profile for the lower convecting zone, or (3) monthly thermal loads
and a minimum extraction temperature.

Outputs from the code include a history (from start of pond warm-up) of
pond temperature as a function of depth, the rate of thermal energy extraction,
and, if desired, the gross and net rates of electrical power generation from a
heat engine operating at 64% of Carnot efficiency. The parasitic power
requirement is 22.8% of the gross power output.

2.   Model Description

The behavior of a solar pond can be approximately described by the
one-dimensional, nonsteady-state heat conduction equation with an insolation
source term and variable thermal property coefficents. A thermal node circuit
is specified for computation of temperature as a function of time and depth
(Figure 2-19).

The pond model considers four zones. The upper convecting zone (UCZ) is
a surface layer from 0.15- to 0.25-m thick. The middle nonconvecting zone
(MNZ), characterized by the presence of vertical salinity, density and tempera-
ture gradients, is typically 0.80- to 1.30-m thick and provides thermal insula-
tion for the lower convecting zone (LCZ), where solar energy is collected and
stored. The Ormat baseload design for the SPPP specifies a thickness for the
LCZ of 3.50 m. The ground (GRD) serves to increase the thermal capacity of the
pond.

The UCZ and LCZ are modeled as isothermal and the temperature of the MNZ
and GRD is computed as a function of both time and depth. The temperature in
the UCZ is equated to the ambient temperature. The lateral temperature
variance in all zones is considered to be negligible and thermal losses through
the pond perimeter are ignored. This approximation appears reasonable for
large-scale ponds.

In order to approach constant daily output from the power plant, the
solar pond must store summer energy for release in the winter. This will
necessitate a storage zone temperature that rises during the summer months and
falls during the winter months. Ormat has found that the temperature will vary
sinusoidally, peaking in the fall and dropping to a minimum in the spring.

THERMAL NODE CIRCUIT
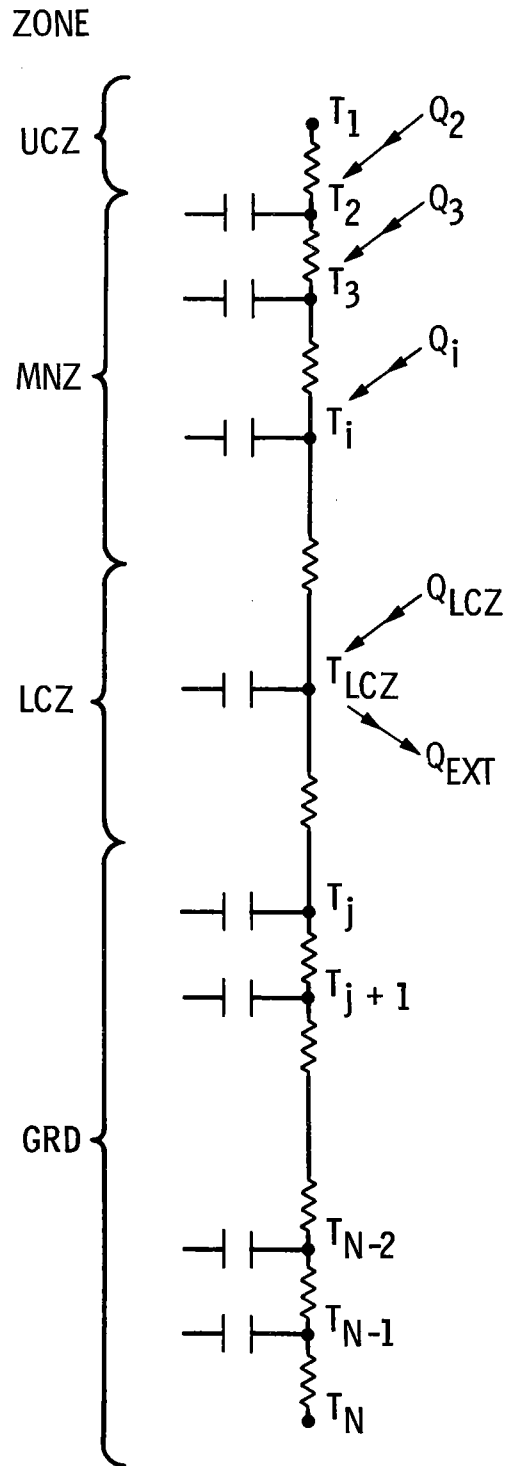
Figure 2-19. Computational Node Diagram

3. Mathematical Formulation

The temperature distribution, $T(t,z)$ is given by

$$(\rho C_p)_f \, (\partial T/\partial t) = k_f \, (\partial^2 T/\partial z^2) + \dot{Q}(t,z) \qquad (1)$$

in the MNZ and by

$$(\rho C_p)_g \, (\partial T/\partial t) = k_g \, (\partial^2 T/\partial z^2) \qquad (2)$$

in the GRD, where

T = temperature (°C)

ρ = fluid or ground density (kg/m^3)

C_p = fluid or ground heat capacity (W – s/kg – °C)

k = fluid or ground thermal conductivity (W/m – °C)

$\dot{Q}$ = volumetric insolation absorption rate (W/m^3)

t = time (s) from January 1, 12:00 A.M.

z = depth below pond surface (m)

and the subscripts f and g denote fluid and ground, respectively.

Equations (1) and (2) may be solved by the method of finite differences. The JPL code is derived from an explicit formulation with time and depth increments of Δt = 21,600 s = 0.25 days and Δz = 0.1 m, respectively.

The temperature of the UCZ is specified by a curve fit to monthly-averaged ambient temperature values. Diurnal fluctuations are not considered.

$$T_{UCZ} = A' + B' \sin\left[2\pi(t - C')/(365 \times 86,400)\right] \, °C \qquad (3)$$

For the Salton Sea, A' = 22.5°C, B' = 10.0°C and C' = 8.7264 x 10^6 s = 101 days. The temperature at a depth of 10 m below LCZ is set at the annual-average ambient temperature, 22.5°C.

The preferred temperature of the LCZ is assumed to vary sinusoidally with a period of 1 year.

$$T'_{LCZ} = A'' + B'' \sin\left[2\pi(t - C'')/(365 \times 86,400)\right] \, °C \qquad (4)$$

Ormat uses the following values in equation (4): A'' = 85°C, B'' = 10°C and C'' = 1.46016 x 10^7 s = 169 days.

Several operational options have been programmed for control of the model. In one option the lower zone temperature is constrained on the high side by equation (4). Thus the storage temperature is given by

$$T_{LCZ} = \min \left[T'_{LCZ}, \ T''_{LCZ} \right] {}^{\circ}C \tag{5}$$

T''_{LCZ} is the temperature of the LCZ for the case of no heat extraction and is given by Eq. (1).

The rate of heat extraction for time step n is given by

$$\dot{Q}_{ext}(n) = \max \left\{ 0., \ (\rho C_p)_f \ A \ D_{LCZ} \ x \ \left[T''_{LCZ}(n) - T'_{LCZ}(n) \right] / \Delta t \right\} W \tag{6}$$

where A is the solar pond area (m^2) and D_{LCZ} is the thickness of the LCZ (m).

A second control option accepts monthly energy delivery requirements with a minimum limit on storage zone temperature. The energy delivery schedule is satisfied so long as the LCZ temperature remains above the specified minimum. Below the specified minimum, no energy is extracted.

The rate at which insolation reaches a depth z is given by

$$\dot{I} = \gamma(t) \ P(\ell:t,z) \ \tau_n(t) \tag{7}$$

where P is a polynomial fit to the data presented in Figure 2-20. The path length is given by

$$\ell = z \ / \cos r \tag{8}$$

where r is the angle of retraction and is given by

$$r = \sin^{-1} (\sin i \ / \ N) \tag{9}$$

$$i = \cos^{-1} \left[\sin \delta \ \sin L - \cos \delta \ \cos L \ \cos (2\pi t \ / \ 86,400) \right], \text{ and}$$

$$N = 1.33 \text{ is the index of refraction} \tag{10}$$

where i is the angle of incidence and L is the site latitude. The solar declination δ is given by

$$\delta = 0.409 \sin \left\{ 2\pi \left[t - (79 \times 86,400)/(365 \times 86,400) \right] \right\} \tag{11}$$

The function $\gamma(t)$ is the rate of insolation just penetrating the pond surface. It is assummed that 85% of the insolation is direct and the remainder hemispherically distributed diffuse radiation.

$$\gamma(t) = \left[0.85 \ \theta(t) + 0.14 \right] \dot{I}'(t) \tag{12}$$
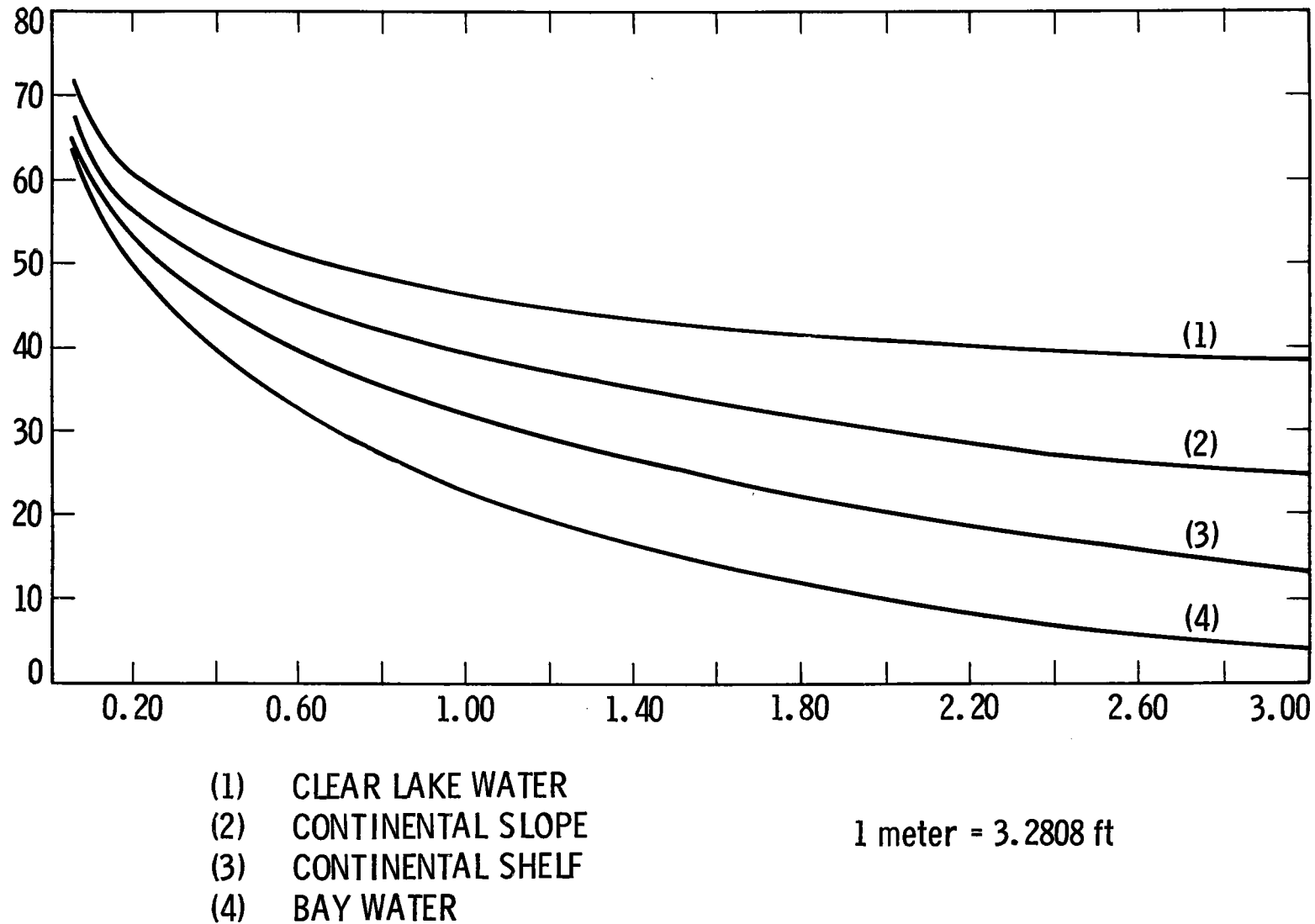
Figure 2-20. Percentage of Solar Radiation Transmitted through Saline Waters (Ref. 1)

(1)   CLEAR LAKE WATER
(2)   CONTINENTAL SLOPE
(3)   CONTINENTAL SHELF
(4)   BAY WATER

1 meter = 3.2808 ft

where 7% of the diffuse radiation is reflected. $\theta(t)$ is the fractional penetration of direct insolation and is computed from the Fresnel equations:

$$\theta(t) = 1 - 0.5 \left[(\sin^2(i - r)/\sin^2(i + r) + \tan^2(i - r)/\tan^2(i + r) \right] \qquad (13)$$

The fractional penetration of insolation through the floating wave-suppression network is

$$\tau_n(t) = 0.71 + 0.29 \left(0.88 + 0.06 \sin \left\{ 2\pi[t - (79 \times 86,400)] / (365 \times 86,400) \right\} \right) \qquad (14)$$

The insolation incident on the pond surface, $I'(t)$, is assumed to vary diurnally as

$$\dot{I}'(t) = \begin{cases} \dot{I}''(t) \; 0.8^{\sec(i)} \cos(i) / \int 0.8^{\sec(i)} \cos(i) \; dt & W/m^2 \\ & \text{between sunrise and sunset} \\ 0 & \text{between sunset and sunrise} \end{cases} \qquad (15)$$

where the limits on integration are sunrise and sunset on a given day. The JPL code assumes that insolation varies over the year according to

$$\dot{I}''(t) = a + b \sin \left\{ 2\pi \left[t - (73 \times 86,400) \right]/(365 \times 86,400) \right\} + \qquad (16)$$
$$c \cos \left\{ 2\pi \left[t - (73 \times 86,400) \right]/(365 \times 86,400) \right\} \quad W/m^2$$

At the Salton Sea, $a = 502 \; W/m^2$, $b = 218.7 \; W/m^2$ and $c = -5.3 \; W/m^2$.

The JPL code also allows for a more exact treatment of transmittance as a function of wavelength and salt concentration. The dependence of transmittance on concentration appears to be important at least for the case of Salton Sea water and is discussed more completely elsewhere (Ref. 5).

The more precise treatment is accomplished by substituting $\tau_{\ell,T}$ for $P(\ell:t,z)$ in Eq. 7, above, where

$$\tau_{\ell,T} = \int_\lambda f(\lambda') \; \tau_\ell(\lambda')d\lambda' \; / \int_\lambda f(\lambda')d\lambda' \qquad (17)$$

and $f(\lambda)$ is the continuous distribution function for insolation over all wavelengths, λ. The denominator in Eq. (17) is unity, by definition. It is assumed that the absorption of insolation is proportional to intensity (Lambert's Law),

$$d\tau(\lambda)/d\ell = -k(\lambda,C) \; \tau(\lambda) \qquad (18)$$

where $k(\lambda,C)$ is an absorption coefficient. Integrating over path length,

$$\tau_\ell(\lambda) = \tau_0(\lambda) \exp \left[-\int_\ell k(\lambda,C) \; d\ell' \right] \qquad (19)$$

and the constant of integration, $\tau_0(\lambda)$, is set equal to unity for all wavelengths.

For computational purposes, discrete variables are substituted for continuous variables and the transmittance is averaged over each of the m wavelength bands as follows:

$$\tau_{\ell,T} = \sum_{i=1}^{m} f_i\, \tau_{\ell,i} \Big/ \sum_{i=1}^{m} f_i = \sum_{i=1}^{m} f_i\, \tau_{\ell,i} \qquad (20)$$

and

$$\tau_{\ell,i} = \exp\left[-\int_{\ell} k_i(C)\, d\ell'\right] \qquad (21)$$

The required input is $k_i(C)$, which is derived from spectrophotometric data for a set of homogenous water samples.

$$k_i(C') = \left[\ln(-\tau_{\ell',i})\right] / \ell' \qquad (22)$$

where C' and ℓ' pertain to a particular sample.

Figure 2-21 shows transmittance as a function of wavelength for Salton Sea water and derived brines. At present, no method has been established for automated transfer of spectrophotometric data to the computer. Therefore, an approximation has been made by averaging the data over each of 15 wavelength bands and curve-fitting the dependence on concentration with a first order polynomial.

$$k_i(C) = a_i + b_i(C) \qquad (23)$$

A further approximation is made by setting either a_i or b_i to zero for all wavelength bands, thereby reflecting the rough equivalence of transmittance values only when these values are close to unity. Tabulated data for settled and filtered Salton Sea water, filtered and carbon-treated Salton Sea water, and distilled water are shown in Table 2-6. Assuming that the concentration gradient varies linearly with depth,

$$C = d + e\, z \qquad (24)$$

$\tau_{\ell,T}$ can be computed using data presented in Table 2-6 and Eqs. (20) and (21). The path length ℓ is computed by Eq. (8) for a given depth z and time t.

The parameters remaining to be specified are the thermal properties. Data for density (ρ), thermal conductivity (k) and heat capacity (C_p) are available in the literature (Refs. 6, 7). It is convenient to curve-fit the property dependence on temperature and salt concentration. For aqueous solution of NaCl and $MgCl_2$, the density (kg/m^3) is given by

$$\rho_{NaCl} = 16.018463 \quad 63.06211874 + 42.93573858\ C -$$
$$0.0075307525\ (1.8\ T - 32) - 0.0107216945\ C\ (1.8\ T - \qquad (25)$$
$$32) + 18.25969526\ C^2 - 0.0000363288\ (1.8\ T - 32)^2\big]$$

$$\rho_{MgCl_2} = 1000\ (1.00522405 + 0.774055163\ C - 0.0002484006\ T +$$
$$0.0001361628\ CT + 0.3993658493\ C^2 - 0.0000018661\ T^2) \qquad (26)$$

2-50
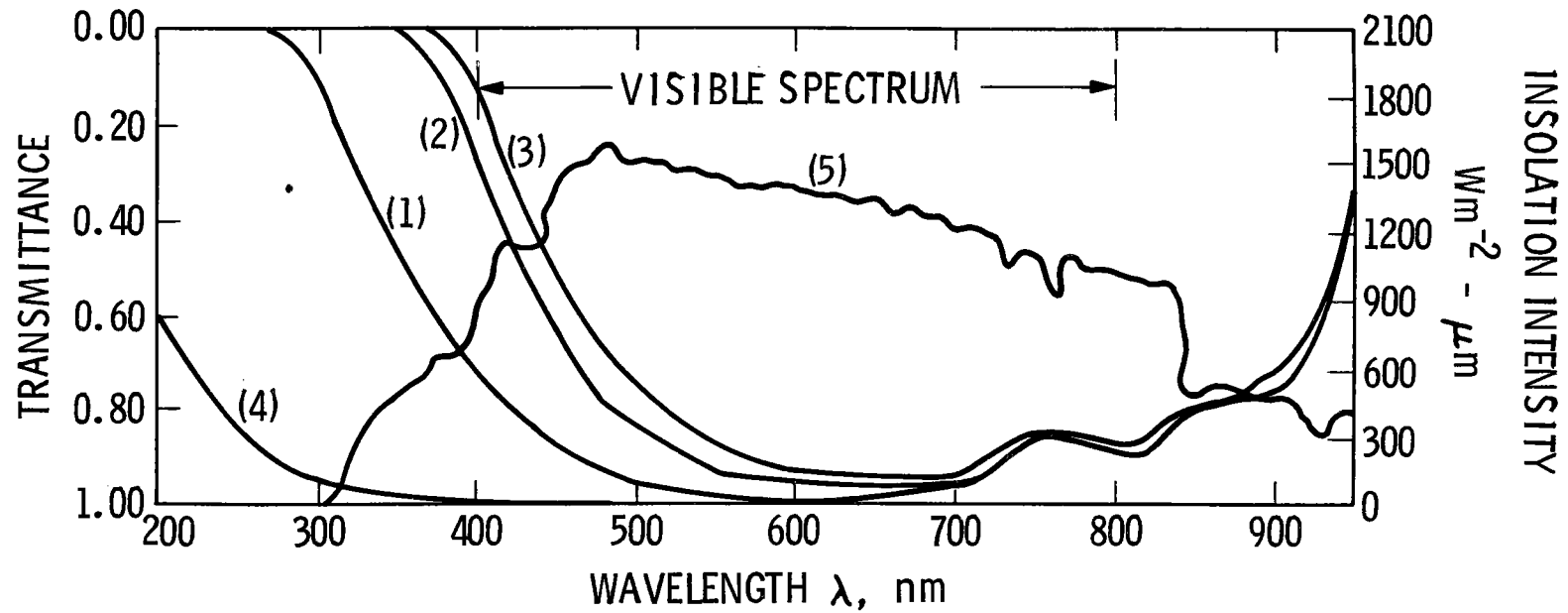
(1) SALTON SEA WATER
     (C = 0.038, ρ = 1020 kg/m^3)

(2) SALTON SEA BRINE
     (C = 0.200, ρ = 1160 kg/m^3)

(3) SALTON SEA BRINE
     (C = 0.280, ρ = 1230 kg/m^3)

(4) DISTILLED WATER

(5) INSOLATION INTENSITY – air mass 1

Figure 2-21. Transmittance as a Function of Wavelength for Salton Sea
Water and Derived Brines, 5-cm Path Length

Table 2-6. Spectral Bands and Band Extinction Coefficients

Constants for Calculating Band Extinction Coefficient ($k_i = a_i + b_i C$)

Band i	Band Limits, nm	Settled, Filtered Salton Sea Water, $a_i(m^{-1})$	$b_i(m^{-1})$	Carbon-Treated Salton Sea Water, $a_i(m^{-1})$	$b_i(m^{-1})$	Distilled Water, $a_i(m^{-1})$	$b_i(m^{-1})$	Band Isolation Fraction, f_i
1	200 – 320	0.0	1278.0	0.0	349.0	2.4	0.0	0.0005
2	320 – 370	0.0	422.0	0.0	115.0	0.7	0.0	0.0114
3	370 – 410	0.0	146.0	0.0	31.7	0.4	0.0	0.0227
4	410 – 440	0.0	64.8	0.0	14.5	0.3	0.0	0.0312
5	440 – 470	0.0	38.5	0.0	8.71	0.2	0.0	0.0420
6	470 – 500	0.0	23.1	0.0	4.68	0.1	0.0	0.0482
7	500 – 530	0.0	23.1	0.0	1.98	0.1	0.0	0.0487
8	530 – 570	0.0	8.51	0.0	0.917	0.0	0.0	0.0642
9	570 – 720	0.0	4.88	0.0	1.24	0.4	0.0	0.2296
10	720 – 830	2.7	0.0	2.7	0.0	2.7	0.0	0.1276
11	830 – 910	5.0	0.0	5.0	0.0	5.0	0.0	0.0749
12	910 – 940	10.3	0.0	10.3	0.0	10.3	0.0	0.0102
13	940 – 1,040	32.6	0.0	32.6	0.0	32.6	0.0	0.0796
14	1,040 – 1,110	15.4	0.0	15.4	0.0	15.4	0.0	0.0437
15	1,110 – 1,200	51.3	0.0	51.3	0.0	51.3	0.0	0.0282

The thermal conductivity, k (W/m-$^\circ$C) is given

$$k = 0.587 \left[1 + 0.00281 (T - 20)\right] (1 - \alpha_{SALT}C) \qquad (27)$$

where α_{SALT} = 0.00248 for NaCl and 0.00488 for $MgCl_2$.

The heat capacity, C_p (W - s/kg - $^\circ$C) is given by

$$C_p^{NaCl} = 4184\,(1.007464361 - 1.396381346\,C - 0.0001150635\,T + \qquad (28)$$
$$0.0014280276\,CT + 1.742790998\,C^2 + 0.0000005143\,T^2)$$

and by

$$C_p^{MgCl_2} = 4184\,(C_p^o + AT); \quad C_p^o = 1.00070 - 1.6746\,C + 1.44\,C^2 \qquad (29)$$

where

$$A = \begin{cases} 0.1 + 39\,C & \text{for } C < 0.15 \\ 2.8 + 20\,C & \text{for } 0.15 \le C < 0.17 \\ 4.5 + 10\,C & \text{for } 0.17 \le C < 0.20 \\ 6.5 & \text{for } 0.20 \le C < 0.24 \\ 8.489 - 8.2\,C & \text{for } 0.24 \le C \end{cases} \qquad (30)$$

Ground thermal properties are known with less accuracy. Ormat suggests using the same thermal conductivity as saline water. Soil conductivity is dependent upon the type of soil and varies over a wide range (Ref. 11). For example, at 20°C the conductivity of sandstone is about four times that of coarse, gravelly earth and three times that of saline water. The JPL code is programmed to accept a temperature-dependent range of soil thermal conductivities.

4.   Comparison of JPL and Ormat Model Output

JPL and Ormat model results are summarized in Table 2-7 for a Salton Sea solar pond with water optical clarity equivalent to Ormat Water Type #2 (continental slope) and #3 (continental shelf). Input data also include:

Upper convecting zone thickness = 0.25 m

Middle nonconvecting zone thickness = 1.30 m

Lower convecting zone thickness = 3.50 m

Effective ground thickness = 10.00 m

Average salt concentration in the UCZ = 0.057 (wt. fraction)

Average salt concentration in the LCZ = 0.246

Start of pond warm-up = March 21 (Spring equinox)

Table 2-7. JPL and Ormat Model Results for Salton Sea Solar Pond

MODEL	WATER TYPE	ELECTRICAL OUTPUT[a] (NET) W_e/m^2	INSOLATION TO LCZ[b]
JPL	Ormat #2	3.73	0.301
Ormat	Ormat #2	3.38	0.292
JPL	Ormat #3	2.63	0.209
Ormat	Ormat #3	2.28	0.210
JPL	Ormat #4	1.26	0.115
Ormat	Ormat #4	1.31	0.110
JPL	Carbon-treated	3.43[c]	0.256
	Salton-Sea	2.98[cd]	0.256

[a]Gross power output is 64% of an engine operating at Carnot efficiency. Net power output is 77.2% of gross output and is the average value for the fourth year of operation.

[b]The annual-average fraction of insolation that reaches the lower convecting zone.

[c]The model simulation for carbon-treated Salton Sea water considers the dependence of optical transmittance on salt concentration in the water. This treatment is discussed more fully in Ref. 5.

[d]All other runs set ground thermal conductivity equal to that of saline water. This run triples this property value (see p. 2-50).

Table 2-8 presents the ambient temperature and total insolation data.

The JPL code yields values of annual-average net electrical output of 3.73 and 2.63 w_e/m^2 for water type #2 and #3, as compared to Ormat predicted results of 3.38 and 2.28 W_e/m^2 (Reference 1). Considering the many model assumptions, this comparison is reasonably good.

Activated carbon-treated Salton Sea water produces an optical quality between type #2 and type #3 waters. The JPL code estimates a net eletrical output of 3.43 W_e/m^2. The output rate is sensitive to the ground conductivity and reduces to 2.98 W_e/m^2 when the conductivity is increased by a factor of 3.

Table 2-8. Salton Sea Climatic Data For Model Input[a]

Month	Temperature, $^{\circ}$C	Total Insolation, W/m^2
Jan.	12.3	140.6
Feb.	14.5	179.4
March	17.8	237.6
April	21.7	300.6
May	25.0	334.6
June	29.7	346.7
July	33.2	315.2
Aug.	32.6	298.2
Sept.	29.6	257.0
Oct.	22.7	213.3
Nov.	17.2	157.6
Dec.	13.1	128.5
Mean	22.4	242.4

[a]From Ormat Feasibility Study Report (Ref. 1).

G.   TRADEOFF STUDIES

1.   Introduction

In response to an action item given to JPL, six 5-MW pond power plant options were studied. The intent was to present options to the project which would meet project requirements, with cost reductions which were more clearly defined and analyzed in a consistent manner. A case study approach was selected for this analysis. The cases were chosen to lead from the Ormat baseline design, to more favorable positioning and to smaller pond areas.

2.   Basic Requirements

The basic requirements of the proof-of-concept plant are:

(1)   5-MWe gross output.

(2) Electric power generation by 1984.

(3) At least one leg of the dike in the sea.

(4) A minimum of 5-MWe electric power production for 36 continuous hours.

In addition, a cost target goal of $20,000,000 was considered very desirable. To achieve the cost goal and to meet the basic requirements, the following options are considered acceptable:

(1) Enhanced brine production by the use of spray nozzles.

(2) Reduction of pond size.

(3) Positioning of the solar pond partially on dry land.

(4) Orienting the solar pond according to WESTEC recommendation.

The performance of a solar pond power plant involves the simultaneous behavior of many major elements. Changes in solar pond area or alterations of the basic duty cycle will generally impose some design modifications on the power conversion module. No effort has been made in the work presented here to examine the power conversion module. A basic assumption has been made that the Ormat 5-MWe power module design can couple, without cost impact, to other solar pond configurations. A reiteration of the Ormat design may be appropriate at some later time. Some of the considerations are discussed further in the text below.

3. Power Module Design Considerations

The design of the power conversion module in a solar pond plant is dependent upon solar pond performance, pond cost, and power plant duty cycle. The current 5-MW power plant has been optimized with a 250-acre solar pond to deliver baseload power. Down-size modifications to the 250-acre solar pond bring about considerations for operating the plant in other modes; i.e. intermittent, peaking, or low-power continuous. These changes may well require a reoptimization of the baseload 5-MW power converter. A brief discussion of three possible cycles follows:

(1) Baseload Intermittent: In this mode the power plant will operate at baseload levels but for short periods of time. Hours of operation in the winter will be equal to hours of operation in the summer. The solar pond storage zone temperature will behave as a baseload plant, peaking in the fall and reaching a minimum in the spring. In this operating mode, very little change will be required in the power conversion module. Perhaps low capacity pumps to circulate hot brine and maintain system temperatures would be a desirable addition.

(2) Peaking: If a peaking profile (defined as maximizing summer production), is desired, then the plant will operate for more hours during the summer and less hours during the winter. Power will be taken as

pond energy is available and the storage temperature will remain relatively constant.

Power plant optimization should then be made around summer operating conditions.

(3) <u>Low-Power Continuous</u>: This mode will consist of low-power contin- uous operation with scheduled excursions to 5 MW. At low power, fluid flow rates will be low and heat exchanger ΔT's will also be lower. Parasitic power losses will be proportionally higher. A rather significant power system redesign can be anticipated if good performance at low operating levels is desired.

Many more duty cycles are possible. The above three are presented to stress the dependency of the power module design on the solar pond configuration and the desired annual duty cycle. Before selecting a smaller solar pond option, it will be necessary to define a power plant design duty cycle.

4.   Pond Study Case Descriptions

Based on the requirements and the acceptable design options, six pond study cases were chosen. These cases were considered to address questions in a logical sequence. Case-to-case comparisons with one another and with the Ormat baseline are possible. The Ormat baseline design is labeled System No. 1. Table 2-9 summarizes the special features of each case, called "systems" in the table.

Figures 2-22 through 2-27 show sketches of the locations and the orienta- tion of those systems. A more detailed discussion of the special features of the six cases will be found in the subsection on pond construction and plant costs.

5.   Essential System Performance Characteristics

To meet the basic demonstration requirements, the important system performance characteristics are the warm-up and the duration of the plant capa- city to run at 5-MWe power output. Both the start-up case (the start of the plant with two feet of storage zone) and the full operation case (the plant starts operation with full storage depth as described in the system descrip- tions) have been analyzed. The results are summarized in Table 2-10.

In each case, the storage zone is first warmed up to a temperature of 90°C, then the energy is extracted to run the plant at 5 MWe until the temperature drops to 85°C, after which the power will be generated based on the following zone temperature profile as determined by Ormat for a 250-acre baseload plant.

$$T_{LCZ} = 85 + 10 \sin (2\pi(D-90)/365)$$

where T_{LCZ} is the storage zone temperature and D is the number of days from March 20. (If the Ormat profile is ignored, the peak duration time can be essentially doubled by operating at 5 MWe until temperature drops to 80°C.)

Table 2-9. A Summary Description of Study Systems

Systems	Descriptions
System No. 1 (Ormat Baseline System)	5-MWe gross power output 250 acres of solar pond, 16.5-ft deep 625 acres of brine production pond All ponds are in the lake
System No. 2	5-MWe gross power output 250 acres of solar pond, 16.5-ft deep, partially on shore 625 acres of brine production pond placed at the most convenient location
System No. 3	Same as System No. 2, but oriented according to WESTEC recommendation
System No. 4	Same as System No. 2, except pond sizes are reduced as follows: 125 acres of solar pond 232 acres of brine production pond (spray pond)
System No. 5	Same as System No. 2, except pond sizes are: 62 acres of solar pond 83 acres of brine production pond (spray pond)
System No. 6	Same as System No. 5, except pond depth is 10 ft

The analysis is based on charcoal-filtered Salton Sea water and a first-order concentration profile.

It should be noted that the warm-up periods from this analysis are somewhat longer than Ormat predictions.

6.   Evaporation Pond Requirements

To produce the brine at more than 200,000 ppm salt concentration from the Salton Sea water with a salt concentration of 38,000 ppm by evaporation in a pond, the volume ratio of the original sea water to the final brine is
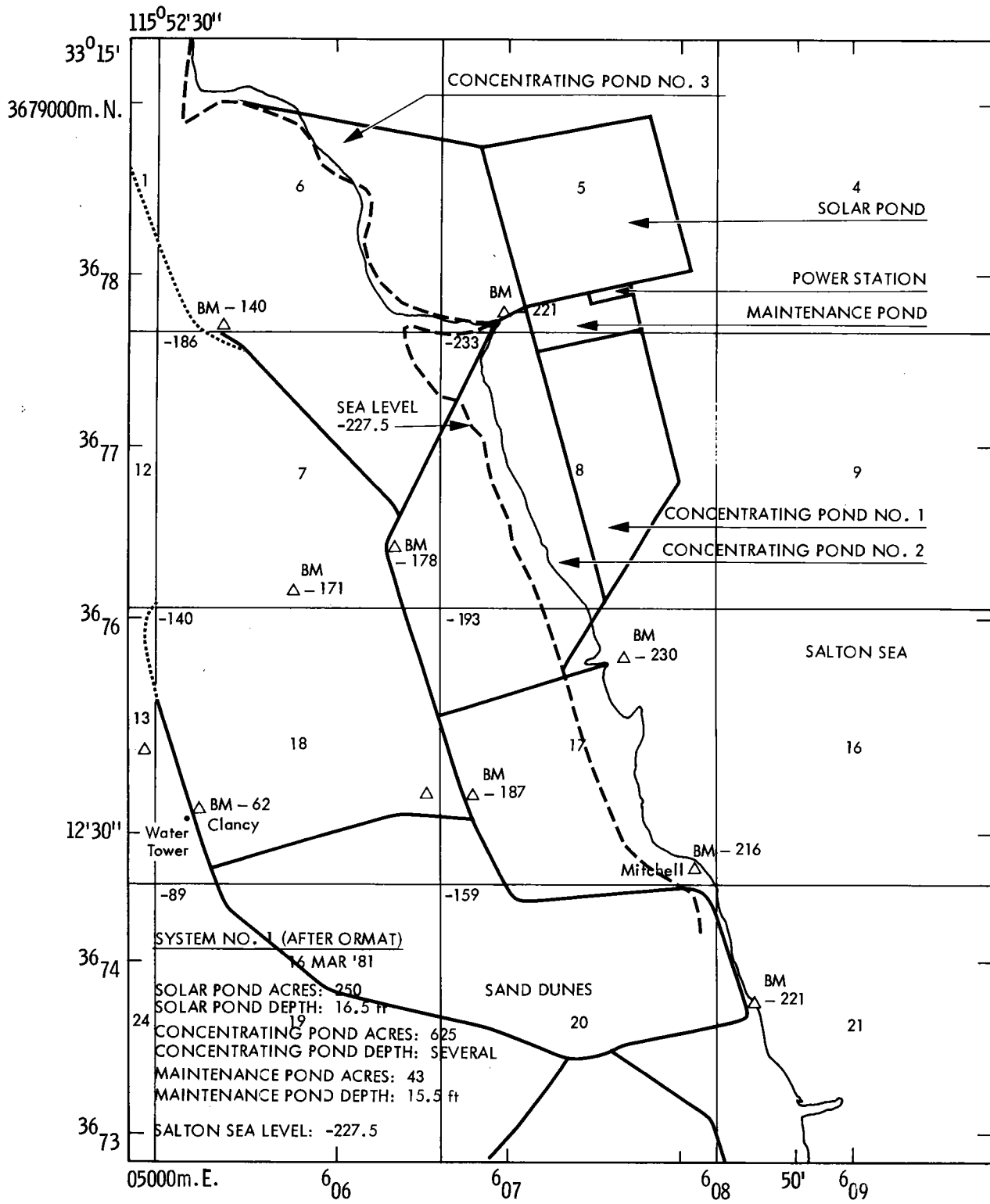
Figure 2-22. Pond Study Case No. 1 Proposed Location

2-59
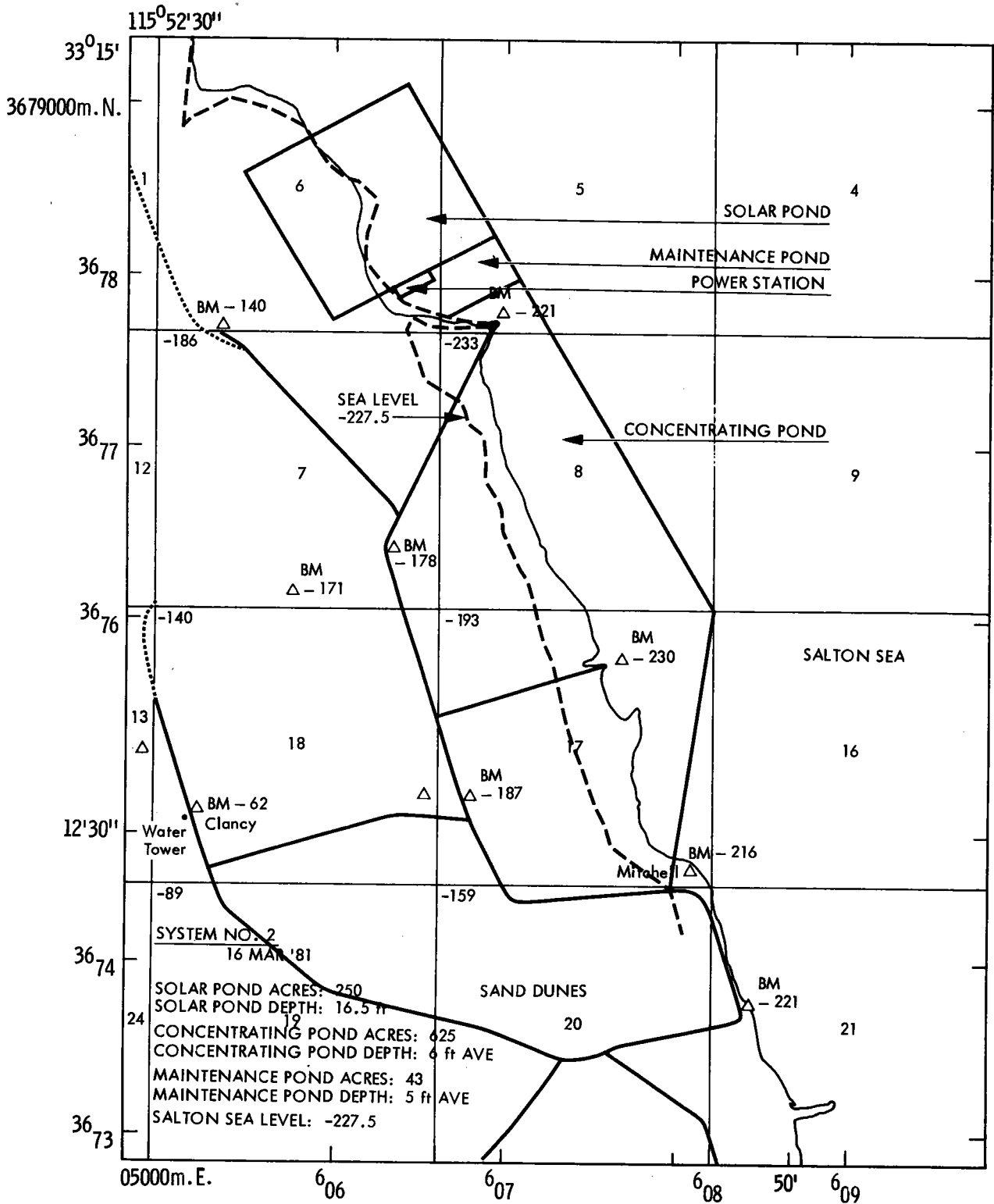
Figure 2-23. Pond Study Case No. 2 Proposed Location

115°52'30"

33°15'

3679000m. N.

EVAPORATING POND NO. 1

MAINTENANCE POND

SOLAR POND

1

6

5

4

36 78

BM − 140

BM
△ − 22

−186

−233

SEA LEVEL
−227.5

36 77

12

7

8

9

EVAPORATING POND NO. 2

△ BM
− 178

BM
△ − 171

36 76

−140

− 193

BM
△ − 230

SALTON SEA

13
△

18

17

16

BM
△ − 187

BM − 62
△ Clancy

12'30"

Water
Tower

△

BM − 216
Mitchell △

−89

−159

SYSTEM NO. 3 (AFTER WESTEC)
16 MAR '81

36 74

SOLAR POND ACRES: 250
SOLAR POND DEPTH: 16.5 ft
CONCENTRATING POND ACRES: 625
CONCENTRATING POND DEPTH: 6 ft AVE
MAINTENANCE POND ACRES: 43
MAINTENANCE POND DEPTH: 5 ft AVE
SALTON SEA LEVEL: −227.5

24

19

SAND DUNES

20

BM
△ − 221

21

36 73

05000m. E.

6 06

6 07

6 08

50'

6 09

Figure 2-24. Pond Study Case No. 3 Proposed Location

2-61
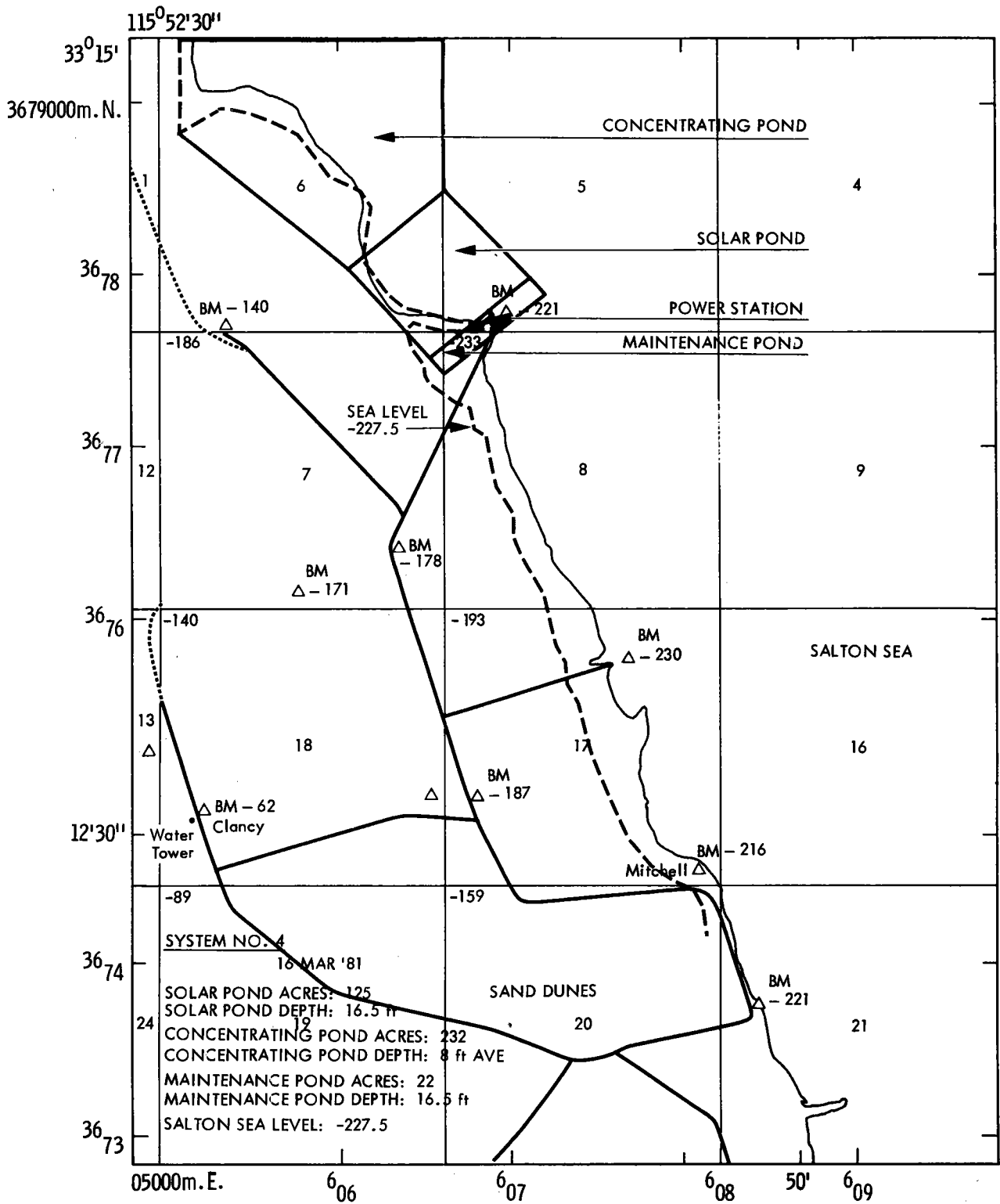
Figure 2-25. Pond Study Case No. 4 Proposed Location
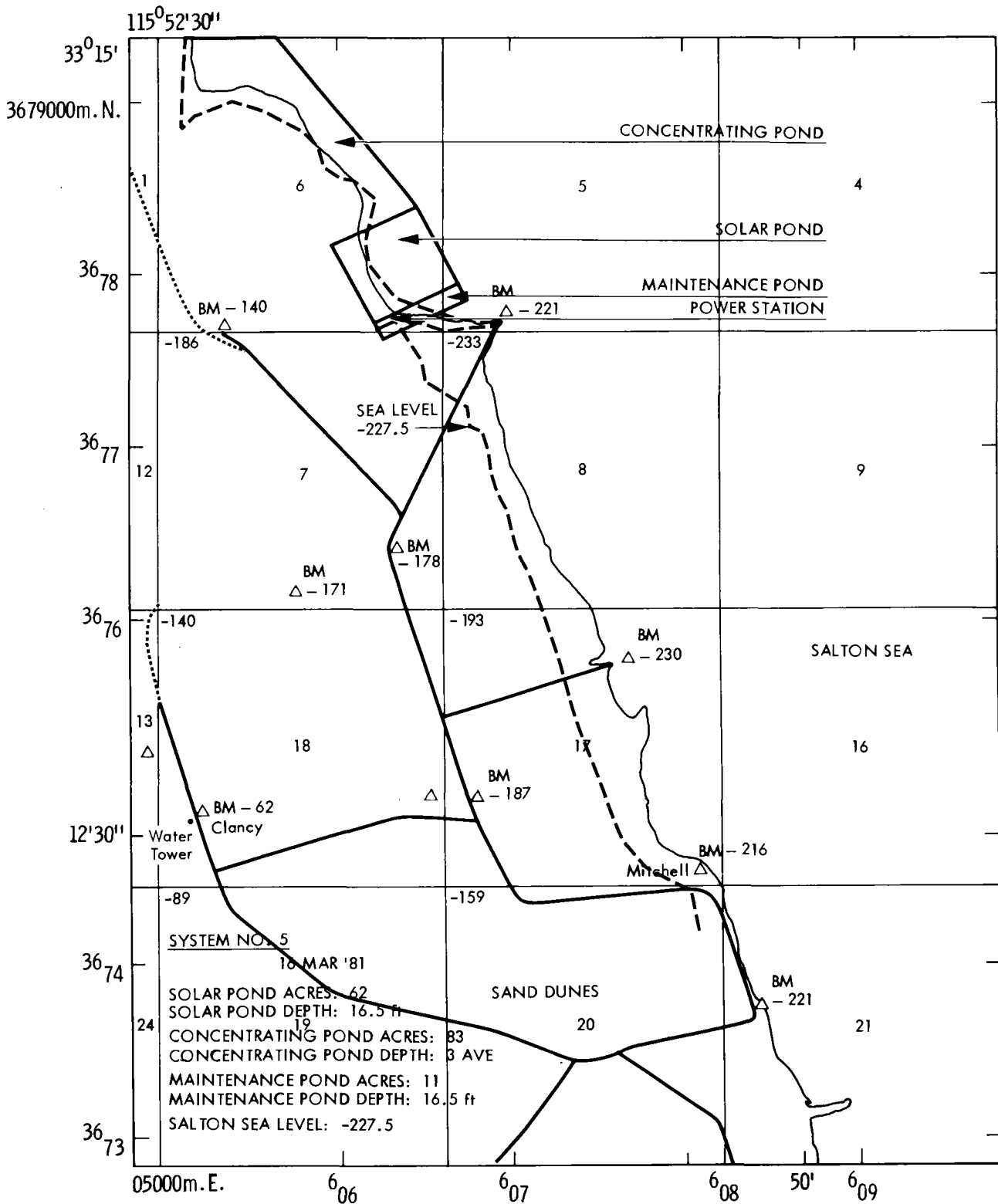
Figure 2-26. Pond Study Case No. 5 Proposed Located

115°52'30"

33°15'

3679000m.N.

CONCENTRATING POND

1   6   5   4

SOLAR POND

36 78   MAINTENANCE POND

BM – 140   BM   POWER STATION
△   △ – 221

-186   -233

SEA LEVEL
-227.5 —

36 77

12   7   8   9

△ BM
– 178

BM
△ – 171

36 76   -140   -193

BM
△ – 230   SALTON SEA

13
△   18   17   16

△   BM
△ – 187

△ BM – 62
Clancy

12'30" Water
Tower

BM – 216
Mitchell △

-89   -159

SYSTEM NO. 6
16 MAR '81

36 74

SOLAR POND ACRES: 62
SOLAR POND DEPTH: 10 ft   SAND DUNES   BM
△ – 221

24   19   CONCENTRATING POND ACRES: 83
CONCENTRATING POND DEPTH: 3 ft AVE   20   21

MAINTENANCE POND ACRES: 11
MAINTENANCE POND DEPTH: 10 ft

36 73   SALTON SEA LEVEL: -227.5

05000m.E.   6 06   6 07   6 08   50'   6 09

Figure 2-27.   Pond Study Case No. 6 Proposed Location

2-64

Table 2-10. Essential System Performance Characteristics

Systems	Start-Up (2-ft Storage)[a]		Full Operations[b]		
	Warm-Up[c] days	Peak Duration,[c] days	Warm-Up[c] days	Peak Duration,[a] days	Annual Avg. Output[d] (W/M^2)
1	97	114.50	178	31.25	4.38
2	97	114.50	178	31.25	4.38
3	97	114.50	178	31.25	4.38
4	97	2.25	178	12.5	4.38
5	97	0.75	178	4.75	4.38
6	97	0.75	103	2.00	4.26

[a]Warm-up to start with 2-ft storage zone.
[b]Warm-up to start with full depth of storage zone.
[c]Pond warms up to 90°C, then heat is extracted to produce 5-MWe gross power until temperature reaches 85°C, then Ormat annual profile is followed.
[d]Based on 1200 days of power output simulation.

about 6.4. If the pan evaporation at Salton Sea is taken at 8 ft per year, and an average pan-to-lake transfer coefficient of 0.65 is assumed, the net annual evaporation, after the subtraction of an annual precipitation of 3 inches, will be slightly over 5 ft. Ormat reports that using the solar pond as the initial evaporation pond, it will take more than 14 years to produce the necessary brine to fill the pond to the full operational depth. If the pond is to start operation with 2 ft of storage zone, the time required to produce the necessary brine is still more than 4 years. Obviously, enhanced evaporation schemes are necessary to shorten this start-up period. Many schemes are possible. More evaporation pond area, multi-stage evaporation by the supply of thermal energy, reverse osmosis, and spray evaporation are some of the possibilities. In principle, all these should be assessed to determine the most promising scheme for use in the current application. However, this is a very tedious and time-consuming process. The alternative is to make a quick assessment and to choose the most appealing evaporation schemes for preliminary studies. With this consideration, the spray evaporation concept was chosen for this study because of its simplicity and great potential.

Spray evaporation cooling has been effectively used in power plants for the dissipation of waste heat. With appropriate ambient conditions, a single spray nozzle can evaporate up to 3% of the water it sprays with accompanying water temperature drop of up to 30°F to supply the required energy for this evaporation rate. Water vapor saturation of the air also has to be considered before an effective spray system can be established. In a conventional power plant application, the energy need is constantly supplied by the power plant. If this evaporation rate can be achieved in the present application, not only

can the brine production time be drastically shortened, but also the evaporation pond area can be dramatically reduced at the same time.

However, in this application, there is no reject power plant energy supply to sustain the high evaporation rate. The evaporation energy supply must come from other sources.

There are three major energy sources that can contribute to the evaporation process: insolation, sensible heat of the air, and sensible heat of the water. Under ordinary evaporation conditions, the three energy sources combine to establish thermodynamic equilibrium and a sustained evaporation rate. For a different evaporation rate, a new sustainable thermodynamic equilibrium condition has to be established. This can be done by the redistribution of these three major energy contributions to the evaporation process by introducing new factors into the process. Spraying is the factor to be explored and assessed.

The assessment is to be based on annual averaged conditions at Salton Sea as listed below:

(1) Ambient temperature: 72.4°F.

(2) Relative humidity: 27.3% (33 grains/lbm dry air, 120 grains/lbm if saturated).

(3) Dew point: 37°F.

(4) Insolation: 1851 Btu/ft^2 - day.

(5) Water temperature: 72.4°F.

(6) Wind speed: 6.23 ft/s.

An assessment based on a first law energy balance was made and the results are summarized in Table 2-11 in terms of the spray pond acreage requirements for various sizes of solar ponds. Included in the table are also some related brine and energy requirement data.

7.   Pond Construction and Plant Costs

A pond construction cost estimate was made for each of the systems studied, and results are summarized in Table 2-12. The total plant costs, which include the pond construction costs, the Ormat costs for brine management and water purification systems, the power generating unit, and the spray evaporation system costs (for Systems 4, 5, and 6) estimated in the previous section, are shown in Table 2-13.

The following comments pertain to all six cases:

(1) In every case, it is assumed that the pond bottoms and the bagged dikes do establish adequate impermeability. This assumption is critical.

Table 2-11. Energy Balance Assessment Results for Spray Evaporation Rate

| Solar Pond Size, Acres | Brine Requirements | | | | Evaporation Pond Size for Start-up in One Year, acres | |
| | To Start Plant[a] | | To Fill Pond[b] | | | |
	Brine, acre-feet	Required Energy, 10^{13}Btu	Brine, acre-feet	Required Energy, 10^{13}Btu	Ordinary Evap.	Spray[c]
250	1000	1.460	3375	4.926	1074	589
125	500	0.7298	1688	2.463	537	232
62	248	0.3621	837	1.222	266	83

[a]Plant starts with 2 ft of storage zone (4 ft of equivalent brine depth).
[b]Fill the storage zone to the full depth plus 2 ft of equivalent for the salt gradient zone.
[c]Spray height H = 15 ft, spray pond shape L/W = 2, air saturated at 54°F.

(2) Sea level is now -227.5 ft. At the start of the study the best available data placed the lake level at -232 ft. Ormat used -232 ft in their analysis. The effects of changing from -232 ft are:

(a) Ponds/dikes positioned relative to the earlier shore line are now in deeper water.

(b) Construction positioned on land encounters steeper ground, hence more dirt to move.

(3) The "bag" construction technique continues to be most favorable. As planned here, the bagged dikes surrounding any unit are placed on the natural seabottom foundation, then the excavation, as needed, slopes downward from line of bags. This means that the bags are not resting on the cut, or level, of excavation.

Wherever cut slopes are made, they are buttressed by a single layer of bags placed on the slope to furnish stability.

(4) Layouts illustrate possible configurations. Optimizations have not been made.

Table 2-12.   Summary of Solar and Evaporation Pond Construction Cost Estimates

Descriptions	Systems					
Architecture	1	2	3	4	5	6
Solar Pond: Area	250 Acre	250 Acre	250 Acre	125 Acre	62 Acre	62 Acre
Depth	16.5ft	16.5ft	16.5ft	16.5ft	16.5ft	10.0ft
Concentrating Ponds: Area	625 Acre	625 Acre	625 Acre	232 Acre	83 Acre	83 Acre
Depth	Several	5ft Avg.	5ft Avg.	6ft Avg.	4ft Avg.	4ft Avg.
Maintenance Pond: Area	43 Acre	43 Acre	43 Acre	22 Acre	11 Acre	11 Acre
Depth	15.5ft	7ft	6ft	10ft	10ft	10ft
Construction Cost Estimates, $K						
Solar Pond	10,216	10,034	11,542	4,822	2,830	2,876
Concentrating Pond(s)	8,393	11,830	7,966	6,030	2,089	2,089
Maintenance Pond	797	886	1,175	1,349	382	258
Power Station Platform	521	606	606	786	723	767
Run-Off Diversion	333	400	242	207	183	183
Sub Total	20,260	23,756	21,531	13,194	6,207	6,173
Add: Contractor 25%	5,065	5,939	5,383	3,299	1,552	1,543
Subtotal	25,325	29,695	26,914	16,493	7,759	7,716
Add: Engineering 5%	1,266	1,485	1,346	825	388	386
TOTAL Construction Estimate:	$26,591	$31,180	$28,260	$17,318	$8,147	$8,102

Table 2-13. Summary of Power Plant Cost Estimates

Descriptions	Systems					
	1	2	3	4	5	6
Solar & Evaporation Pond Construction Cost, $k	26,591	31,180	28,260	17,318	8,147	8,102
Spray Evaporation System Cost, $k	-0-	-0-	-0-	3,520	1,760	1,760
Brine Management & Water Purification System Cost, $k	3,852	3,852	3,852	3,512	3,227	3,227
Power Generating Unit Cost, $k	8,100	8,100	8,100	8,100	8,100	8,100
TOTAL Plant Cost:	38,543	43,132	40,212	32,450	21,234	21,189

(5)   All sea-front dikes, but not the interior, are assumed protected in making the estimate.

(6)   Attempts were made to site the power station on solar pond center-lines for the sake of pond piping, and in or adjacent to the maintenance pond, regardless of its relative position to the evaporation pond.

(7)   These estimates, as well as the data or the sketches on which they are based, must be considered as very preliminary.

(8)   Systems 1, 2, and 3 use parts of four Sections (5, 6, 8, & 17). By agreement with the Navy, only Sections 5 and 6 are available.

(9)   The 25% add-on costs for contractor and 5% for engineering are reasonable assumptions.

(10)   All cases provide a 1-ft thick by 16-ft wide rock surface roadway along all dikes.

Specific comments on each of the cases are as follows:

    a.   System No. 1 (Figure 2-22):

        (1)   This is Ormat's baseline system, moved westward to occupy a position near the modified shore line.

        (2)   Its drawbacks include:

            (a)   Extension outside the "designated area" (into Section 8).

            (b)   Very large volume of earthworks.

            (c)   The depth of water at the easternmost dike (-253 (-) -227.5) = 25.5 ft.

            (d)   Siting of power station offshore is doubtful because of stability.

        (3)   It appears that modest dredge spoil (800K yd^3) can be stowed on Section 6.

        (4)   Interior dikes hold a freeboard of 6 ft; exterior, 8 ft. Concentrating ponds sited on sloping, natural bottoms.

    b.   System No. 2 (Figure 2-23):

        (1)   This layout moves ponds shoreward and is a tradeoff of additional dredging of land for more shallow dike construction.

(2) The evaporating pond area is compromised to stay south of T. 11 S boundary.

(3) Storage and evaporation ponds utilize natural sea-floor bottoms.

(4) Special Note:

About 6 million cubic yards of dredge spoil are the concern here. This large volume must probably be placed as fill on land (the logical spoil sites lie in Sections 7 and 8 (11 S, 11 E). Spoil to sea is considered unacceptable.

c. System No. 3 (Figure 2-24):

(1) This is WESTEC's layout intended to obviate a catch basin along the northern perimeter where the N-to-S current might establish an eddy.

(2) The power station positioning herein is awkward to pond piping geometry.

(3) It appears that the siting would allow storage of the dredged spoil (in this instance, about 2.5 million cubic yards) which may go to Section 6.

d. System No. 4 (Figure 2-25):

(1) Essentially, this alternative establishes a "half" pond (125 acres) that is moved astride the shoreline to economize on dike construction at the expense of more dredging.

(2) This effort dredges about 3 m yd^3. It appears that the spoil could most conveniently go to Sections 7 and 8.

(3) The power station orientation, as shown, is flexible in this case.

e. Systems No. 5 and 6 (Figures 2-26 and 2-27):

(1) Both establish 62-acre solar ponds in the same architecture, and both allow 83 acres of evaporation pond conveniently. System No. 5 is evaluated with a 16.5-ft solar pond depth while No. 6 assumes a 10-ft depth. The former dredges 1.4 m yd^3, the latter, 650K yd^3. Spoiling from both cases could most conveniently go to Sections 7 and 8.

H. ELECTRIC POWER POTENTIAL[1]

1. Introduction

This section presents the results of a survey analysis made to identify the solar pond electric power potential in the United States. This part of the Phase 1 study was sponsored by the Department of Defense through the Office of Civil Preparedness.

National interest in the Salton Sea solar pond experiment centers on the belief that the technology is suitable for other locations. From the point of view of the Office of Civil Preparedness, a network of distributed solar pond power plants might offer a valuable emergency power reserve.

The potential of solar pond electric power systems depends upon physical resources, insolation, weather, economics, regional energy needs, environmental impacts and land availability. Many of these factors must be addressed on a regional or site basis. The results presented here reflect on a regional level only the availability of physical resources, insolation and weather. The quoted potential must therefore be regarded as a limit value with the real potential being tempered downward by consideration of regional energy needs, availability and economics of competing energy sources, and environmental impacts.

In order for solar pond power plants to be economically viable, several site requirements must exist. These requirements are high insolation, large areas of inexpensive land, readily available salt and a continuous supply of fresh or low salinity water. In areas having high insolation, a square kilometer pond will yield a baseload net output of 2-1/2 to 3-1/2 MW. Commercial plants are envisioned to be constructed of 20- to 50-MW modules; therefore land requirements will range from 6- to 14-km^2 (1500 to 5500 acres) for each module.

An economic analysis based on Salton Sea power plant cost estimates was conducted as part of this study. Judging from insolation and availability of other essential resources, the primary siting states for solar pond power plants are California, Nevada, Utah, Arizona, Colorado, New Mexico, Oklahoma, Texas, Louisiana, Mississippi, Alabama, Florida, Puerto Rico, and Hawaii. The Tennessee Valley and Pacific Northwest were not included in the primary siting regions because salt reserves are not known to exist. The cost impact of importing salt to these regions for solar pond power plants would likely increase busbar electric costs by more than 25%.

A clear distinction can be drawn between solar ponds which deliver thermal energy as the end product and a solar pond power plant. Because of the relatively low power conversion cycle efficiency (8 to 9%), a solar pond for electric application must be very low in cost and attain a relatively high performance. As a result the best siting locations will be in the southern regions of the country where large areas of low-valued land, clay lining materials, abundant salt and makeup saline water are available. Importation of salt or installation of a synthetic pond liner will likely result in a power cost that is not competitive in the existing commercial market.

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[1]This section was extracted for the Regional Assessment Study, Reference 2.

To the above general observations, there are exceptions. If sites can be found that have existing ponds or that have a problem of storing excess salt, technologies may be combined to yield a cost-effective power plant. Examples of these sites might be in the chemical industry which has a large number of waste ponds for the storage of toxic or waste products. The possibility of converting these into cost-effective power plants may be achieved since the ponds will be providing multiple benefits. Within the United States, there are some 275,000 ponds in existence. At this point, we do not know the nature of these ponds, but they are involved with industrial processes, sewage effluent, petroleum production and toxic effluent storage. Other interesting applications for power plants can be found in conjunction with chloride control projects. A river, such as the Colorado River, has tributaries which feed salt to the main body. If these salt-feeding tributaries are diverted into a holding area and solar ponds are constructed, multiple benefits can be realized. These include reduction of salinity in the main river, and the production of electric power from an otherwise waste product.

Electric energy in remote or island locations is much more expensive than utility grid-supplied energy. Solar pond power plants offer to become the least expensive option for remote applications. In Hawaii, for example, electric energy cost is near 150 mills/kWh. Land on islands is generally a precious entity, however, and may offset otherwise attractive economics.

2. Potential

In the grid-connected U.S., the solar pond potential is perceived to be resource-limited rather than need-limited. That is, the utility grid is so large that all the potential power from solar ponds could be readily absorbed by the grid. No regional considerations relative to future power needs were folded into this analysis.

In examining specific sites, difficult choices were necessary. Judgment decisions were rendered using a variety of criteria. For example, at the Salton Sea in California, the sea surface area is 922 km^2 (355 mi^2). The fraction of the sea that can be converted to solar ponds is perhaps arbitrary. We have chosen 20%, but clearly the potential exists for more, perhaps 40 or 50%. Other evaluators could look at the same basic data and develop other choices. The merit of this analysis is that conservative assumptions have been attempted and a large potential has resulted. Clearly, the solar pond power plant technology can be applied to more than the the Salton Sea and the Great Salt Lake.

Since solar ponds have long-term storage capability and the capacity to supply high demand peaking, the installed electrical capacity for a given pond can vary widely. Capacity numbers presented in this report are in terms of average continuous net output, (i.e., a load factor of one has been assumed). In addition, the numbers reported are net output. Power for parasitic losses and for pumping underground water when required have been subtracted from the gross capacity to yield net output.

The primary siting regions for solar pond electric production are those in the southern zones. In general, viewing from west to east, resource characteristics change dramatically. In the west, high insolation will be

found and a relative abundance of salt or high-saline underground water, but a shortage of low-saline or fresh water exists. In the central region (Texas, Oklahoma, Louisiana) all of the appropriate ingredients appear to be present in relative abundance. Insolation is lower than in the far west but sufficient. Large sources of salt are readily available and water, which is in short supply on the western boundary, becomes plentiful on the eastern boundary. Land and suitable clays are perceived to be realtively available. In some areas of this region, salt and saline water excess are major problems and are contaminating fresh water supplies.

The eastern region of the United States has adequate insolation, a plentiful supply of water, land, and clay-type soils. Salt resource is limited, except in Louisiana, and a high water table may complicate pond construction throughout the area. Ocean water could be a source of salt, but the high rainfall and high relative humidity limit the use of evaporation ponds for salt production.

In the southwest, water is the critical and limiting factor for solar ponds. Since most water studies are directed toward fresh water supplies, data is inadequate to define the amount of available saline water and the annual replenishment. A solar pond will require as much as 16 acre-ft. of water per acre of pond for the initial fill and from 7 to 9 acre-ft. per year of evaporation replenishment water. The annual replacement is truly the factor that limits the potential in the southwest. If evaporation can be effectively controlled, the solar pond potential would be greatly expanded. This evaluation has assumed no consumption of fresh water in water-short areas.

An alternative to local water is importation of ocean water. In Southern California, coastal property is highly valued, and flat open areas near the ocean are not candidate sites. However, it is conceivable to bring ocean water into the lower California desert or into Arizona from Baja, a distance of 40 miles. Water costing $100/acre-ft. will only translate to an increase of about 1¢/kWh in busbar electric cost. This concept is, however, beyond the scope of this study.

Along the Texas Gulf Coast, ocean water for solar pond surface washing appears very plausible. In island installations, use of ocean water is a basic prerequisite. As average humidity increases, evaporation losses and the ability to make brine from ocean water both diminish. This has both positive and negative effects and only emphasizes the fact that solar ponds will be site-specific not only in terms of construction but also in terms of operation and maintenance.

The discussion that follows supports the summary of solar pond power plant potential presented in Table 2-14. Each state in the primary siting area is discussed.

PRIMARY SITING AREA

California: The largest potential site in California is clearly the Salton Sea. The Salton Sea is 922 km^2 in area; if 20% of the sea is converted into solar pond power plants, a net power output of 650 MW can be realized. Other water bodies include San Francisco Bay and San Diego Bay.

Table 2-14. Solar Ponds - Electric Power Potential Baseload Average Output

State	MWe (Net)
California	2,000
Nevada	500
Utah	5,000
Arizona	400
Colorado	220
New Mexico	700
Oklahoma	2,300
Texas	20,000
Louisiana	4,000
Mississippi	500
Alabama	400
Florida	2,000
Total	38,000 MWe
	3.4 Quads

However, San Diego Bay does not appear large enough to support a commercial power plant. Many potential smaller sites exist within the state and have the necessary ingredients of high insolation, land area and salt, but are limited by water for evaporation makeup. These sites are typically inland dry desert lakes with surface salt crusts and underground saline water. Water and brine for initial pond fill are frequently available, but the long term evaporation makeup source is unknown.

One approach to estimating potential makeup water is to look at the reported average depth of water at nominally dry inland lakes following a winter season. Normally such water resides on the surface, contained by impervious clays, until evaporation causes surface water to disappear. If a portion of this water could be channeled into storage, perhaps underground, then a reliable source of replenishment water might be created. Such a scheme might involve pumping down the existing saline water table and building percolation basins to quickly dispose of surface water. In Table 2-14, a notation indicating surface water management is a reflection of managing winter rain water accumulation and preserving a portion (50%) to supply water to the surface of solar ponds.

Along the California-Mexico border near the Pacific Ocean, there appears to be an area in which ocean water could be imported to create a large solar

pond. An estimate of this potential as well as other inland sites is presented in Table 2-14. The potential for California is judged to be 2000 MW.

Arizona: The limiting factor in Arizona is water. As part of the Colorado River Chloride Control Project, sufficient Colorado river water would be diverted in Arizona to support 360 MW of solar pond electric production. Additionally, sites around Phoenix have been suggested. Salt is readily available and saline water sources have been identified, but the extent of the resource could not be determined; therefore, no reflection of the Phoenix potential has been included.

Nevada: The three candidate sites for the state of Nevada are Walker Lake, Carson Sink and an additional element of the Colorado River Chloride Control Project. Walker Lake is similar to the Salton Sea in that the lake is becoming more saline. The concept proposed for the Salton Sea, of diking a portion of the lake to achieve lake salinity control, could be applied to Walker Lake. Diking 20% of Walker Lake and creating solar pond power plants could produce 120 MW of electric power.

Carson Sink is 450 square miles in area and receives water from the Carson and Humbolt Rivers. Salt is readily available, and the area is underlined with clay and saline water. An estimate of 260 MW has been made for Carson Sink.

The third Nevada site utilizes Colorado River water and is part of the Colorado River Chloride Control Project. The power potential was taken from the Bureau of Reclamation's Colorado River Study (Reference 10).

New Mexico: The most interesting potential in New Mexico is in the Pecos River area or southeast plains. Large quantities of salt are being introduced into the Pecos River, creating a severe contamination problem. The information from New Mexico indicates that water should be available to support approximately 36 mi^2 of solar ponds. If underground brine is pumped also, the estimated potential is 700 MW. Near Carlsbad and Rosewald, New Mexico, there is a potash industry. Natural ponds exist and excess brines are available, but further data is sparse in assessing a potential for developing solar ponds. One of the needs of this area may well be a desalination plant.

SALT LAKE REGION

Utah: The solar pond potential in Utah is dominated by the Great Salt Lake. This highly saline, large, concentrated body of water was recognized early as a major site for solar pond development. A specific Utah assessment was commissioned to Drs. Paul Riley and Clair Batty of Utah State University (Ref. 9).

Drs. Riley and Batty have developed a proposed master plan for the Great Salt Lake that recognizes the industrial, social and recreational needs of the area. The lake is subdivided and developed into solar ponds, high concentrated regions for supporting mineral extraction industries, low salinity areas and a fresh water zone for recreation. This master plan thus proposes a lake management plan which will develop the resource in an environmentally acceptable manner. The total potential for the Great Salt Lake is 4000 MW.

Utah also has other vast resources of open land and salt away from the Great Salt Lake, though water becomes a limiting factor. Of particular interest is the concept of integrating solar ponds with oil shale development. Large quantities of brine or contaminated water are by-products of the oil shale operation, which, incidentally, requires substantial electric power.

The overall total Utah solar pond power production has been estimated to be 5000 MW.

Colorado: Colorado has excess salt brine and salt-rich shale in Paradox Valley. It is estimated that 200,000 tons of salt enter the Dolores River annually. Control concepts involve pumping the brine waters into evaporation ponds as an alternative to letting the brine flow into the Dolores River. Again, the availability of solar pond makeup water becomes a limiting factor. From the Bureau of Reclamation Study of Colorado River Chloride Control, there appears to be a potential for developing 360 MW of solar pond power.

Like Utah, Colorado has vast reserves of oil shale. In the northwest corner of Colorado a large synfuel production operation could be undertaken which will produce large quantities of brine and contaminated water and require large quantities of electric power. A detailed study of this entire concept should be undertaken and the integration of solar ponds into the oil shale operation evaluated.

RED RIVER REGION

Oklahoma: In Oklahoma, water becomes more available than in the far west and evaporation rates are lower. Oklahoma has been divided into east and west portions for this assessment. In the west, the focus is the Cimarron River area where some 2,600 tons of salt per day are carried away and evaporation ponds exist to produce commercial salt. From underground and surface water, about 1400 MW of power could be produced. In east Oklahoma, the focus is principally on the Red River and the Arkansas River which contain high levels of salt. Intercepting the saline water in-flows and diverting them to enclosed areas is a feasible concept and compatible with the creation of solar ponds. This area is being studied in detail by the Army Corps of Engineers, Tulsa District. In estimating the pond potential, one can consider using only the diverted saline water, or supplementing the saline waters with other available ground and river waters. If only diverted saline waters are used, the power potential has been estimated at 400 MW. Using supplementary water, this potential might be increased to 900 MW.

Texas: Texas may be the most ideal state for solar pond power plants. Approximately half the state is said to be underlaid with salt and saline water. The Permian Basin in the western panhandle has a salt resource that is measured in cubic miles. Another huge salt resource is located in east Texas. The major salt beds are the Haynesville Salt and Louann Salt which contain bedded salt, salt domes and brines.

The extent of water availability in west Texas is uncertain, but saline ground water is reported over most of the area. Water sources in the west include the Pecos, Red, Colorado, and Canadian Rivers plus irrigation runoff.

In assessing the potential, an assumption was made that ponds could be constructed almost anywhere, i.e., that surface characteristics are very uniform. If one-half of one percent of the land area were converted to solar ponds, 2000 MW of power could be produced in the Permian Basin alone.

The southern tip of Texas is characterized by an arid landscape, a humid climate and extensive underground saline water and salt deposits. The Rio Grande River is also a potential source of water. In addition, the area is sufficiently close to the ocean to think in terms of utilizing ocean water. If 5% of the 80,000 km^2, could be converted to solar ponds, a potential of 8800 MW would result.

East and central Texas also have ample surface water and are near the ocean. Along the coastline the Barrier Islands enclose bays, and on land private and state ownership of large tracts exist. The amount of land and coastline that might be dedicated to solar ponds is a question that must be answered by the residents of the state of Texas. However, a 5% land area dedication would yield 14,000 MW of electric power potential.

GULF COAST REGION

Louisiana: Louisiana has large amounts of saline water. There are deep sources of saline water throughout the state, and salt domes exist in places. State officials imply that land is probably available although the water table is generally very high. Large quantities of grey-to-red clay exist throughout the area. Louisiana, like Texas, appears to have the necessary ingredients for solar ponds providing one finds the right specific contour at any site. If 2% of the land area could be converted to solar ponds, then the potential in Louisiana is estimated to be 4,000 MW.

Mississippi: The southern portion of Mississippi has salt and a small potential for solar ponds, perhaps 500 MW.

Alabama: Alabama, much like Mississippi, seems to have a small potential for solar pond power plants in the southern regions. Salt, however, becomes a non-available constituent.

Georgia: Georgia has no known salt sources, high ground water, and high humidity. However, it has extensive amounts of clay and swamp areas that potentially could be converted to solar ponds. The estimate for Georgia, assuming that ocean water is used as a salt source, is 400 MW.

Florida: Florida can be viewed in terms of the panhandle area and the peninsula area. Characteristics of Florida are again a high water table and a lack of salt. However, if ocean water is imported and brine made from ocean water, then the potential might be very large; or if salt can be imported by ocean shipping, then a large potential exists in Florida. In the panhandle area the estimated potential is 500 MW.

There are institutions in Florida interested in the solar pond concept. Under study are the phosphate pits remaining from the mining of phosphate ore. Rather large land areas are being exposed in this manner and they are otherwise

unusable because of a low-level residual radiation. One of the concepts being promoted for Florida is to combine solar ponds, open phosphate pits, and new generation coal-fired power plants. The coal-fired power plants will use calcium carbonate in cleaning the flue gas, generating large quantities of calcium sulfate mixed with fly ash. If handled quickly this material, which is like a low-grade cement, can be spread in the bottom of the phosphate ponds to almost any depth desired, creating an impervious liner. The amount of residue phosphate fly ash to be generated is perceived to be enormous in quantity, sufficient for lining many solar ponds. Thus, the estimated potential for Florida is 2000 MW.

REFERENCES

1. *A Study of the Feasibility of a Solar Salt Pond Generating Facility in the State of California, U.S.A., Final Study Report*, Volumes I and II, prepared by Ormat Turbines Ltd., Yavne, Israel for The Southern California Edison Company, under P.O. No. MOO 79003, May 1981.

2. *The Solar Pond Regional Applicability Study*, to be published by JPL for DOE.

3. Weinberger, H., "The Physics of the Solar Pond," *Solar Energy*, Vol. 8, (1964), pp. 45-56.

4. Moon, P., "Proposed Standard Solar-Radiation Curves for Engineering Use," *Journal of the Franklin Institute*, Vol. 230, (1940), p. 583.

5. Marsh, H.E., DeFranco, D.M., Haack, R.F., McMurrin, J.C., Reilly, W.W., Singer, M.J., and Wu, Y.C., "Solar Ponds in the Salton Sea: Brine Optical Quality and Performance," *Proceedings 1981 IECEC*, pp. 1720-25.

6. *Saline Water Conversion Engineering Data Handbook*, prepared by the M.W. Kellogg Co., N.Y., for the U.S. DOI, July 1965.

7. International Critical Tables.

8. Jayadev, T.S., and Henderson, J., "Salt Concentration Gradient Solar Ponds - Modeling and Optimization," *SERI Report #SERI/TP-35-277*, presented at *ISES Annual Meeting*, Atlanta, May 28-June 1, 1979.

9. Riley, J. Paul, and J. Clair Batty, "The Potential for Solar Pond Development in Utah," Aug. 1981.

10. *Saline Water Use and Disposal Opportunities, Colorado River Water Quality Improvement Program*, Special Report, United States Department of the Interior, Bureau of Reclamation, September 1981.

11. *Analysis of Heat and Mass Transfer*, E. R. G. Eckert and R. M. Drake, Jr., McGraw Hill Co., N.Y. 1972.

APPENDIX A

SALT-GRADIENT SOLAR PONDS IN THE SALTON SEA:
BRINE OPTICAL QUALITY AND PERFORMANCE

SALT-GRADIENT SOLAR PONDS IN THE SALTON SEA:

BRINE OPTICAL QUALITY AND PERFORMANCE

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ABSTRACT

In a joint project, the Southern California Edison Company, Ormat Turbines, Ltd., of Israel, and the Jet Propulsion Laboratory are studying the feasibility of solar pond power plants in the Salton Sea. Construction of a one-square-kilometer (250-acre), 5-MWe unit is scheduled to begin in 1982. Spectrographic measurements made of Salton Sea water revealed the presence of dissolved matter, thought to be organic, and trace ions, which absorb light in the blue end of the spectrum. Settling, filtering, and activated-carbon treatment of the water improved the predicted annual-average transmittance of insolation to the pond storage zone. Approximate transmittances of 8 and 26 percent, respectively, for untreated and treated Salton Sea brine were calculated. Other decolorizing treatments are being explored to find the most cost-effective approach.

NOMENCLATURE

a_i, b_i = linear regression coefficients for extinction coefficient versus concentration, m^{-1}

C = concentration (total salts mass fraction of solution)

c', c'' = constants in Eq. (7)

D, E, F = linear regression coefficients for daily total insolation versus time Eq. (9) W/m^2

$f(\lambda), f_i$ = continuous and discretized distribution functions for insolation as a function of wavelength λ or spectral band i

$I(z,t)$ = insolation reaching depth z at time t, W/m^2

$I'(z=0,t)$ = insolation at the pond surface, W/m^2

$\bar{I}_j$ = total daily insolation for day j

j = Julian date

k = extinction coefficient, m^{-1}

k_i = extinction coefficient for the ith spectral band, m^{-1}

ℓ = path length, m

n = index of refraction at water surface

r = angle of refraction, radians

R = fraction of direct insolation penetrating water surface

z = depth below pond surface, m

γ = variable defined in Eq. (10)

δ = angle of declination, radians

θ = angle of incidence, radians

λ = wavelength, m

π = 3.14159

ρ = density, kg/m^3

τ = transmittance

$\tau_o(\lambda)$ = constant of integration in Eq. (2)

$\tau_{\ell,i}$ = integral-average transmittance for spectral band i over path length

$\tau_{\ell,T}$ = integral-average transmittance for all wavelengths over path length

ϕ = latitude, radians

i = spectral band index

INTRODUCTION

Among the solar energy concepts now under development is the nonconvecting, salinity-gradient solar pond. Although solar pond technology has been studied for the past twenty years, it has only recently become feasible to apply it to large-scale energy production. Southern California Edison (SCE) and the State of California are proposing the use of solar ponds at the Salton Sea in Imperial Valley, California, to generate commercial electric power.[1]

The following parameters have been identified in terms of effect on the fraction of insolation that reaches the storage layer, and hence on solar pond performance and economic feasibility. These parameters include water clarity, surface layer (upper convecting zone) and intermediate layer (gradient zone) thicknesses. The fraction of insolation reaching the storage layer increases as the water is made clearer and as these zone thicknesses decrease. There is an optimal gradient zone thickness in terms of the tradeoff of thermal insulation versus penetration of insolation [1].

This paper discusses the analytical and experimental work being conducted at the Jet Propulsion Laboratory to improve the clarity of Salton Sea water and to determine the effect of clarification on solar pond thermal performance and electric power generation capability.

Prior solar pond thermal performance simulation [1-6] assumed that transmittance was a function of wavelength but not of concentration. Usmanov, et al. [7], have shown that transmittance of light depends on magnesium chloride concentration in the water and concluded that this dependence must be considered in solar pond thermal performance simulation. The present research has determined the dependence of transmittance on wavelength and concentration for Salton Sea water. This dependence has been incorporated into thermal performance simulation of a solar pond at the Salton Sea.

SPECTROPHOTOMETRIC MEASUREMENTS

Transmittance measurements were performed using a recording spectrophotometer (Cary Model 14, Applied Physics Corporation). The instrument was adjusted for 100 percent transmittance at 500 nm using a quartz cell with 50 mm optical path length filled with distilled water.

The transmittance of light through unconcentrated Salton Sea water as a function of wavelength is shown by Curve "a" of Figure 1. Water samples were obtained near the proposed site for the 5-MW_e prototype plant at a depth of 0.3 m (1 ft). The water samples were heated to 75°C to enhance evaporation to produce brines of increasing concentrations. These brines are characterized by total salt mass fraction as shown in Table 1, and their corresponding spectra are shown as curves "b" and "c" of Figure 1. Identical chemical compositions and equivalent spectra were obtained by solar evaporation of Salton Sea water. Also shown in Figure 1 is the transmittance through distilled water. The spectra were obtained for a path length of 50 mm.

Figure 1.   Transmittance vs. Wavelength for Salton Sea Water and Derived Brines, 50 mm Path Length

(a)   Salton Sea water (C = 0.038, ρ = 1020 kg/m^3).
(b)   Salton Sea brine (C = 0.200, ρ = 1160 kg/m^3).
(c)   Salton Sea brine (C = 0.280, ρ = 1230 kg/m^3).
(d)   Distilled water.
(e)   Insolation intensity - air mass 1.
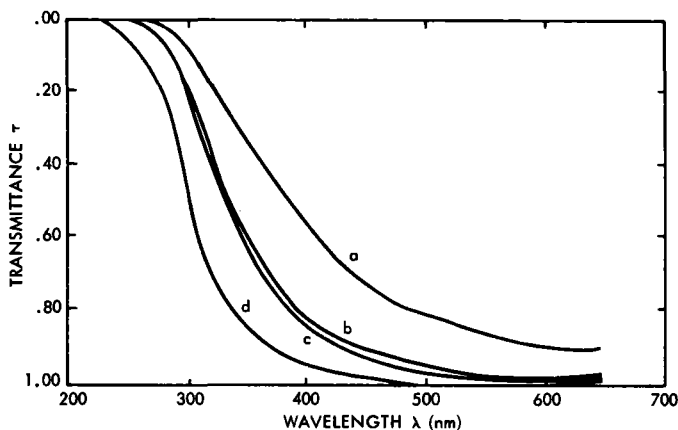
Figure 2.   Transmittance Gain With Treatment for Unconcentrated Salton Sea Water (C = 0.038, ρ = 1020 kg/m^3), 50 mm Path Length

(a)   Turbid.
(b)   Settled.
(c)   Settled, filtered (0.45 μm).
(d)   Settled, filtered, carbon-treated.

Table 1.   Chemical Analysis of Salton Sea Water and Concentrated Brines

	Salt Concentration Mass Fraction*	K$^+$	Na$^+$	Ca^{++}	Mg^{++}	SO$_4^=$	Cl$^-$	PO$_4$	HCO$_3^-$	pH
					kg solute/m^3 solution					
Salton Sea Water (ρ = 1020 kg/m^3)	0.038	0.20	10.7	0.47	1.1	11.6	15.9	0.0002	0.22	7.5
Salton Sea Brine (ρ = 1160 kg/m^3)	0.200	1.30	71.0	0.29	7.5	55.8	104.0	0.0002	0.41	8.1
Salton Sea Brine (ρ = 1230 kg/m^3)	0.280	2.00	102.0	0.14	10.7	69.0	143.0	0.0002	0.64	8.2

*Concentration of Salton Sea water produces a precipitation of certain components (e.g., CaSO$_4$). The supernatant liquid was used.

In order to determine the reduction in transmittance attributable to suspended particulates (turbidity), spectrophotometric measurements were made of unconcentrated Salton Sea water samples before and after settling. The significant effect of settling is seen by comparing curves "a" and "b" of Figure 2. Filtration of the settled samples through a 0.45 μm filter produced no appreciable change in transmittance as seen in Curve "c" of Figure 2. Other tests, not shown here, indicated that the improvement in transmittance due to settling and filtering decreased as the Salton Sea water samples were concentrated.

The color of Salton Sea water darkens to an amber-yellow color as it is concentrated (see Figure 1, 400 nm region). Of the dissolved constituents in Salton Sea water, organic matter and ions such as Fe^{+++} could reduce transmittance in the near-visible and ultraviolet region of the spectrum (350 nm to 500 nm). Trace concentrations of iron and other metal ions are known to be present in Salton Sea water. Their effect and potential removal have not been studied yet in this program. The unconcentrated Salton Sea water was treated with activated carbon in order to determine the effect, if any, upon transmittance. The improvement in transmittance due to carbon treatment, after settling and filtering, is shown in Curve "d" of Figure 2. There is a marked improvement in the 350 nm to 500 nm wavelength region. This band is of prime importance because it represents a major portion of the solar spectrum (Figure 1, Curve "e").

In order to determine the expected maximum improvement by carbon or other treatment, a synthetic Salton Sea solution was prepared which included neither dissolved organic matter nor trace ions. The natural and synthetic solutions were concentrated to 28 percent by weight, which is higher than the maximum concentration to be used in the proposed solar pond (approximately 25 percent). A comparison of the clarity of brine made from carbon-treated Salton Sea water with that of the synthetic brine is illustrated in Figure 3, Curves "b" and "c". This comparison shows that carbon treatment produces transmittance very close to the theoretical maximum in the important 450 nm to 700 nm band. An additional test, not shown here, demonstrated that carbon treatment of natural Salton Sea water can be used either prior to or after concentration, with negligible difference in spectral improvement.
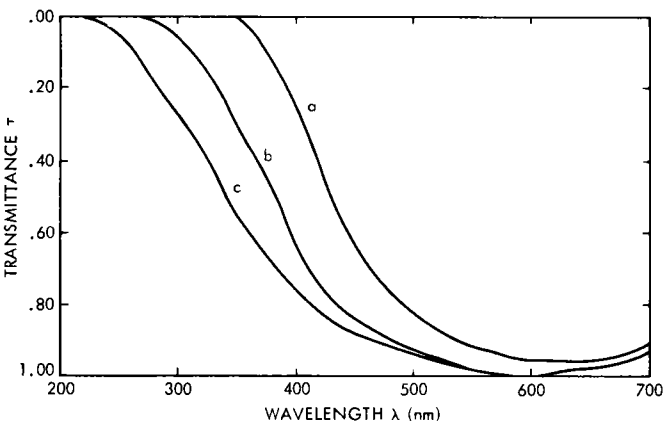
Figure 3. Effect of Carbon Treatment, 50 mm Path Length

(a) Natural Salton Sea brine (C = 0.280, ρ = 1230 kg/m^3).
(b) Natural Salton Sea brine (same as "a", also carbon treated).
(c) Synthetic Salton Sea brine (same as "a", no dissolved matter or trace ions).

REDUCTION OF DATA

Spectrophotometric measurements were taken of settled, concentrated natural Salton Sea water at 50 mm and 100 mm path lengths to determine if absorptance (=1-transmittance) for each wavelength is proportional only to the intensity of insolation. Table 2 shows the measured data. The instrument is accurate to within roughly ± 0.005 in measured transmittance, which corresponds to ± 0.10 and ± 0.05 uncertainty in apparent k for 50 mm and 100 mm path lengths, respectively. Within the accuracy of the instrument, k is a constant for each wavelength shown, except for 1,000 nm, where transmittance beyond 100 mm is negligible. For purposes of analysis, it is assumed that absorption in the homogeneous brine is proportional to intensity, that is,

$$d\tau(\lambda)/d\ell = -k(\lambda,C)\ \tau(\lambda) \tag{1}$$

for all wavelengths λ . Here τ is the fraction of light of wavelength λ transmitted over path length ℓ and k is the net extinction coefficient. We assume k is a function of wavelength and salts concentration C only.

Integrating Eq. (1) over path length,

$$\tau_{\ell}(\lambda) = \tau_o(\lambda)\ \exp\left[-\int_{\ell} k(\lambda,C)\ d\ell'\right] \tag{2}$$

where the constant of integration, $\tau_o(\lambda)$, is determined by boundary conditions. Concentration may vary along the path length. The integral-average transmittance for all wavelengths, $0 < \lambda < \infty$, is given by

$$\tau_{\ell,T} = \int_{\lambda} f(\lambda')\ \tau(\lambda')\ d\lambda' / \int_{\lambda} f(\lambda')d\lambda' = \sum_{i=1}^{n}(f_i\ \tau_{\ell,i}) \tag{3}$$

Table 2. Variation of Extinction Coefficient with Wavelength and with Path Length Through Unconcentrated Turbid Salton Sea Brine*

Wavelength λ (nm)	Path Length ℓ (mm)	Transmittance τ	Apparent Extinction Coefficient k(m^{-1})*
400	50	.180	34.3
	100	.033	34.1
500	50	.756	5.6
	100	.584	5.4
600	50	.926	1.5
	100	.845	1.7
700	50	.929	1.5
	100	.869	1.4
800	50	.872	2.7
	100	.754	2.8
900	50	.747	5.8
	100	.557	5.9
1,000	50	.152	37.6
	100	.020	39.1

*The apparent extinction coefficient is calculated by the relationship k = $(-\ln\tau)/\ell$ for each case.

Table 3. Spectral Bands and Band Extinction Coefficients

Constants for calculating band extinction coefficient ($k_i = a_i + b_iC$)

Band i	Band Limits (nm)	Settled, Filtered Salton Sea Water $a_i(m^{-1})$	$b_i(m^{-1})$	Carbon-Treated Salton Sea Water $a_i(m^{-1})$	$b_i(m^{-1})$	Distilled Water $a_i(m^{-1})$	$b_i(m^{-1})$	Band Insolation Fraction f_i
1	200-320	0.0	1278.0	0.0	349.0	2.4	0.0	0.0005
2	320-370	0.0	422.0	0.0	115.0	0.7	0.0	0.0113
3	370-410	0.0	146.0	0.0	31.7	0.4	0.0	0.0227
4	410-440	0.0	64.8	0.0	14.5	0.3	0.0	0.0312
5	440-470	0.0	38.5	0.0	8.71	0.2	0.0	0.0420
6	470-500	0.0	23.1	0.0	4.68	0.1	0.0	0.0482
7	500-530	0.0	14.4	0.0	1.98	0.0	0.0	0.0487
8	530-570	0.0	8.51	0.0	0.917	0.0	0.0	0.0642
9	570-720	0.0	4.88	0.0	1.24	0.4	0.0	0.2296
10	720-830	2.7	0.0	2.7	0.0	2.7	0.0	0.1276
11	830-910	5.0	0.0	5.0	0.0	5.0	0.0	0.0749
12	910-940	10.3	0.0	10.3	0.0	10.3	0.0	0.0102
13	940-1,040	32.6	0.0	32.6	0.0	32.6	0.0	0.0796
14	1,040-1,110	15.4	0.0	15.4	0.0	15.4	0.0	0.0437
15	1,110-1,200	51.3	0.0	51.3	0.0	51.3	0.0	0.0282

where $f(\lambda)$ is the distribution function of insolation over all wavelengths, f_i is the fraction of insolation in the ith discrete spectral band, and $\tau_{\ell,i}$ is the integral-average transmittance for the ith band. Fifteen bands were chosen to represent the insolation spectrum, as shown in Columns 1 and 2 of Table 3. Six bands were chosen for wavelengths between 370 nm and 570 nm in order to maintain accuracy as concentration was varied.

The integral-average band transmittance was calculated by trapezoidal rule integration from spectral data (e.g., Figures 1 and 2) for each concentration. The extinction coefficient k_i was determined by

$$k_i(C) = [\ln(-\tau_{\ell,i})] / \ell \qquad (4)$$

for each band for a path length $\ell = 50$ mm.

Linear regression curve fits of the extinction coefficient k_i versus concentration

$$k_i(C) = a_i + b_iC \qquad (5)$$

fall into two groups for $C > 0.036$, depending on wavelength. Either the intercept a_i or the slope b_i is approximately equal to zero, so that there is either a proportional dependency or a constancy of k with regard to C (Table 3, Columns 3-8).

PERFORMANCE IMPROVEMENT WITH WATER TREATMENT

For purposes of solar pond thermal simulation, concentration C is considered a function of depth z only, where

$$z = \ell / \cos(r) \qquad (6)$$

and r is the angle of refraction of insolation at the water surface. It is assumed that the refractive index is not a strong function of concentration [8], and therefore the angle of refraction is constant with depth. Then each k_i is a function of z only.

For modeling the Salton Sea solar pond an average concentration of 0.057 weight fraction of salts in a surface layer of thickness = 0.25 m is used. Concentration increases linearly to 0.246 at a depth of 1.55 m at the top of the storage layer. The integral in Eq. (2) is computed separately over two path length intervals. The first is over the surface layer, where C is constant so each k_i is constant. The second is over the gradient zone where C is assumed to increase linearly with depth:

$$C = c' + c''z \qquad (7)$$

where $c' = 0.021$ and $c'' = 0.145$ for the concentrations and zone thicknesses given.

Values of a_i, b_i, and f_i (fraction of insolation in the ith band) from Table 3 were used to compute solar pond thermal performance and rate of electric power generation for settled and for filtered and carbon-treated Salton Sea water samples. The assumption was made that the intensity of insolation at the water surface varies throughout the day according to

$$I'(z=0,t) = \overline{I}_j \times 0.8^{\sec(\theta)} \cos(\theta) / \int 0.8^{\sec(\theta)} \cos(\theta)dt \qquad (8)$$

where the average rate of total insolation on a given day $\overline{I}_j$ is given by

$$\overline{I}_j \int_{sunrise}^{sunset} 0.8^{\sec(\theta)} \cos(\theta)dt = D + E \sin \delta + F \cos \delta \qquad (9)$$

and

$$\delta = 2\pi j/365 \qquad (10)$$

The linear regression coefficients D, E, and F are fit to average daily total insolation values for each month. At the Salton Sea, $D = 220.3$ W/m^2, $E = 105.8$ W/m^2 and $F = 2.6$ W/m^2.

The angle of incidence, θ, varies as a function of time,

$$\cos \theta = \sin(\delta) \sin(\phi) - \cos(\delta) \cos(\phi) \cos(2\pi t/86400) \qquad (11)$$

where ϕ is the latitude at the site, δ is the angle of declination and t is time (seconds) after midnight.

The model assumes that 85 percent of the total insolation is direct and that the fraction of direct insolation just penetrating the water surface is given by the Fresnel equation,

$$R = 1 - 0.5 \ [\sin^2(\theta-r)/\sin^2(\theta+r) + \tan^2(\theta-r)/\tan^2(\theta+r)] \qquad (12)$$

where the angle of refraction is

$$r = \sin^{-1} \ [\sin \theta/n] \qquad (13)$$

and $n = 1.33$, the refractive index of water.

Assuming that diffuse insolation is uniformly distributed and that 93 percent of the diffuse insolation penetrates the water surface, the total insolation just penetrating the surface is

$$I(0,t) = I'(z=0,t) \ (0.85 \ R + 0.14) \qquad (14)$$

and the rate at which insolation reaches depth z at time t is given by

$$I(z,t) = \tau_{\ell,T} \ I(0,t) \qquad (15)$$

where $\tau_{\ell,T}$ is given by Eq. (3), above.

The effect of water clarification on insolation fraction reaching the storage layer and on solar pond electrical power generation is shown in Figure 4. For settled and filtered Salton Sea water, the annual-average fraction of insolation reaching the storage layer was estimated to be 0.08 and the annual-average net electrical power generation was estimated to be 0.9 W/m². Carbon treatment raised these values to 0.26 and 3.4, respectively, approximately a four-fold increase in net power output. The calculations assume that system conversion efficiency is 64 percent of
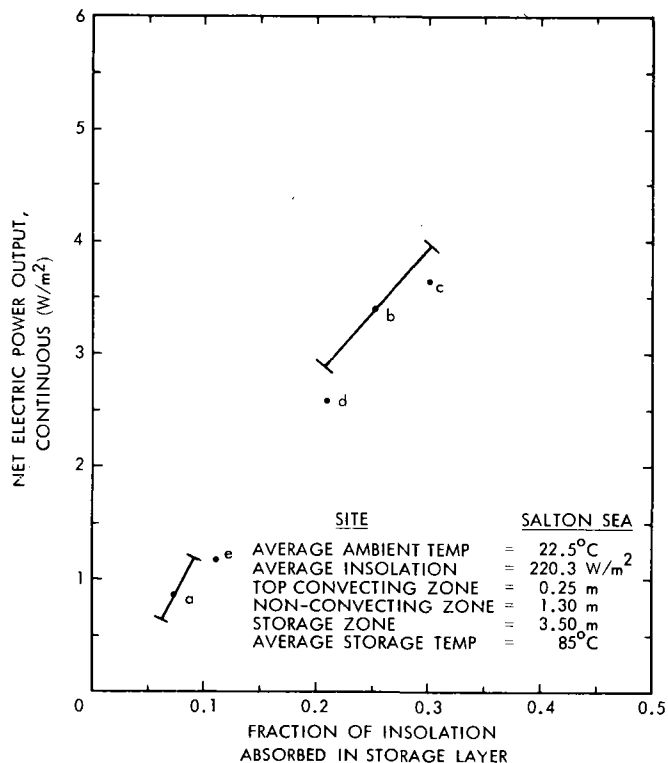
Figure 4. Calculated Solar Pond Electric Power Output Using Waters With a Variety of Spectral Absorption Characteristics

(a) Salton Sea brine, settled and filtered, transmittance varies with concentration.
(b) Same as (a), carbon-treated.
(c) Continental slope seawater, unconcentrated.
(d) Continental shelf seawater, unconcentrated.
(e) Bay seawater, unconcentrated.

Carnot efficiency and that pond auxiliary power consumption is 22.8 percent of gross power production. The wide uncertainty bands shown in Figure 4 are the result of extrapolating from 50 mm to approximately 1.75 m with a ±0.1 uncertainty in values of k_i. Longer path length in measured samples would reduce this uncertainty.

Also shown in Figure 4 are performance estimates based on published [9] transmittance measurements of continental slope, continental shelf and bay seawater that did not account for variation of transmittance with concentration.

Brines from two other sites (performance estimates not shown) were also tested at JPL, but one of the brines did not respond to carbon treatment.

CONCLUSION

The presence of dissolved light-absorbing substances in water and brine is a major concern in solar pond applications. Calculations based on measured transmittance of Salton Sea brines show that the potential for generating electric power in a solar pond is strongly influenced by the fraction of insolation transmitted to the pond storage zone. Simple carbon treatment roughly quadrupled the expected electric power output of the Salton Sea pond. However, a brine sample from another site did not respond to carbon treatment.

An economic study of carbon treatment applied to the Salton Sea Solar Pond Project has not yet been made. However, it is reasonable to assume that the well-developed technology used mostly for treatment of both domestic water and sewage effluent will be applicable. A preliminary cost estimate indicates that the capital costs for water treatment, of which carbon treatment would be only a part, will be less than 10 percent of the capital cost of the Salton Sea 5-MWe pond.

The water analysis effort at JPL is being extended to the broader goal of developing cost-effective water treatment systems for solar ponds. Within the limits of available resources, this effort will include research on transmittance measurement and the development of small-scale testing for verification.

REFERENCES

1. Kooi, C. F., "The Steady State Salt Gradient Solar Pond," Solar Energy, Vol. 23 (1979), pp. 37-45.

2. Weinberger, H., "The Physics of the Solar Pond," Solar Energy, Vol. 8 (1964), pp. 45-56.

3. Lumsdaine, E., "Transient Solution and Criteria for Achieving Maximum Fluid Temperature in Solar Energy Applications," Solar Energy, Vol. 13 (1970), pp. 3-19.

4. Viskanta, R. and J. S. Toor, "Absorption of Solar Radiation in Ponds," Solar Energy, Vol. 21 (1978), pp. 17-25.

5. Ahmadj, G. and A. Akbarzadeh, "Computer Simulation of the Performance of a Solar Pond in the Southern Part of Iran," SUN: Mankind's Future Source of Energy, Proceedings ISES Congress, New Delhi, Vol. 2 (January 1978), pp. 1181-1189.

6. Hull, J. R., "Computer Simulation of Solar Pond Thermal Behavior," Solar Energy, Vol. 25 (1980), pp. 33-40.

7. Usmanov, Y., V. Eliseev, and G. Y Umarov, "On the Optical Characteristics of a Solar Pond," Starodubtsev Physicotechnical Institute, Report No. UDC 622.997:64 (1971), pp. 47-49.

8. Sverdrup, H. U., Johnson, M. W. and R. H. Fleming, The Oceans: Their Physics, Chemistry, and General Biology. Prentice-Hall, Englewood Cliffs, New Jersey, 1942.

9. Clarke, G. L. and H. R. James, "Laboratory Analysis of the Selective Absorption of Light by Sea Water," Journal of the Optical Society of America, Vol. 2 (1939), pp. 43-55.

APPENDIX B

CHARACTERIZATION OF SALTON SEA WATERS

Characterization of Salton Sea Waters

by

Dr. James L. Giulianelli

ABSTRACT

The following report is based upon work performed on the Salton Sea water samples supplied to me by Mr. Hal Marsh. Reported are an initial characterization of the colored and particulate material in the natural water and recommendations for its clarification. Also discussed are the results of absorption measurements and correlations with the transmission of solar radiation through various depths of the natural water, the brine, and the clarified water.

EXPERIMENTAL

The filtration, liquid adsorption chromatography, and organic carbon analyses were performed with the assistance of Dr. E.M. Thurman at the Water Resources Division of the USGS in Denver. X-ray analysis of a single residue was done at the Crystal Research Laboratory of the Department of Chemistry/Geochemistry. The UV-Visible Spectroscopic work and computer graphics work were also done in the Chemistry Department of CSM.

(1) <u>Filtration</u> - Two hundred milliliters of natural Salton Sea water, supplied by Hal Marsh, was filtered under pressure of 15 psi N₂ through a 0.45 micron silver filter.

(2) <u>Adsorption Chromatography.</u> To concentrate and separate the hydrophobic organic acids from the nearly colorless filtrate as well as from the original sea water, solid-liquid adsorption chromatography on Amberlite XAD-8, a porous acrylic ester resin was done. The columns were prepared by passage of 0.1 N NaOH and 0.1 N HCl and were acidified with phosphoric acid to pH 2 prior to pumping down the column using a peristaltic pump. After the effluent was collected the column was inverted, eluted with 0.1 N NaOH and then the adsorbed material also collected in a 2 ml volumetric for carbon analysis. Drops exiting from the column at this point were yellow colored. The 2 ml of basic effluent was diluted to 5 ml for carbon analysis.

(3) <u>Carbon analysis</u> - Analysis for total dissolved carbon was performed on the original filtered natural Salton Sea sample, the column effluent and the concentrate which remained on the column. Solutions were acidified with phosphoric acid and degassed to removed inorganic carbon and 25 microliter amounts were injected in triplicate into the Beckman 915 carbon analyzer with 25A infrared detector. Pre-prepared solutions of acid phthalate were used to calibrate the instrument.

(4) <u>X-Ray Crystallography</u> - A piece of the dried residue which was light orange colored was dried and an x-ray scan taken.

(5) <u>UV-Visible Spectra</u> - A Beckman DK-2A spectrometer and one centimeter curvettes were employed. The base line and zero transmission were run using triply-distilled dionized water in the matched quartz cells. Samples were run using a tungsten lamp over the 350-750 nm range and a hydrogen lamp below 350 nm.

(6) <u>Calculation of Transmitted Radiation</u> - A computer program was supplied by Mr. John Webb of SERI and adapted for use on the CSM DEC system 1091 computer. The program integrates an input solar spectrum and calculates the total energy transmitted through a given depth of a two component solution. Both the solar irradiance curve data (W/m^2 nm) of Air Mass 1.5 (a graph of which has been included) and the extinction coefficient ($1 \ g^{-1}cm^{-1}$) of distilled water are stored as data files. Absorbance values at different wavelengths (see below) of candidate solar pond solutions are measured and input at the terminal. The program allows for input of a density gradient and selection of the depth and wavelength integration intervals, and performs a linear interpolation over these intervals.

The School of Mines Chemistry Department has just received a Cary 219 Spectrophotometer suited to continua-

tion of this work. I am in the process of interfacing this instrument with an Apple II Plus computer for automatic data aquisition.

RESULTS

DOC Analysis

Copies of the carbon analysis and spectral runs accompany this report. Calculations of dissolved organic carbon (DOC) for the samples are summarized in the table below. The results show that about 20% of the dissolved organic carbon was present as hydrophobic acids in the Salton Sea sample supplied.

Table 1: DOC Values (mg C/liter) for Salton Sea Samples (±5%)

Salton Sea, filtered	34
Salton Sea, effluent (hydrophilic)	31
Hydrophobics adsorbed on column	6.8

Visible Spectral Analysis and Transmission Studies

Copies of the visible and UV spectra are attached. The data for the Salton Sea water and concentrated brine are consistent with those presented in the Monthly Report by H.E. Marsh dated Nov. 17, 1980 (see attachment). As shown, filtration through a

0.45 micron filter increases the clarity considerably. Absorption values taken from these spectra have been used to calculate the percent of energy expected to be transmitted through varying depth intervals down to 1.4 meters of these solutions. The initial energy at the surface in the range from 295 mμ to 2500 mμ was 815 W/m². Only absorption by water was considered above 800 mμ.

Annexed to this report are the computer outputs (Runs 1 through 10) for samples of varying descriptions. Table 2 summarizes these results in terms of the amount of energy transmitted at four depths. Since extinction coefficients called for in the program were of course not determined, absorbance values measured on solutions contained in one centimeter cells were used in their place and the concentrations of these solutions taken as unity. Measured absorbances were multiplied by 2.303 prior to input since the program defines the extinction coefficient in terms of the natural logarithm.

As a check on the validity of the program calculations the program was run using as input a hypothetical material having an extinction coefficient or "absorbance" of ln(100/90) = 0.10536 at all wavelengths in the range. The result (Run 2) is as expected (see, for example, at a depth of 10 centimeters the transmitted radiation is $(0.9)^{10}$ = 0.349 of the original.

Table 2

Summary of Calculated Transmissions of Solar Spectrum
Through Various Solutions

Run	Solution Description	Integration Range (nm)	Water Conc. (g/l)	Percent Transmitted at Depth			
				1 cm	10 cm	100 cm	140 cm
1.	Triply distilled water	295-2500	997	80.3	64.8	44.8	42.0
2.	A_e = 0.10536	295-2500	0	90	34.9	0.06	-
3.	Salton Sea, Brine	310-2500	997	71.9	27.3	0	-
4.	Salton Sea, Natl.	295-2500	997	74.7	30.5	0	-
5.	Salton Sea, Natl.	295-900	997	91.3	43.1	0.0	0.0
6.	Salton Sea, Filtered, 0.45 microns	295-2500	997	79.1	56.4	15.4	10.1
7.	Salton Sea, Filtered .45 microns	295-900	997	97.6	80.1	18.8	9.2
8.	Salton Sea, Filtered .45 microns	295-2500	0	98.6	87.3	31.7	21.4
9.	Salton Sea, Brine 1/3-1.0 gradient	295-2500	99.7	77.3	45.4	0.81	0.05
10.	Salton Sea, Filtered 1.0 3.0 x grad.	295-2500	997	79.1'	55.9	8.3	3.2

DISCUSSION OF RESULTS

Identity of Colored Material

A number of important conclusions can be drawn from the above results. At first it was thought that the yellow tinge was due mostly to dissolved humic type soluble acids (see below) in the water. However, the high degree of clarification accomplished by simple filtration shows this not to be the case. The colored material of the natural water and therefore of the brine also, is most probably due to iron sites on clays and humic-type molecules adsorbed on the clays. The X-ray scan data of this filtered material was consistent with a montmorillonite clay which, by the way, is prevalent in the Salton Sea region.

Ordinarily about one-half the DOC of natural waters is made up of humic material, most of which falls in the molecular weight range of 1000-2000. These are the colored organics and it usually requires much less than was adsorbed in the column in the present case to impart a color more intense than the almost clear filtered water separated in this experiment (private communication, Dr. Thurman). The result suggests that Salton Sea water could be a very unusual water with a high hydrophobic humic-like content which would be of considerable interest to the geochemist. Furthermore, the very high hydrophilic DOC values found are also unusual and are attributed to low molecular weight (less than 1000) organics. These might possibly be naturally occurring but more probably were introduced in the collection or storage process. The sensitivity of the technique is such that

even organics (e.g., phthalic acid) absorbed from the plastic containers can be detected. For this reason, for a reliable DOC analysis it is recommended that the separation be made on site or at least that samples be contained in sterilized, pre-baked glass bottles and packed in ice until analysis.

Transmission of Solar Radiation

The most notable conclusions to be drawn from the optical data of Table 2 and the computer outputs is that even the Salton Sea water as supplied to me was way "too" dirty to serve as a solar pond transmitting material. Upon filtration this slightly murky solution with a yellowish tinge was clarified to the extent that it exhibited no notable turbidity and only a hint of yellow caste when observed in direct sunlight through about ten centimeters of solution in its bottle. The approximately 19% transmission of this solution at a depth of one meter (Table 2, Run 7) is a considerable improvement over the unfiltered water but still is not nearly as transmitting as is distilled water (44.8% at one meter).

It is seen that even an apparently low level of contamination can drastically impair solar transmission. These estimates may however be high. This method of calculating transmission by applying Beer's Law to measurements made on solutions contained in cylindrical cells and attempting to correlate these with temperature rises within the convecting layer of a three dimensional pond probably underestimates the transmission of heating radiation. The presence of any turbidity within the measured solution

would cause scattering losses which in a pond might not be lost to the bottom. These losses are exagerated by repeated integrations. Although the filtered solution did not appear turbid to the eye, some error of this kind could still be present. Errors of this type could be checked by remeasurement in a cell of longer path length (10 cm) and possibly avoided by either placement of the sample cell within a special integrating sphere to capture scattered radiation or design of a special long (1 m) path length cell.

It should be commented that it is difficult to imagine the waters within the few operating outdoor ponds being any cleaner than this filtered water. The question is presented, therefore, of how such ponds can operate at 25% thermal efficiency as is sometimes claimed. It would be interesting to find an operating pond upon which reliable immersed spectral radiometer data is being taken and compare this to laboratory-based calculations such as these. The problem has been that such reliable radiometer measurements do not exist due to problems with the thermal response and calibrations of the radiometers, leakage, and collection angle. This author would like to obtain a spectral radiometer with fiber optics such that the detector is not immersed and make the measurements needed to develop a laboratory model.

Removal of Color and Turbidity

Based upon the results presented above and a brief review of the water clarification literature, a number of suggestions for the clarification of the Salton Sea water can now be presented.

Some of the pertinent literature is attached. The best source of information on the subject appears to be the American Water Works Association Journal (main office of which is based in Denver) and also the manufacturers of clarifying agents themselves. It should be emphasized that clarification of natural waters is a complicated, multivariable business wherein the procedures used and combinations thereof are highly dependent upon the specific water in question. Although more knowledge of the nature of the particulates and dissolved color in this water is desirable, a large number of jar test evaluations and laboratory filtration tests also need to be performed in order to select the best and most economic procedure.

A few brief recommendations are appropriate:

(1) The high particulate content of this water, especially associated as it is with color, makes coagulation and filtration a necessary first step. Initial treatment with activated carbon would not be beneficial on large batches or economic since the absorption sites would be quickly blocked by the large-sized particles.

(2) The cationic polyelectrolytes and polyamines may offer a viable alternative to the more conventional alum or iron salt treatment. The latter work best with water more acidic (<pH 6) than the Salton Sea water (pH 8). One advantage of the polyelectrolyte coagulants is that they are completely removed in the filtrations, whereas the inorganics are not.

(3) Coagulation should be followed by passage through either diatomacious earth for removal of the floc or possibly sand or a mixture of sand and anthracite. These filters can be backwashed and regenerated. The diatomacious earth filter is especially effective for the montmorillonite clays of these samples.

(4) Although the great majority (99+%) of particulates and most of the color should be removable by the above mentioned treatment it may also be desirable to remove most (>80%) of the remaining small amount of colored dissolved organics by treatment with granular activated carbon. It might also be infomative to investigate the types of color absorbants used in the pulp industry (Dualite H-8?) since these are especially effective in basic media.

(5) If it is economically feasible, it might be advantageous to acidify the water prior to flocculation.

(6) A combination of alum or Fe^{3+} treatment and polyelectrolyte treatment is also possible.

The enclosed literature discusses these and other points in greater detail. It is apparent that numerous laboratory tests will be needed to discover the best procedures. There are literally hundreds of coagulating agents and the suppliers of these should be of great help in making specific recommendations. Some may even be willing to run preliminary tests upon the water and recommend specific procedures.

TOTAL INCIDENT ENERGY AVAILABLE BETWEEN   295.000 AND   2500.000
NANOMETERS IS   814.684 WATTS/M2

DISTILLED WATER NO. 2

1	2	3	4	5	6	7
1.000	0.000	997.000	160.385	19.687	160.385	19.687
2.000	0.000	997.000	36.386	4.466	196.771	24.153
3.000	0.000	997.000	21.730	2.667	218.501	26.820
4.000	0.000	997.000	15.538	1.907	234.039	28.728
5.000	0.000	997.000	12.269	1.506	246.308	30.233
6.000	0.000	997.000	10.237	1.257	256.545	31.490
7.000	0.000	997.000	8.836	1.085	265.381	32.575
8.000	0.000	997.000	7.804	0.958	273.185	33.533
9.000	0.000	997.000	7.012	0.861	280.198	34.393
10.000	0.000	997.000	6.384	0.784	286.582	35.177
15.000	0.000	997.000	25.547	3.136	312.129	38.313
20.000	0.000	997.000	19.360	2.376	331.489	40.689
25.000	0.000	997.000	15.749	1.933	347.238	42.622
30.000	0.000	997.000	13.291	1.631	360.529	44.254
35.000	0.000	997.000	11.473	1.408	372.002	45.662
40.000	0.000	997.000	10.057	1.234	382.059	46.897
45.000	0.000	997.000	8.918	1.095	390.977	47.991
50.000	0.000	997.000	7.981	0.980	398.958	48.971
55.000	0.000	997.000	7.197	0.883	406.155	49.854
60.000	0.000	997.000	6.534	0.802	412.689	50.656
65.000	0.000	997.000	5.967	0.732	418.657	51.389
70.000	0.000	997.000	5.479	0.673	424.136	52.061
75.000	0.000	997.000	5.055	0.621	429.191	52.682
80.000	0.000	997.000	4.685	0.575	433.876	53.257
85.000	0.000	997.000	4.361	0.535	438.237	53.792
90.000	0.000	997.000	4.074	0.500	442.311	54.292
95.000	0.000	997.000	3.821	0.469	446.132	54.761
100.000	0.000	997.000	3.595	0.441	449.727	55.203
105.000	0.000	997.000	3.393	0.417	453.120	55.619
110.000	0.000	997.000	3.213	0.394	456.333	56.013
115.000	0.000	997.000	3.050	0.374	459.383	56.388
120.000	0.000	997.000	2.904	0.356	462.287	56.744
125.000	0.000	997.000	2.771	0.340	465.058	57.084
130.000	0.000	997.000	2.651	0.325	467.709	57.410
135.000	0.000	997.000	2.541	0.312	470.250	57.722
140.000	0.000	997.000	2.442	0.300	472.692	58.021

COLUMN 1 = POND DEPTH (CM)
COLUMN 2 = SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
COLUMN 3 = WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
COLUMN 4 = ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 5 = PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 6 = CUMULATIVE ENERGY (W/M2) ABSORBED AT DEPTH 1
COLUMN 7 = CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED

INTEGRATION INTERVAL = 20 NM

RUN 1

Triply Distilled Water

B-12

ST ABS=.10536, NO WATER

1	2	3	4	5	6	7
1.000	1.000	0.000	31.468	10.000	81.468	10.000
2.000	1.000	0.000	73.305	8.998	154.773	18.998
3.000	1.000	0.000	65.962	8.097	220.735	27.095
4.000	1.000	0.000	59.355	7.286	280.091	34.380
5.000	1.000	0.000	53.412	6.556	333.502	40.936
6.000	1.000	0.000	48.064	5.900	381.566	46.836
7.000	1.000	0.000	43.252	5.309	424.819	52.145
8.000	1.000	0.000	38.923	4.778	463.741	56.923
9.000	1.000	0.000	35.027	4.299	498.769	61.222
10.000	1.000	0.000	31.522	3.869	530.291	65.092
11.000	1.000	0.000	28.369	3.482	558.658	68.574
12.000	1.000	0.000	25.529	3.134	584.188	71.707
13.000	1.000	0.000	22.975	2.820	607.163	74.527
14.000	1.000	0.000	20.677	2.538	627.840	77.065
15.000	1.000	0.000	18.609	2.284	646.449	79.350
16.000	1.000	0.000	16.747	2.056	663.196	81.405
17.000	1.000	0.000	15.072	1.850	678.268	83.255
18.000	1.000	0.000	13.565	1.665	691.833	84.920
19.000	1.000	0.000	12.209	1.499	704.042	86.419
20.000	1.000	0.000	10.988	1.349	715.030	87.768
21.000	1.000	0.000	9.889	1.214	724.919	88.982
22.000	1.000	0.000	8.900	1.092	733.819	90.074
23.000	1.000	0.000	8.011	0.983	741.830	91.057
24.000	1.000	0.000	7.210	0.885	749.039	91.942
25.000	1.000	0.000	6.489	0.797	755.529	92.739
26.000	1.000	0.000	5.841	0.717	761.369	93.456
27.000	1.000	0.000	5.257	0.645	766.626	94.101
28.000	1.000	0.000	4.732	0.581	771.358	94.682
29.000	1.000	0.000	4.259	0.523	775.616	95.205
30.000	1.000	0.000	3.833	0.471	779.450	95.676
31.000	1.000	0.000	3.450	0.424	782.900	96.099
32.000	1.000	0.000	3.106	0.381	786.006	96.480
33.000	1.000	0.000	2.796	0.343	788.802	96.823
34.000	1.000	0.000	2.516	0.309	791.318	97.132
35.000	1.000	0.000	2.265	0.278	793.583	97.410
36.000	1.000	0.000	2.039	0.250	795.622	97.660
37.000	1.000	0.000	1.836	0.225	797.458	97.885
38.000	1.000	0.000	1.653	0.203	799.111	98.088
39.000	1.000	0.000	1.488	0.183	800.598	98.271
40.000	1.000	0.000	1.339	0.164	801.938	98.435
41.000	1.000	0.000	1.206	0.148	803.144	98.583
42.000	1.000	0.000	1.086	0.133	804.229	98.717
43.000	1.000	0.000	0.979	0.120	805.207	98.837
44.000	1.000	0.000	0.880	0.108	806.087	98.945
45.000	1.000	0.000	0.793	0.097	806.880	99.042
46.000	1.000	0.000	0.714	0.088	807.594	99.130
47.000	1.000	0.000	0.643	0.079	808.237	99.209
48.000	1.000	0.000	0.579	0.071	808.816	99.280
49.000	1.000	0.000	0.522	0.064	809.337	99.344
50.000	1.000	0.000	0.470	0.058	809.807	99.401

RUN 2

Program Test: Absorbance = 0.10536

51.000	1.000	0.000	0.423	0.052	810.230	99.45
52.000	1.000	0.000	0.381	0.047	810.612	99.500
53.000	1.000	0.000	0.344	0.042	810.956	99.54
54.000	1.000	0.000	0.310	0.038	811.265	99.58
55.000	1.000	0.000	0.279	0.034	811.545	99.61
56.000	1.000	0.000	0.252	0.031	811.796	99.67
57.000	1.000	0.000	0.227	0.028	812.023	99.673
58.000	1.000	0.000	0.205	0.025	812.228	99.69
59.000	1.000	0.000	0.185	0.023	812.413	99.721
60.000	1.000	0.000	0.167	0.020	812.580	99.74
61.000	1.000	0.000	0.150	0.018	812.730	99.76
62.000	1.000	0.000	0.136	0.017	812.866	99.777
63.000	1.000	0.000	0.123	0.015	812.989	99.79
64.000	1.000	0.000	0.111	0.014	813.100	99.80
65.000	1.000	0.000	0.100	0.012	813.200	99.81
66.000	1.000	0.000	0.091	0.011	813.290	99.83
67.000	1.000	0.000	0.082	0.010	813.373	99.84
68.000	1.000	0.000	0.074	0.009	813.447	99.84
69.000	1.000	0.000	0.067	0.008	813.514	99.85
70.000	1.000	0.000	0.061	0.007	813.575	99.86
71.000	1.000	0.000	0.055	0.007	813.630	99.87
72.000	1.000	0.000	0.050	0.006	813.681	99.88
73.000	1.000	0.000	0.046	0.006	813.726	99.88
74.000	1.000	0.000	0.042	0.005	813.768	99.89
75.000	1.000	0.000	0.038	0.005	813.806	99.89
76.000	1.000	0.000	0.034	0.004	813.840	99.90
77.000	1.000	0.000	0.031	0.004	813.872	99.90
78.000	1.000	0.000	0.029	0.004	813.900	99.90
79.000	1.000	0.000	0.026	0.003	813.927	99.91
80.000	1.000	0.000	0.024	0.003	813.951	99.91
81.000	1.000	0.000	0.022	0.003	813.973	99.91
82.000	1.000	0.000	0.020	0.003	813.993	99.91
83.000	1.000	0.000	0.019	0.002	814.012	99.92
84.000	1.000	0.000	0.017	0.002	814.030	99.92
85.000	1.000	0.000	0.016	0.002	814.046	99.92
86.000	1.000	0.000	0.015	0.002	814.060	99.92
87.000	1.000	0.000	0.014	0.002	814.074	99.9
88.000	1.000	0.000	0.013	0.002	814.087	99.93
89.000	1.000	0.000	0.012	0.001	814.099	99.93
90.000	1.000	0.000	0.011	0.001	814.111	99.93
91.000	1.000	0.000	0.011	0.001	814.121	99.93
92.000	1.000	0.000	0.010	0.001	814.131	99.93
93.000	1.000	0.000	0.009	0.001	814.141	99.93
94.000	1.000	0.000	0.009	0.001	814.149	99.93
95.000	1.000	0.000	0.008	0.001	814.158	99.93
96.000	1.000	0.000	0.008	0.001	814.166	99.93
97.000	1.000	0.000	0.008	0.001	814.174	99.937
98.000	1.000	0.000	0.007	0.001	814.181	99.93
99.000	1.000	0.000	0.007	0.001	814.188	99.93
100.000	1.000	0.000	0.007	0.001	814.195	99.940

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COLUMN 1 =POND DEPTH (CM)
COLUMN 2 =SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING  DEPTH INTERVAL
COLUMN 3 =WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECIDIN  DEPTH INTERVAL
COLUMN 4 =ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVA
COLUMN 5 =PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING  DEPTH INTERVAL
COLUMN 6 =CUMULATIVE ENERGY (W/M2)ABSORBED AT DEPTH 1
COLUMN 7 =CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED
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RUN 2

continued

TOTAL INCIDENT ENERGY AVAILABLE BETWEEN   295.000 AND   2500.000
NANOMETERS IS   814.684 WATTS/M2

SSBRINE, 310-2500, 10NM,

1	2	3	4	5	6	7
1.000	1.000	997.000	228.790	28.083	228.790	28.083
2.000	1.000	997.000	85.272	10.467	314.063	38.550
3.000	1.000	997.000	60.679	7.448	374.742	45.998
4.000	1.000	997.000	47.810	5.868	422.551	51.867
5.000	1.000	997.000	39.556	4.855	462.107	56.722
6.000	1.000	997.000	33.617	4.126	495.725	60.849
7.000	1.000	997.000	29.060	3.567	524.785	64.416
8.000	1.000	997.000	25.425	3.121	550.210	67.537
9.000	1.000	997.000	22.447	2.755	572.657	70.292
10.000	1.000	997.000	19.961	2.450	592.617	72.742
15.000	1.000	997.000	73.260	8.992	665.877	81.734
20.000	1.000	997.000	45.706	5.610	711.583	87.345
25.000	1.000	997.000	30.096	3.694	741.679	91.039
30.000	1.000	997.000	20.513	2.518	762.192	93.557
35.000	1.000	997.000	14.327	1.759	776.519	95.315
40.000	1.000	997.000	10.192	1.251	786.711	96.566
45.000	1.000	997.000	7.354	0.903	794.065	97.469
50.000	1.000	997.000	5.368	0.659	799.434	98.128
55.000	1.000	997.000	3.956	0.486	803.390	98.614
60.000	1.000	997.000	2.939	0.361	806.329	98.974
65.000	1.000	997.000	2.199	0.270	808.528	99.244
70.000	1.000	997.000	1.656	0.203	810.184	99.448
75.000	1.000	997.000	1.255	0.154	811.439	99.602
80.000	1.000	997.000	0.957	0.117	812.396	99.719
85.000	1.000	997.000	0.734	0.090	813.130	99.809
90.000	1.000	997.000	0.567	0.070	813.696	99.879
95.000	1.000	997.000	0.441	0.054	814.138	99.933
100.000	1.000	997.000	0.346	0.042	814.484	99.975
105.000	1.000	997.000	0.274	0.034	814.758	100.009
110.000	1.000	997.000	0.220	0.027	814.978	100.036
115.000	1.000	997.000	0.178	0.022	815.156	100.058
120.000	1.000	997.000	0.147	0.018	815.303	100.076
125.000	1.000	997.000	0.123	0.015	815.425	100.091
130.000	1.000	997.000	0.104	0.013	815.530	100.104
135.000	1.000	997.000	0.090	0.011	815.620	100.115
140.000	1.000	997.000	0.080	0.010	815.699	100.125

COLUMN 1 =POND DEPTH (CM)
COLUMN 2 =SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
COLUMN 3 =WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECIDIN DEPTH INTERVAL
COLUMN 4 =ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVA
COLUMN 5 =PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 6 =CUMULATIVE ENERGY (W/M2) ABSORBED AT DEPTH 1
COLUMN 7 =CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED

Run 3

Salton Sea Brine

TOTAL INCIDENT ENERGY AVAILABLE BETWEEN 295.000 AND 2500.000
NANOMETERS IS 814.684 WATTS/M2

1	2	3	4	5	6	7
1.000	1.000	997.000	214.479	26.327	214.479	26.327
2.000	1.000	997.000	77.323	9.553	292.302	35.970
3.000	1.000	997.000	56.629	6.951	348.930	42.830
4.000	1.000	997.000	45.706	5.610	394.636	48.440
5.000	1.000	997.000	38.645	4.744	433.281	53.184
6.000	1.000	997.000	33.466	4.108	466.749	57.292
7.000	1.000	997.000	29.410	3.610	496.159	60.902
8.000	1.000	997.000	26.103	3.204	522.262	64.106
9.000	1.000	997.000	23.340	2.865	545.603	66.971
10.000	1.000	997.000	20.991	2.577	566.593	69.548
15.000	1.000	997.000	78.987	9.695	645.581	79.243
20.000	1.000	997.000	50.833	6.240	696.414	85.480
25.000	1.000	997.000	34.099	4.186	730.512	89.660
30.000	1.000	997.000	23.495	2.884	754.007	92.552
35.000	1.000	997.000	16.505	2.026	770.512	94.578
40.000	1.000	997.000	11.767	1.444	782.279	96.006
45.000	1.000	997.000	8.490	1.042	790.769	97.064
50.000	1.000	997.000	6.195	0.759	796.953	97.388
55.000	1.000	997.000	4.543	0.558	801.497	98.081
60.000	1.000	997.000	3.364	0.413	804.359	98.792
65.000	1.000	997.000	2.509	0.307	807.362	99.102
70.000	1.000	997.000	1.876	0.230	809.235	99.332
75.000	1.000	997.000	1.414	0.174	810.652	99.507
80.000	1.000	997.000	1.072	0.132	811.724	99.637
85.000	1.000	997.000	0.817	0.100	812.541	99.737
90.000	1.000	997.000	0.628	0.077	813.169	99.814
95.000	1.000	997.000	0.488	0.060	813.654	99.874
100.000	1.000	997.000	0.378	0.046	814.032	99.920
105.000	1.000	997.000	0.295	0.037	814.330	99.967
110.000	1.000	997.000	0.237	0.029	814.567	99.986
115.000	1.000	997.000	0.191	0.023	814.758	100.009
120.000	1.000	997.000	0.156	0.019	814.915	100.028
125.000	1.000	997.000	0.130	0.016	815.044	100.044
130.000	1.000	997.000	0.109	0.013	815.153	100.055
135.000	1.000	997.000	0.094	0.012	815.247	100.066
140.000	1.000	997.000	0.082	0.010	815.320	100.079

COLUMN 1 = POND DEPTH (CM)
COLUMN 2 = SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
COLUMN 3 = WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECIDIN DEPTH INTERVAL
COLUMN 4 = ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVA
COLUMN 5 = PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 6 = CUMULATIVE ENERGY (W/M2) ABSORBED AT DEPTH 1
COLUMN 7 = CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED

RUN 4

Salton Sea Water, Untreated

TOTAL INCIDENT ENERGY AVAILABLE BETWEEN 295.000 AND 900.000
NANOMETERS IS 561.385 WATTS/M2

, NATL ONLY TO 900NM

1	2	3	4	5	6	7
1.000	1.000	997.000	48.710	8.677	48.710	8.677
2.000	1.000	997.000	43.596	7.766	92.306	16.444
3.000	1.000	997.000	39.156	6.976	131.462	23.420
4.000	1.000	997.000	35.279	6.285	166.741	29.704
5.000	1.000	997.000	31.876	5.679	198.618	35.383
6.000	1.000	997.000	28.875	5.144	227.492	40.527
7.000	1.000	997.000	26.220	4.671	253.712	45.198
8.000	1.000	997.000	23.862	4.251	277.573	49.449
9.000	1.000	997.000	21.760	3.876	299.333	53.325
10.000	1.000	997.000	19.882	3.542	319.215	56.867
15.000	1.000	997.000	76.043	13.653	395.058	70.555
20.000	1.000	997.000	51.077	9.099	447.135	79.653
25.000	1.000	997.000	34.968	6.233	482.123	85.886
30.000	1.000	997.000	24.573	4.378	506.696	90.264
35.000	1.000	997.000	17.638	3.142	524.334	93.405
40.000	1.000	997.000	12.915	2.301	537.249	95.709
45.000	1.000	997.000	9.663	1.717	546.863	97.426
50.000	1.000	997.000	7.333	1.306	554.222	98.733
55.000	1.000	997.000	5.690	1.014	559.912	99.746
60.000	1.000	997.000	4.509	0.803	564.418	100.549
65.000	1.000	997.000	3.647	0.650	568.065	101.199
70.000	1.000	997.000	3.018	0.538	571.082	101.736
75.000	1.000	997.000	2.555	0.455	573.637	102.192
80.000	1.000	997.000	2.212	0.394	575.849	102.586
85.000	1.000	997.000	1.957	0.349	577.806	102.934
90.000	1.000	997.000	1.767	0.315	579.573	103.249
95.000	1.000	997.000	1.624	0.289	581.197	103.533
100.000	1.000	997.000	1.517	0.270	582.714	103.803
105.000	1.000	997.000	1.436	0.256	584.150	104.059
110.000	1.000	997.000	1.375	0.245	585.525	104.303
115.000	1.000	997.000	1.329	0.237	586.853	104.540
120.000	1.000	997.000	1.294	0.230	588.147	104.770
125.000	1.000	997.000	1.267	0.243	589.414	105.013
130.000	1.000	997.000	1.247	0.222	590.661	105.234
135.000	1.000	997.000	1.231	0.219	591.892	105.454
140.000	1.000	997.000	1.220	0.217	593.112	105.661

COLUMN 1 = POND DEPTH (CM)
COLUMN 2 = SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
COLUMN 3 = WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECIDING DEPTH INTERVAL
COLUMN 4 = ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 5 = PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 6 = CUMULATIVE ENERGY (W/M2) ABSORBED AT DEPTH 1
COLUMN 7 = CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED

RUN 5

Salton Sea Water, Untreated, Spectral Range 295-900 nm only

TOTAL INCIDENT ENERGY AVAILABLE BETWEEN   295.000AND   2500.000
NANOMETERS IS   814.684WATTS/M2

FILTERED SALTON SEA, .45MICRON, 10NM INT

1	2	3	4	5	6	7
1.000	1.000	997.000	170.192	20.891	170.192	20.891
2.000	1.000	997.000	44.751	5.493	214.943	26.384
3.000	1.000	997.000	29.365	3.604	244.308	29.988
4.000	1.000	997.000	22.645	2.780	266.953	32.768
5.000	1.000	997.000	18.946	2.326	285.899	35.093
6.000	1.000	997.000	16.550	2.031	302.449	37.125
7.000	1.000	997.000	14.830	1.820	317.279	38.945
8.000	1.000	997.000	13.517	1.659	330.796	40.604
9.000	1.000	997.000	12.471	1.531	343.267	42.135
10.000	1.000	997.000	11.612	1.425	354.880	43.560
15.000	1.000	997.000	48.810	5.991	403.690	49.552
20.000	1.000	997.000	38.830	4.766	442.520	54.318
25.000	1.000	997.000	32.364	3.973	474.883	58.290
30.000	1.000	997.000	27.671	3.397	502.555	61.687
35.000	1.000	997.000	24.058	2.953	526.613	64.640
40.000	1.000	997.000	21.172	2.599	547.785	67.239
45.000	1.000	997.000	18.812	2.309	566.597	69.548
50.000	1.000	997.000	16.847	2.068	583.444	71.616
55.000	1.000	997.000	15.187	1.864	598.631	73.480
60.000	1.000	997.000	13.768	1.690	612.399	75.170
65.000	1.000	997.000	12.544	1.540	624.943	76.710
70.000	1.000	997.000	11.479	1.409	636.421	78.119
75.000	1.000	997.000	10.545	1.294	646.966	79.413
80.000	1.000	997.000	9.720	1.193	656.686	80.605
85.000	1.000	997.000	8.987	1.103	665.673	81.709
90.000	1.000	997.000	8.333	1.023	674.006	82.732
95.000	1.000	997.000	7.745	0.951	681.751	83.683
100.000	1.000	997.000	7.215	0.886	688.966	84.568
105.000	1.000	997.000	6.735	0.827	695.701	85.395
110.000	1.000	997.000	6.299	0.773	702.000	86.168
115.000	1.000	997.000	5.900	0.724	707.900	86.893
120.000	1.000	997.000	5.535	0.679	713.435	87.572
125.000	1.000	997.000	5.201	0.638	718.636	88.210
130.000	1.000	997.000	4.892	0.601	723.529	88.811
135.000	1.000	997.000	4.608	0.566	728.136	89.376
140.000	1.000	997.000	4.344	0.533	732.481	89.910

COLUMN 1 =POND DEPTH (CM)
COLUMN 2 =SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
COLUMN 3 =WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECIDIN DEPTH INTERVAL
COLUMN 4 =ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVA
COLUMN 5 =PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 6 =CUMULATIVE ENERGY (W/M2)ABSORBED AT DEPTH 1
COLUMN 7 =CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED

RUN 6

Salton Sea Water, Filtered through 0.45 micron Filter

TAL INCIDENT ENERGY AVAILABLE BETWEEN   295.000AND   900.000
NOMETERS IS   555.811WATTS/M2

FILT TO 900μONLY, NO GRAD, 10 NM

1	2	3	4	5	6	7
1.000	1.000	997.000	13.203	2.376	13.203	2.376
2.000	1.000	997.000	12.622	2.271	25.825	4.646
3.000	1.000	997.000	12.094	2.176	37.920	6.822
4.000	1.000	997.000	-11.612	2.089	49.532	8.912
5.000	1.000	997.000	11.166	2.009	60.698	10.921
6.000	1.000	997.000	10.753	1.935	71.451	12.855
7.000	1.000	997.000	10.368	1.865	81.819	14.721
8.000	1.000	997.000	10.007	1.800	91.826	16.521
9.000	1.000	997.000	9.667	1.739	101.493	18.260
10.000	1.000	997.000	9.347	1.682	110.840	19.942
15.000	1.000	997.000	42.293	7.609	153.132	27.551
20.000	1.000	997.000	36.365	6.543	189.497	34.094
25.000	1.000	997.000	31.642	5.693	221.139	39.787
30.000	1.000	997.000	27.806	5.003	248.945	44.790
35.000	1.000	997.000	24.650	4.435	273.595	49.224
40.000	1.000	997.000	22.022	3.962	295.617	53.187
45.000	1.000	997.000	19.813	3.565	315.430	56.751
50.000	1.000	997.000	17.938	3.227	333.368	59.979
55.000	1.000	997.000	16.334	2.939	349.703	62.918
60.000	1.000	997.000	14.951	2.690	364.654	65.607
65.000	1.000	997.000	13.749	2.474	378.403	68.081
70.000	1.000	997.000	12.699	2.285	391.102	70.366
75.000	1.000	997.000	11.774	2.118	402.875	72.484
80.000	1.000	997.000	10.955	1.971	413.830	74.455
85.000	1.000	997.000	10.226	1.840	424.057	76.295
90.000	1.000	997.000	9.574	1.723	433.631	78.018
95.000	1.000	997.000	8.989	1.617	442.620	79.635
100.000	1.000	997.000	8.460	1.522	451.080	81.157
105.000	1.000	997.000	7.980	1.436	459.060	82.593
110.000	1.000	997.000	7.544	1.357	466.605	83.950
115.000	1.000	997.000	7.147	1.286	473.751	85.236
120.000	1.000	997.000	6.782	1.220	480.533	86.456
125.000	1.000	997.000	6.447	1.160	486.981	87.615
130.000	1.000	997.000	6.139	1.105	493.120	88.721
135.000	1.000	997.000	5.855	1.053	498.974	89.774
140.000	1.000	997.000	5.591	1.006	504.565	90.780

COLUMN 1 =POND DEPTH (CM)
COLUMN 2 =SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
COLUMN 3 =WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECIDIN DEPTH INTERVAL
COLUMN 4 =ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVA
COLUMN 5 =PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 6 =CUMULATIVE ENERGY (W/M2)ABSORBED AT DEPTH 1
COLUMN 7 =CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED

RUN 7

Salton Sea Water, Filtered, Spectral Range 295-900 nm

B-19

TOTAL INCIDENT ENERGY AVAILABLE BETWEEN 295.000AND 2500.000
NANOMETERS IS 814.684WATTS/M2

SALTON SEA, FILTERED, NO WATER, INT. 10

1	2	3	4	5	6	7
1.000	1.000	0.000	11.629	1.427	11.629	1.427
2.000	1.000	0.000	11.268	1.383	22.897	2.811
3.000	1.000	0.000	10.948	1.344	33.845	4.154
4.000	1.000	0.000	10.659	1.308	44.504	5.463
5.000	1.000	0.000	10.395	1.276	54.899	6.739
6.000	1.000	0.000	10.152	1.246	65.051	7.985
7.000	1.000	0.000	9.926	1.213	74.977	9.203
8.000	1.000	0.000	9.714	1.192	84.692	10.396
9.000	1.000	0.000	9.515	1.168	94.206	11.564
10.000	1.000	0.000	9.325	1.145	103.531	12.709
15.000	1.000	0.000	44.073	5.410	147.604	18.119
20.000	1.000	0.000	40.339	4.952	187.944	23.070
25.000	1.000	0.000	37.144	4.559	225.088	27.629
30.000	1.000	0.000	34.340	4.215	259.428	31.844
35.000	1.000	0.000	31.842	3.909	291.270	35.753
40.000	1.000	0.000	29.595	3.633	320.365	39.385
45.000	1.000	0.000	27.559	3.383	348.425	42.768
50.000	1.000	0.000	25.705	3.155	374.130	45.923
55.000	1.000	0.000	24.009	2.947	398.139	48.870
60.000	1.000	0.000	22.452	2.756	420.592	51.626
65.000	1.000	0.000	21.019	2.580	441.611	54.206
70.000	1.000	0.000	19.697	2.418	461.308	56.624
75.000	1.000	0.000	18.474	2.268	479.782	58.892
80.000	1.000	0.000	17.341	2.129	497.123	61.020
85.000	1.000	0.000	16.291	2.000	513.414	63.020
90.000	1.000	0.000	15.315	1.880	528.728	64.900
95.000	1.000	0.000	14.406	1.763	543.135	66.568
100.000	1.000	0.000	13.561	1.665	556.696	68.333
105.000	1.000	0.000	12.773	1.568	569.469	69.901
110.000	1.000	0.000	12.037	1.478	581.506	71.378
115.000	1.000	0.000	11.351	1.393	592.356	72.771
120.000	1.000	0.000	10.709	1.314	603.565	74.086
125.000	1.000	0.000	10.108	1.241	613.674	75.327
130.000	1.000	0.000	9.546	1.172	623.220	76.498
135.000	1.000	0.000	9.020	1.107	632.240	77.606
140.000	1.000	0.000	8.527	1.047	640.767	78.652

COLUMN 1 =POND DEPTH (CM)
COLUMN 2 =SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
COLUMN 3 =WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECIDIN DEPTH INTERVAL
COLUMN 4 =ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVA
COLUMN 5 =PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 6 =CUMULATIVE ENERGY (W/M2)ABSORBED AT DEPTH 1
COLUMN 7 =CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED

RUN 8

Salton Sea, Filtered, excluding water

BRIN WITH GRADIENT FROM .333TO 1.0, 10

1	2	3	4	5	6	7
1.000	0.335	997.000	185.235	22.737	185.235	22.737
2.000	0.340	997.000	57.025	7.000	242.260	29.737
3.000	0.345	997.000	40.048	4.916	282.308	34.652
4.000	0.350	997.000	32.179	3.950	314.487	38.602
5.000	0.354	997.000	27.570	3.384	342.058	41.987
6.000	0.359	997.000	24.420	2.997	366.477	44.984
7.000	0.364	997.000	22.057	2.707	388.535	47.691
8.000	0.369	997.000	20.184	2.478	408.719	50.169
9.000	0.373	997.000	18.643	2.288	427.362	52.457
10.000	0.378	997.000	17.341	2.128	444.702	54.586
15.000	0.393	997.000	72.055	8.845	516.757	63.430
20.000	0.416	997.000	55.282	6.786	572.039	70.215
25.000	0.440	997.000	43.906	5.389	615.945	75.605
30.000	0.464	997.000	35.494	4.357	651.439	79.962
35.000	0.488	997.000	28.991	3.559	680.430	83.521
40.000	0.512	997.000	23.831	2.925	704.262	86.446
45.000	0.535	997.000	19.667	2.414	723.929	88.860
50.000	0.559	997.000	16.269	1.997	740.198	90.857
55.000	0.583	997.000	13.473	1.654	753.570	92.511
60.000	0.607	997.000	11.160	1.370	764.830	93.881
65.000	0.631	997.000	9.239	1.134	774.070	95.015
70.000	0.655	997.000	7.641	0.938	781.711	95.953
75.000	0.678	997.000	6.309	0.774	788.020	96.727
80.000	0.702	997.000	5.199	0.638	793.220	97.365
85.000	0.726	997.000	4.275	0.525	797.495	97.890
90.000	0.750	997.000	3.505	0.430	801.000	98.320
95.000	0.774	997.000	2.866	0.352	803.866	98.672
100.000	0.798	997.000	2.337	0.287	806.204	98.959
105.000	0.821	997.000	1.900	0.233	808.103	99.192
110.000	0.845	997.000	1.540	0.169	809.643	99.361
115.000	0.869	997.000	1.244	0.153	810.887	99.534
120.000	0.893	997.000	1.003	0.123	811.890	99.657
125.000	0.917	997.000	0.806	0.099	812.696	99.756
130.000	0.940	997.000	0.647	0.079	813.344	99.835
135.000	0.964	997.000	0.519	0.064	813.863	99.899
140.000	0.988	997.000	0.416	0.051	814.279	99.950

LUMN 1 =POND DEPTH (CM)
LUMN 2 =SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
LUMN 3 =WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECIDIN DEPTH INTERVAL
LUMN 4 =ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVA
LUMN 5 =PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING DEPTH INTERVAL
LUMN 6 =CUMULATIVE ENERGY (W/M2)ABSORBED AT DEPTH 1
LUMN 7 =CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED

RUN 9

Salton Sea Brine, with linear gradient from
1/3 concentrated to concentrated, as received

TOTAL INCIDENT ENERGY AVAILABLE BETWEEN   295.000AND   2500.000
NANOMETERS IS   814.664WATTS/M2

SSFILTERED WITH 1 TO 3X DENSTIY GRAD, 10

1	2	3	4	5	6	7
1.000	1.007	997.000	170.261	20.899	170.261	20.899
2.000	1.021	997.000	44.933	5.515	215.194	26.414
3.000	1.036	997.000	29.640	3.638	244.834	30.053
4.000	1.050	997.000	23.000	2.823	267.833	32.876
5.000	1.064	997.000	19.371	2.378	287.204	35.253
6.000	1.079	997.000	17.036	2.091	304.240	37.345
7.000	1.093	997.000	15.371	1.887	319.612	39.231
8.000	1.107	997.000	14.107	1.732	333.718	40.963
9.000	1.121	997.000	13.104	1.609	346.823	42.571
10.000	1.136	997.000	12.285	1.508	359.107	44.079
15.000	1.179	997.000	52.620	6.459	411.727	50.538
20.000	1.250	997.000	43.113	5.292	454.841	55.830
25.000	1.321	997.000	36.851	4.523	491.692	60.354
30.000	1.393	997.000	32.183	3.950	523.875	64.304
35.000	1.464	997.000	28.471	3.495	552.345	67.799
40.000	1.536	997.000	25.405	3.118	577.750	70.917
45.000	1.607	997.000	22.809	2.800	600.559	73.717
50.000	1.679	997.000	20.571	2.525	621.130	76.242
55.000	1.750	997.000	18.615	2.285	639.745	78.527
60.000	1.821	997.000	16.887	2.073	656.632	80.600
65.000	1.893	997.000	15.346	1.884	671.978	82.483
70.000	1.964	997.000	13.964	1.714	685.942	84.197
75.000	2.036	997.000	12.716	1.561	698.658	85.758
80.000	2.107	997.000	11.583	1.422	710.241	87.180
85.000	2.179	997.000	10.552	1.295	720.793	88.475
90.000	2.250	997.000	9.609	1.180	730.402	89.655
95.000	2.321	997.000	8.746	1.074	739.148	90.729
100.000	2.393	997.000	7.955	0.976	747.103	91.705
105.000	2.464	997.000	7.228	0.887	754.331	92.592
110.000	2.536	997.000	6.560	0.805	760.891	93.397
115.000	2.607	997.000	5.946	0.730	766.837	94.127
120.000	2.679	997.000	5.382	0.661	772.220	94.788
125.000	2.750	997.000	4.864	0.597	777.084	95.385
130.000	2.821	997.000	4.389	0.539	781.473	95.923
135.000	2.893	997.000	3.954	0.485	785.427	96.409
140.000	2.964	997.000	3.555	0.436	788.982	96.845

COLUMN 1 =POND DEPTH (CM)
COLUMN 2 =SALT CONCENTRATION (G/L) AT MIDPOINT OF PRECEDING DEPTH INTERVAL
COLUMN 3 =WATER CONCENTRATION (G/L) AT MIDPOINT OF PRECIDIN DEPTH INTERVAL
COLUMN 4 =ENERGY (W/M2) ABSORBED IN PRECEDING DEPTH INTERVA
COLUMN 5 =PERCENT OF AVAIL. ENERGY ABSORBED IN PRECEDING DEPTH INTERVAL
COLUMN 6 =CUMULATIVE ENERGY (W/M2)ABSORBED AT DEPTH 1
COLUMN 7 =CUMULATIVE PER CENT OF AVAIL. ENERGY ABSORBED

RUN 10

Salton Sea Filtered, with linear gradient
from 1 to 3X concentration

APPENDIX C

BBEC CALCULATIONS

A.   INTRODUCTION

The calculations of busbar energy costs are made using a method and model[2] developed at the Jet Propulsion Laboratory. This Appendix describes the methodology used to calculate the $\overline{BBEC}$ and the assumptions used for the financial assessment.

B.   COST MODEL DESCRIPTION

Delivered energy cost ($\overline{BBEC}$) may be calculated as

$$\overline{BBEC} = \frac{LCC \cdot CRF}{CAP \cdot CF \cdot 8760}$$

where

$\overline{BBEC}$ = busbar energy cost
LCC = solar pond life cycle costs
CRF = capital recovery factor
CAP = system capacity
CF = capacity factor.

A discussion of the variables on the right-hand side, and their derivation, follows.

Before describing the methods used to aggregate costs and energy output, a discussion of the concept of discounting may help avoid confusion which could arise later in the section. The patterns of cost and revenue flow are very important to investors. Uncertainty, the possibility of investment obsolescence, alternative uses of investment dollars and other such factors make options with immediate and rapid returns more attractive than options for which the same returns occur more slowly. To account for these differences in preferences, financial analysis uses the concept of discounting. The costs and revenues occurring in any period t are weighted by the discounting term $(1 + R)^{-t}$, where R is the investor's discount rate. This term indicates that future revenues are less desirable compared to present ones, and future taxes are not as burdensome as current payments. Discounting allows numerous cost outflows and revenue inflows, which occur in different time periods, to be aggregated into a single number.

1.   Solar Pond Life Cycle Costs

Solar pond system costs were derived using the previously referenced ESEA financial model developed at JPL. This model calculates life-cycle system costs based upon the size and timing of costs outflows and assumptions about financial considerations such as taxes and depreciation.

The total costs of the system will be the summation of several terms. The basic formula for calculating life cycle costs is:

Life cycle costs = capital investment

           − tax reduction from depreciation

           − tax reduction from investment tax credits

           + recurrent costs

           + income tax payments

           + miscellaneous expenses

All values on the right hand side are in present value terms. The initial investment, I, is described later. Each of the remaining terms is translated into a numerical formula below. The variables which will be utilized in this discussion are:

Initial capital cost (I)

Discount rate; rate of return (R)

System lifetime (T, in years)

Depreciation rate (D)

Investment tax credit rate (ITC)

Tax rate (TR)

Annual recurrent costs (C_j)

Escalation rate for recurrent costs (E_j)

Miscellaneous expense rate (MISC).

      a.   Tax Reduction from Depreciation

This requires calculating a depreciation rate, multiplying the rate by the capital investment to determine total depreciation, and then multiplying total depreciation by the tax rate to derive the amount of tax-savings from depreciation. Most private corporations, for tax purposes, use a depreciation rate which reflects the fact that an investment depreciates most rapidly in the initial years. The depreciation method used in this study is the sum-of-the-years-digits method; a declining proportion of the investment is amortized each year. For example, an investment with a 10-year life has a sum-of-years of 1+2+3+ ... +9+10 = 55; 10/55 is amortized the first year, 9/55 the second year, ... and until 1/55 is depreciated in the final year. This pattern of depreciation has a present day equivalent depreciation rate of:

$$D = \frac{2 \cdot \left[T - \dfrac{1 - (1+R)^{-T}}{R} \right]}{T \cdot (1+T) \cdot R}$$

Once a depreciation method is chosen, the depreciation rate may be combined with the user tax rate and the capital investment to determine the present value of the income tax savings.

Tax reduction from depreciation = TR D I

b. Tax Reduction from Investment Tax Credits

If a tax credit for the new system exists, it reduces the tax burden by a factor ITC.

Tax reduction from investment tax credit = ITC · I

c. Recurrent Costs

This category includes all the recurrent costs (O&M, consumables, etc.) associated with system operation throughout its lifetime. Since the various costs could escalate at different rates, and these rates do not necessarily coincide with the discount rate, it will be necessary to escalate costs separately before discounting them to present-day dollars. If C_j represents annual recurrent costs (escalated from base year dollars to dollars in first year of commercial operation) and E_j is the escalation rate (where subscript j denotes various recurrent costs), the general formula for a constant amount of recurrent costs is given below. C_j represents the annual cost of parasitic power or operation and maintenance; the remainder of the right-hand side adjusts this cost into current dollars:

$$\text{Recurrent Costs} = \sum_j C_j \frac{1 + E_j}{R - E_j} \left[1 - \left(\frac{1 + E_j}{1 + R} \right)^T \right]$$

(j = fuel, O&M)

d. Income Tax Payments

Income tax payments are based on an adjustment to the amortized investment which reflects the pre-tax revenue necessary to amortize a given amount with after-tax dollars. The adjustment is computed using the equation

$$\text{Adjustment} = \frac{1}{(1 - TR)} (1 - TR \cdot D - ITC) \cdot I$$

where D is the depreciation factor. The income tax payments are then:

Income Tax Payments = Adjustment TR

e. Miscellaneous Expenses

Other payments, such as property taxes and insurance premiums, may be approximated by a constant multiple (MISC) of the initial capital cost.

Miscellaneous expenses = MISC · I

2.   Capital Recovery Factor

        The capital recovery factor converts life cycle costs into a uniform annual cost stream.   The equation is

$$CRF = \frac{R}{1 - (1 + R)^{-T}} \qquad R \neq 0$$

and

$$CRF = \frac{1}{T} \qquad R = 0$$

3.   Calculating Solar Pond Energy Costs

        As mentioned previously, energy costs may be derived using the equation:

$$\overline{BBEC} = \frac{LCC \cdot CRF}{CAP \cdot CF \cdot 8760}$$

From the preceeding discussion, life cycle costs may be calculated using the formula:

$$LCC = I - TR \cdot \overset{\bullet}{D} \cdot I - ITC \cdot I$$

$$+ \sum_j C_j \cdot \frac{1 + E_j}{R - E_j} \cdot \left[1 - \left(\frac{1 + E_j}{1 + R} \right)^T \right]$$

$$+ \frac{1}{1 - TR} \cdot (1 - TR \cdot D - ITC) \cdot I$$

$$+ MISC \cdot I$$

These life cycle costs are multiplied by the capital recovery factor to get an annual cost estimate.   The resultant annual cost is divided by annual energy output (system capacity, multiplied by capacity factor and the number of hours in a year), to obtain energy output costs.

C.   INPUT DATA AND SENSITIVITIES FOR THE SALTON SEA SOLAR POND

1.   Capital Costs

        The capital cost associated with the Salton Sea Solar Pond has been estimated as follows:

Cost Item	Salton Sea 26,400-Acre 600-MWe Plant
Solar Pond System (10^6\$)	558
Power Generating System (10^6\$)	540
Total Power Plant Construction (10^6\$)	1,098
Unit Pond Construction (\$/m^2)	5
Power Equipment(\$/kW)	900
Electric Energy (\$/kW Installed)	1,830

Solar pond life cycle costs are more heavily weighted toward initial capital costs as opposed to recurring costs. Thus, a change in the capital cost input can have significant impact on the $\overline{BBEC}$. For example, for a 1990 first year of commercial operation, an increase in capital will increase $\overline{BBEC}$ from 91 mills/kWh to 171 mills/kWh. In other words, an increase of 100% in capital costs causes an increase of nearly 90% in $\overline{BBEC}$. Table C-1 details some of the capital cost sensitivities.

2.   Operations and Maintenance

Operations and Maintenance costs of \$14,120,000 per year were assumed for the 600-MW operating plant. These estimates made by Ormat, and are based on their operating experience with the Yavne and Ein Bokek ponds.

3.   Construction Time

A 2-year time from start of construction to year of commercial operation has been assumed. The pond costs are, in fact, fairly insensitive to construction times. Table C-2 gives the pond costs for 1990 relative to differences in construction time.

4.   Financial Parameter

The system is assumed to have a usable lifetime of 20 years, and is depreciated using the sum-of-years-digits method. There is a 10% investment

Table C-1.   Solar Power Sensitivity to Capital Costs (Salton Sea Installation, 1990 Operation, 1981\$)

\$/kW Installed	$\overline{BBEC}$
\$1830	85
2000	91
2500	111
3000	131
3500	151
4000	171

Table C-2. Sensitivity to Solar Pond Construction Times, 1990 $\overline{BBEC}$, 1981$

Years of Construction Time	$\overline{BBEC}$, mills/kWh
0	80
1	82
2	85
3	87
4	90
5	93

tax credit. The composite tax rate is the sum of state and federal rates, less the product of state and federal rates. For California, this is

$$TR = T_s + T_f - T_s \cdot T_f$$
$$= 0.46 + 0.092 - (0.46)(0.092)$$
$$= 0.51$$

The discount rate for an investor-owned public utility is based on the following financial structure:

Source of Funds	Capitalization Rate (%)	Rate of Return on Funding Source (%., real)
Debt	50%	3%
Preferred Stock	15%	3.5%
Common Stock	35%	6.5%

To determine overall return, this structure is aggregated in the following manner:

Real Return = (1 - TR) (% debt) (return on debt)
    + (% preferred) (return on preferred)
    + (% common) (return on common)

With a general inflation rate of 7.2% this translates into a discount rate of 11%.

The output costs are highly sensitive to the discount rate chosen. If publc utilities must start paying more for funds, this could significantly impact the cost of energy. Table C-3 gives the sensitivity to discount rates. Note that the sensitivity is non-linear. The higher the discount rate, the greater the impact on $\overline{BBEC}$ of a change in the rate.

5. Inflation Rates

The inflation rates used were based on estimates for the next 20 years by Data Resources, Inc. The general inflation rate was 7.2%, with

Table C-3. Sensitivity to Discount Rates (Salton Sea Installation, 1990 Operation, 1981$)

Discount Rate Nominal	BBEC mills/kWh
8%	69
10%	79
11%	85
12%	91
14%	103
16%	117
18%	131
20%	147

capital costs expected to escalate at the same rate. O&M is expected to escalate at a 2% higher rate, or a nominal rate of 9.3%

D.   SUMMARY

Levelized busbar energy costs enable the investor to look at energy costs on a per-unit-of-output basis. The costs can, however, be heavily influenced by the initial assumptions. The costs for a given level of output are most influenced by the discount rate, and by the capital cost estimates. Under reasonable base case input assumptions, a solar pond installed at the Salton Sea by an investor-owned utility would produce energy at the following rates:

	Year of Commercial Operation			
	1985	1990	1995	2000
BBEC (mills/kWh, 1981$)	84	85	86	87

1.   Doane, J. W., et. al, The Cost of Energy from Utility Owned Solar Electric Systems, JPL 5040-29, Jet Propulsion Laboratory, Pasadena, CA, June 1976.

2.   Slonski, M. L., Energy Systems Economic Analysis (ESEA), Methodology and User's Guide, JPL 5101-102, Jet Propulsion Laboratory, Pasadena, CA, February 1979.