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Management of the Great Salt Lake: A Research Plan and Strategy

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MANAGEMENT OF THE GREAT SALT LAKE:

A RESEARCH PLAN AND STRATEGY

by

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ABSTRACT

The primary purposes of this report are to indicate the following two research items in connection with the management of the water resource system of the Great Salt Lake:

1. Research needs and priorities.

2. A research coordination strategy.

Research needs are identified by the report in terms of (1) various management, or use, categories (such as lake industries), and (2) the need to understand the physical characteristics of the lake system itself. The research needs are identified in each category as information (including data) or understanding gaps. In cases where there seems to be sufficient information, a research need is assumed not to exist.

In the case of the Great Salt Lake system, the development of a management plan is still in the early stages, so that research needs are not prioritized in terms of a specific plan. However, the various research needs are grouped into four broad categories in terms of priority levels for providing planners with the needed information to proceed logically with the development of a management plan which of necessity will be dynamic in terms of changing social needs and priorities.

In order for research to develop information about the lake system in accordance with management needs and priorities, a research coordination procedure is proposed. The objective of this procedure is to coordinate research between various funding sources and research organizations and groups.

ACKNOWLEDGMENTS

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Many people contributed to this study, and their help is appreciated. The names of some of these people appear in the Appendix to this report. Others offered helpful suggestions and comments at informal sessions and discussions. In this regard, the authors are grateful to Dr. E. Arlo Richardson, State Climatologist at Logan, Dr. Frederick Post, Dr. Donald B. Porcella, and Professor Joel E. Fletcher at Utah State University. In particular, the authors wish to express appreciation for the helpful suggestions and other assistance which were provided throughout the course of the study by Mr. Douglas Stewart, Director, and Owen Burnham, Planning Coordinator, of the Great Salt Lake Division, and to Mr. Lloyd Austin of the State Water Resource Division.

Gratitude also is expressed to the laboratory review committee for its careful examination of the manuscript. The committee consisted of C. Earl Israelsen, Eugene K. Israelsen, and Gary Z. Watters. Their comments contributed much to the content of the report. In a very real sense, the report represents our attempt to integrate the thinking of many dedicated and well informed people on the subject of the Great Salt Lake.

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INTRODUCTION

Description of Great Salt Lake

Great Salt Lake (Figure 1) is the largest salt water lake in the United States. The lake lies at the bottom of a closed basin and is fed principally by flow from the Bear, Weber, and Jordan Rivers. Because it is a terminal lake, the only outflow from the lake is by evaporation. At a surface elevation of 4,200 feet the lake has a surface area of approximately 1,600 square miles and an average depth of 13 to 16 feet.

The natural features of the lake have been significantly affected by the construction of dikes and causeways. The construction of evaporation ponds to facilitate the recovery of minerals from the lake brine has altered the natural surface area of the lake. Causeways have altered the natural lake circulation patterns and induced local changes in salinity levels. For example, the construction of a causeway from the mainland to a state park on the north end of Antelope Island has impounded the inflow from the Jordan River. This situation will cause a dilution of the brine in Farmington Bay which may create a fresh water environment in the bay (Utah Division of Water Resources, 1974).

A semi-permeable, rock-fill railroad causeway was completed across the lake in 1959 by the Southern Pacific Railroad Company. As a result the lake was divided into two arms with the south arm containing approximately twice the volume of the north arm. The causeway has altered the concentration of brine and the circulation patterns and has changed the hydrology of the lake.

Since the completion of the railroad causeway, the north arm has contained a well mixed concentrated brine. South of the causeway the lake is vertically stratified with a relatively dilute brine overlying a more concentrated brine. The lower brine represents about 10 percent of the total volume of the south arm.

Data on the elevation of the surface of Great Salt Lake have been gathered since 1851 and are given in Figure 2. The level has varied from a high of 4,211.6 feet in 1873 to a low of 4,191.4 feet in 1963. The lake reached a 48 year high in the spring of 1976.

Under present lake conditions the south arm receives approximately 95 percent of the surface inflow to the lake. This inflow pattern has created a head difference across the causeway, with the south arm elevation being greater than the north arm, which causes the major inflow to the north arm to be brine from the south arm.

Study Background

An increased concern for the proper management of the resources of Great Salt Lake resulted in the creation of the Great Salt Lake Division in the Department of Natural Resources by the Utah Legislature in 1975. The division was given the responsibility to prepare and maintain a general, comprehensive plan for the use and development of Great Salt Lake. The division recognized that in the comprehensive planning process there is a parallel need for research to provide effective and timely information essential in the formulation and comparison of alternative plans. This need to discern the research component of comprehensive planning resulted in a cooperative agreement between the division and the Utah Water Research Laboratory (UWRL). Under the terms of the agreement the UWRL was assigned to:

1. Assess research "state of the art" with respect to the Great Salt Lake comprehensive planning program.

2. Identify technical and scientific research needs on Great Salt Lake and its environs relevant to the Great Salt Lake comprehensive planning program.

3. Organize the needed research into a recommended coherent framework according to logical sequence and timing relationships.

4. Establish recommended research priorities in terms of critical problem areas and gaps in key information needed for planning and decision-making, particularly related to the comprehensive planning program.

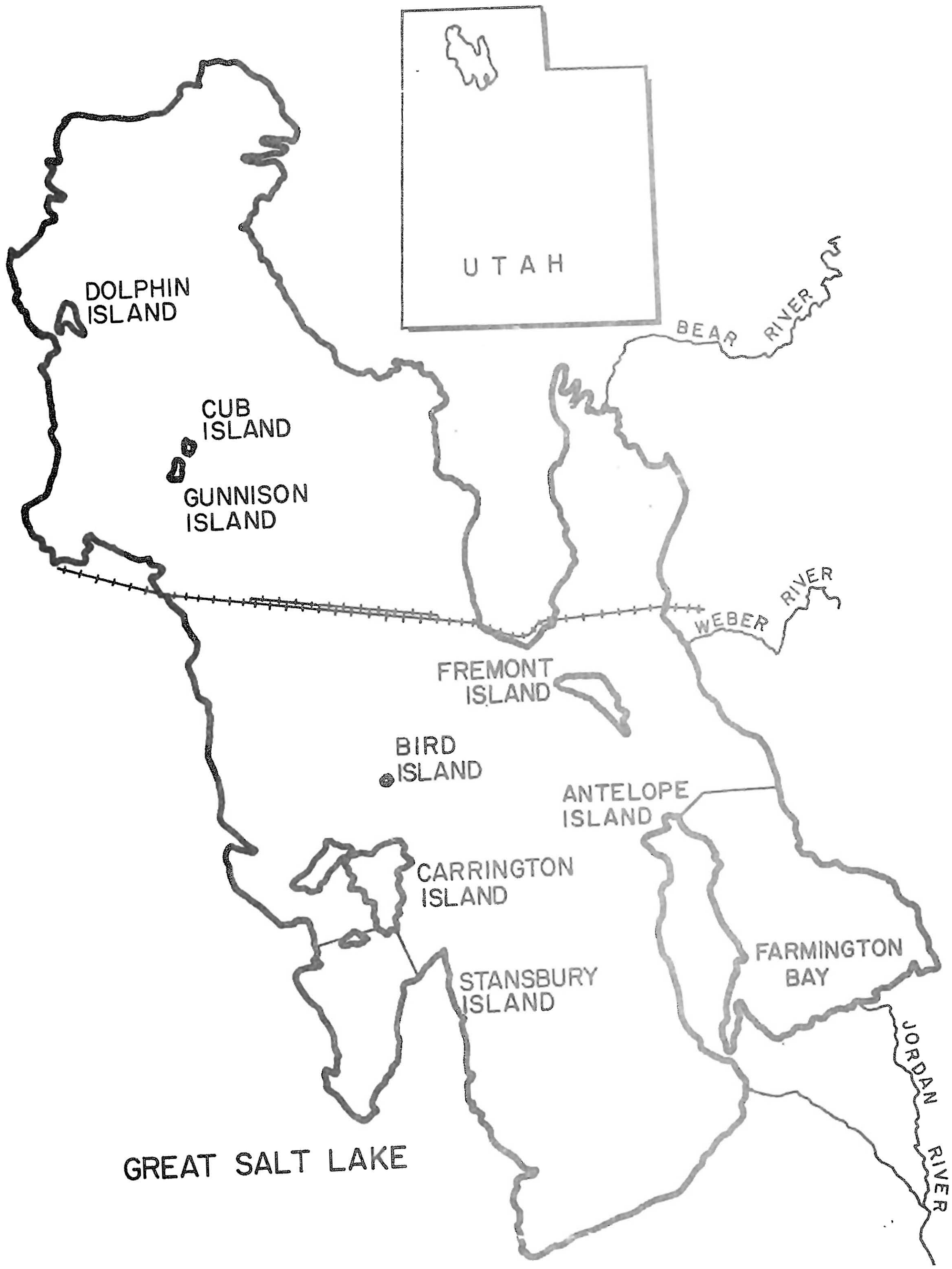


Figure 1. Map of Great Salt Lake.

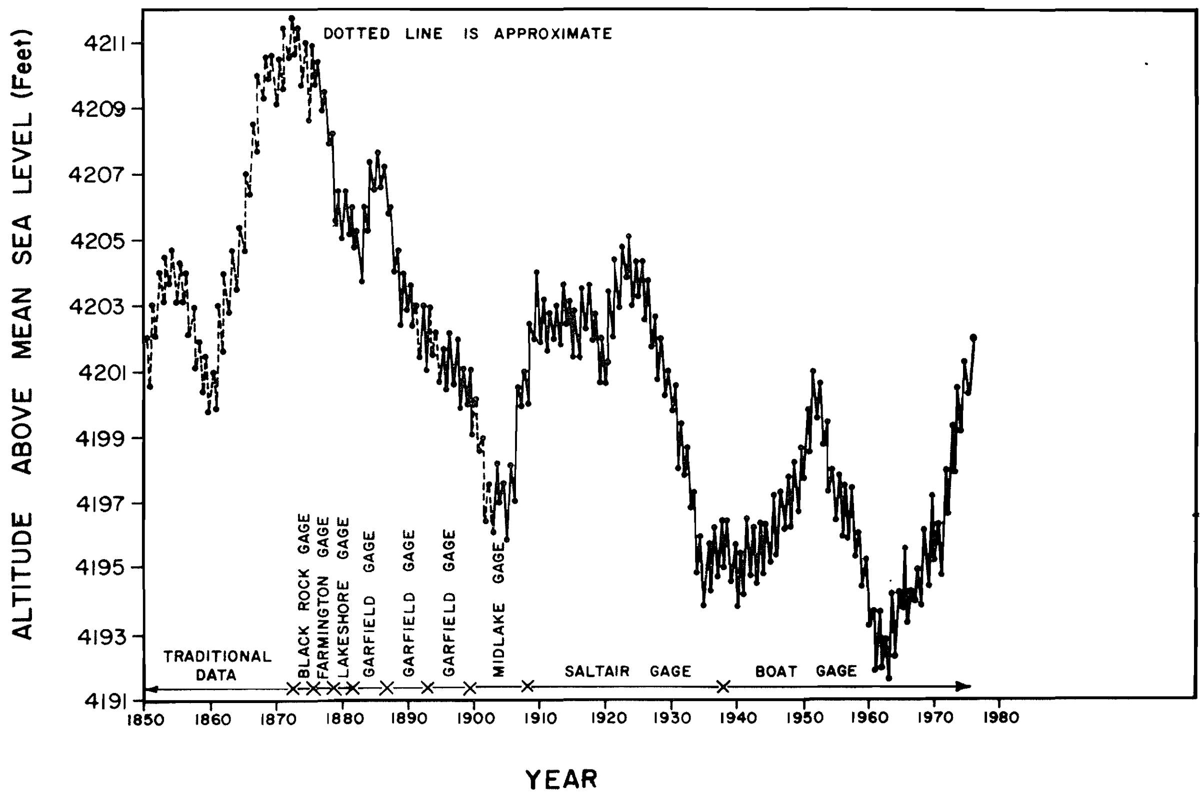


Figure 2. Historic surface elevation of Great Salt Lake.

5. Formulate an integrated research technique and procedure to support comprehensive planning of Great Salt Lake.

6. Consider the capabilities of researchers and research units in relation to research needs and propose an effective program of coordination among agencies, universities, and others.

7. Propose a program which would integrate and correlate the research effort with the current and future comprehensive planning through joint seminars or workshops with the Great Salt Lake Division and its board.

The UWRL study divided the assignments into two main tasks. The first task addressed items one through four above which focus on research needs and priorities. In this study, research needs were viewed as data or study needs necessary to understand the physical, social, or economic components of the Great Salt Lake system. The first task of the study was approached by performing a review of pertinent literature and meeting with groups of experts knowledgeable on various aspects of the lake system. The input from these meetings was valuable in identifying both research needs and priorities for the lake system. A list of participants in these meetings is given in the Appendix.

Because the comprehensive plan is still in preparation, the setting of research priorities was confined to specific use areas. However, once use priorities of the lake resources are set by the comprehensive plan, absolute priorities will be readily established from the information presented in this report.

The second task of the study, items five through seven, dealt with the manner in which the research identified during the first task could be accomplished. At present, it is not anticipated that the Great Salt Lake Division will support its own research staff but rather the division will rely on other state agencies, federal agencies, universities, and private individuals to perform the needed research. Task II outlines a procedure by which the division can coordinate the research efforts of these groups.

CHAPTER II

OVERALL APPROACH ADOPTED

System Representative

A system is managed in order to accommodate particular uses which are associated with specific goals and objectives of society. For this reason, the first step in evaluating areas where data gathering or research is necessary is to accurately identify the physical system and the potential social uses of the system.

George Smeath in his role as planning consultant to the Great Salt Lake Division, formulated general guidelines for the development of a comprehensive plan of the Great Salt Lake System (Smeath, 1975). Smeath recognized that the development of the comprehensive plan must be based on an understanding of the physical system, the social uses of the system, and the interactions which occur among the uses of the physical system. Smeath divided the comprehensive plan into elements and components as shown in Figure 3. The elements of the plan describe both the physical system and the social uses of the system; namely, the lake brine industries, recreation and tourism, wildlife, and transportation. The components of the plan account for areas where interactions between elements may develop.

While the work by Smeath was complete in identifying the social uses of the system and the interactions which must be addressed in formulating the comprehensive plan, it was found that by rearranging the boxes, it was easier to portray the interactions which occur among uses of the system and to discuss the system with regard to research needs.

The understanding of a complex system such as Great Salt Lake is greatly aided by decomposing the system into the various levels of what is termed a hierarchical structure (Haimes and Macko, 1973). The basic outline for a hierarchical structure of the Great Salt Lake system is given in Figure 4. The first layer of the hierarchical structure represents the physical system. The second layer which is broken into two levels represents society's influence on the system. At the first level are the social and economic goals or the uses society wants to make of the lake resources. The second level accounts for the political and decision-making process. The decision-maker (who may be at the level of the Utah State Government, the State Legislature, a local government, or a federal agency) will need to determine the kind and amount of control measures that should be enacted to achieve specific social use objectives.

The system can be further subdivided to any degree which makes it easier to understand. In Figure 5 the physical system was divided into three components; the lake, the near shore, and the lake watershed. The first level of the second layer was divided into specific social use areas following Smeath's outline of the system:

1. Lake brine industries

2. Recreation and tourism

3. Wildlife

4. Transportation

An additional box is included at the side of Figure 5 to emphasize the constraints placed on the use of the lake system by society. These include considerations such as abiding with health standards and laws governing water and air pollution.

The principal advantage of dividing the system into the multi-level hierarchical structure is that it allows the easy identification of the system components, and thus, the provision of information necessary to understand the entire system. Additionally, the routes of interaction or impact between the various social uses and the physical system are clearly defined.

Obviously any action by the decision-maker which requires an alteration of the physical system will create adjustments throughout the system which will produce trade off effects among the social uses of the lake. For this reason the decision-maker (second layer-second level) must act as a higher level coordinator and account for multiobjective analysis. Trade offs among uses of the system which can be analyzed by the decision-maker through some type of multiobjective analysis are quite common in a system as complex as Great Salt Lake. A prime example of trade offs be-

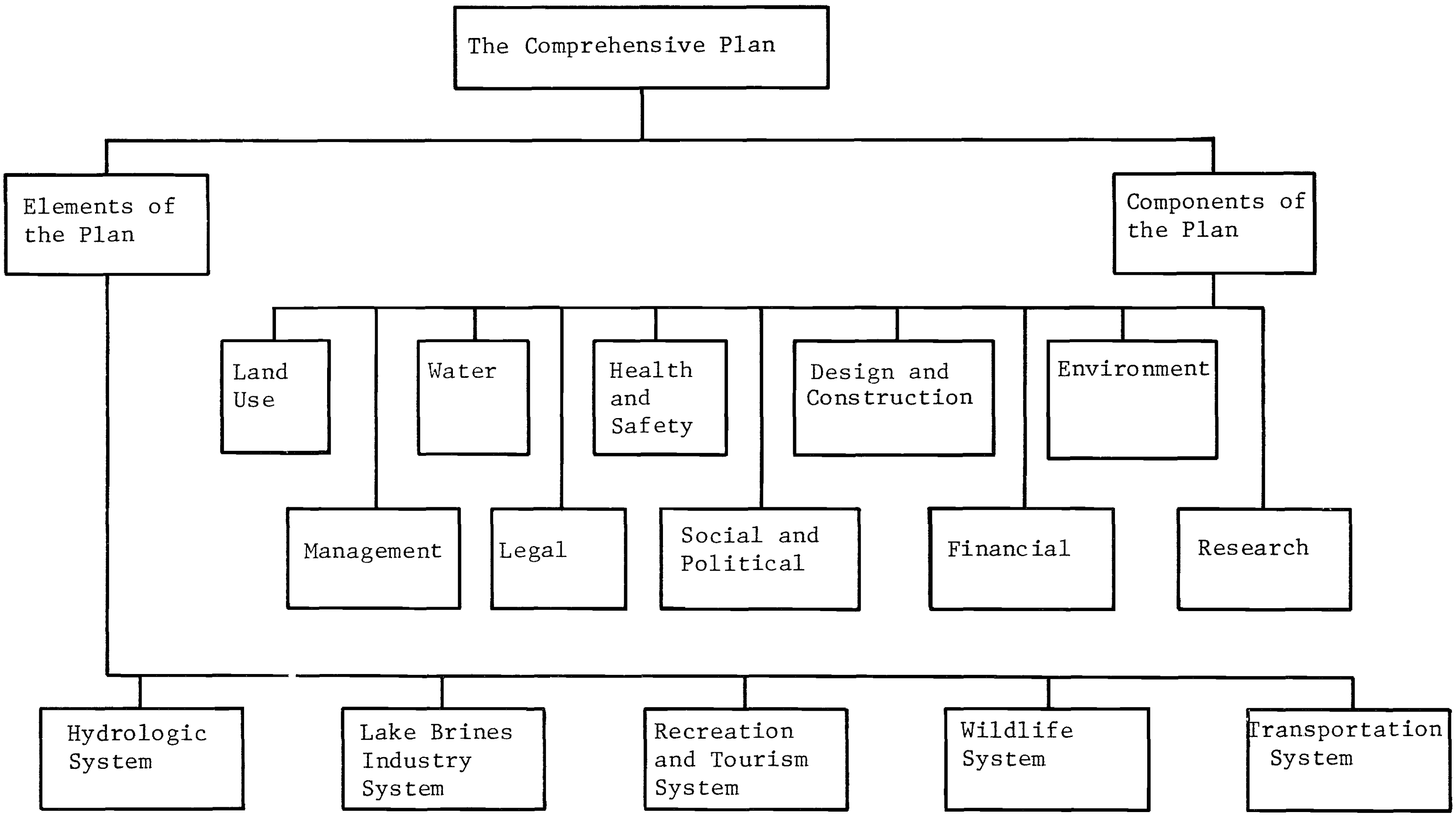


Figure 3. **Elements and components of the plan identified by Smeath (Smeath, 1975).**

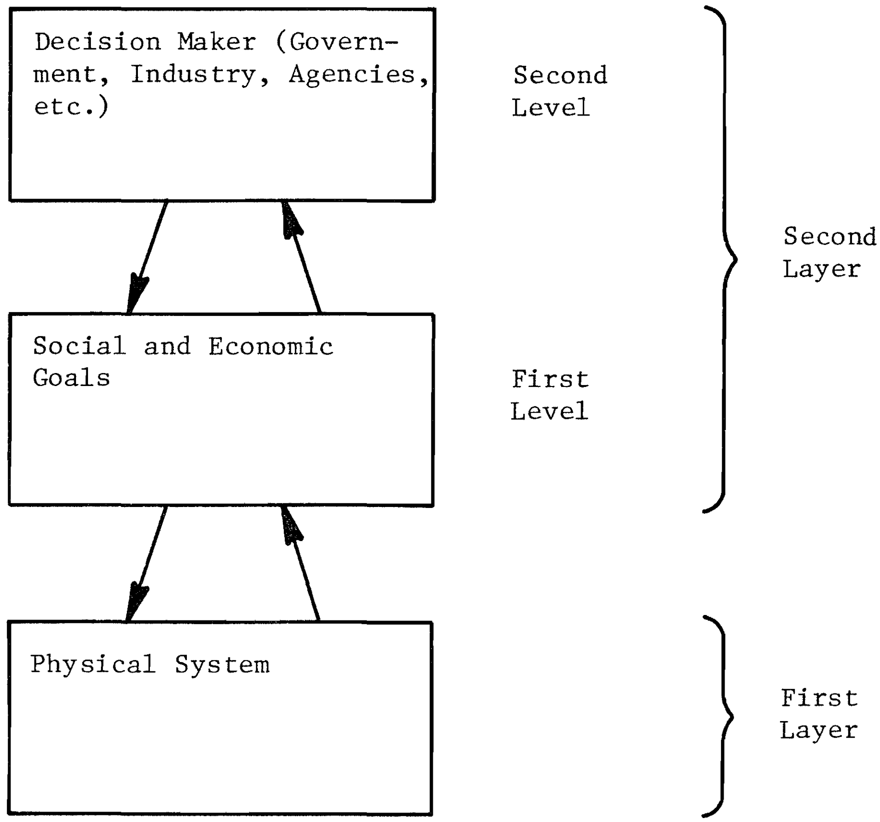


Figure 4. Basic decomposition of a system into a hierarchical structure.

tween social uses was the construction of the railroad causeway across the lake to aid transportation, but which at the same time produced negative effects on the south arm salt producers.

The first level of the second layer must provide the decision-maker with all necessary information about each social use of the system. All interactions between social uses, of course, occur through the physical system. In the case of the construction of the railroad causeway (social use), the hydrologic and salinity characteristics of the lake (physical system) were altered which produced an adverse impact on the south arm lake brine industries (social use). Thus, the arrows between the social uses and the physical system represent the impacts that social uses produce on the physical system, and, in the other direction, the impacts the physical system has on the social uses. Alterations of the physical system will, of course, have the potential of altering the impacts.

The "what if" type of uncertainty about the consequences of altering the physical system can only be addressed if the understanding of the physical system is advanced enough to provide the answers. The predictive ability necessary to answer this "what if" type of question is best handled by the development of computer models of each component of the system. The hierarchical structure given in Figure 5 is easily adapted to the computer modeling of the complete system. Each subsystem of the hierarchy can be modeled in its own terms and at the level of sophistication required by the decision-maker. A thorough discussion of development of a framework of management models of Great Salt Lake in a hierarchical structure is given in Riley et al. (1975). Although the development of computer models would greatly aid the decision-making process, the basic requirement is a complete understanding of the physical and social elements of the system. In order to assess the impacts of any management scheme, a clear identification of the entire system is needed, including the physiographic, hydrologic, salinity, biologic, limnologic, and social aspects, and the complex and dynamic coupling which are inherent in a system of this nature. The basic understanding of the system can only be gained through data gathering and research efforts directed at each component of the system.

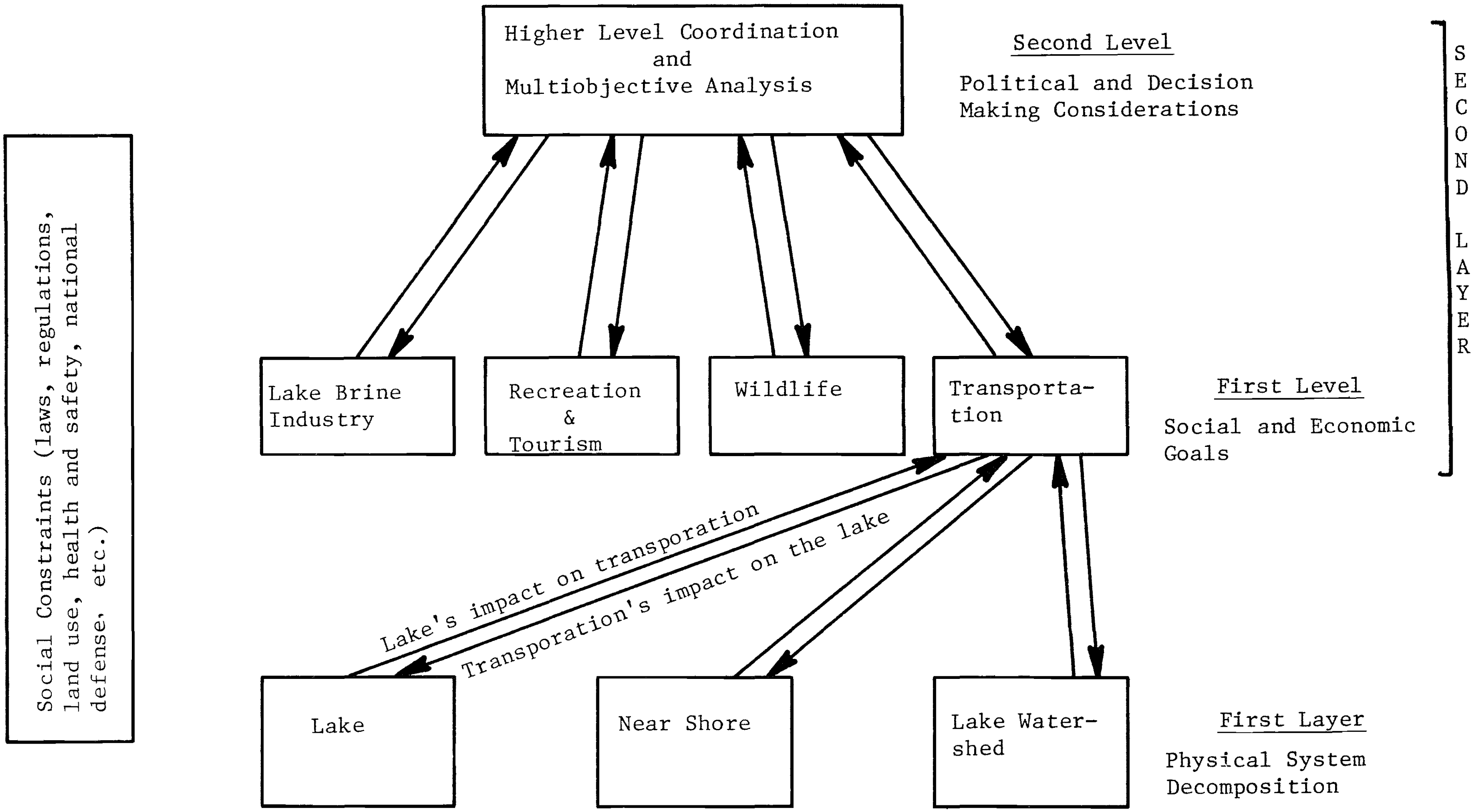


Figure 5. Refined decomposition of the Great Salt Lake system (adapted from Riley et al., 1975).

Identification of Data and Research Needs

The need for data collection and research arises from the necessity to understand the impact on the lake system created by alterations of the physical system to accommodate society's use of the lake resources. These impacts may be direct alterations of the physical system to accommodate a specific social use, such as the construction of a dike or causeway, or an unplanned alteration such as pollution which creates a change in the ecology of the lake. In addition to helping evaluate impacts, data and research are necessary to evaluate both the physical and economic feasibility of management schemes as well as to assess the desire of society for any proposed development on the lake.

Based on the four major social uses of the lake identified earlier, a chart (Table 1) was prepared which starts with possible social uses of the system and logically develops the information necessary to understand the system characteristics or the areas of influence or impact created by altering the system. This approach was adapted from Riley et al. (1975).

The chart was broken into several geographic areas; the entire lake system, the south shore area, Farmington Bay, and the north arm. The entire lake system consists of the lake and its drainage basin. The other geographic areas are subareas of the system and were isolated because of the special or intense uses which may be made of these subareas.

Information needs were identified by proceeding through the chart from left to right. First the possible social uses of the system were listed. For convenience these general topics can be divided into specific uses. For example, the lake brine industry system was divided into the mineral extraction industry, the brine shrimp industry, and oil and gas development. This division of uses within a use system is appropriate since conflicts may develop between components of the same use system.

Once the possible uses were identified the desired system characteristics for the use and some possible methods of achieving the desired system characteristics were listed. For example, access to brine with a high concentration of total dissolved solids (salinity) to benefit the mineral extraction industry might be achieved by using north arm rather than south arm brines. Also suggested by Table 1 are areas which may be negatively influenced by implementing the method. These are possible areas of adverse influence on social uses. The social use areas of impact also are indicated by the table. Continuing with the mineral extraction example, if the mineral extraction companies were to relocate to the north arm they would change the character of the present land use. The last column of the chart gives the information needed to understand the system characteristics or areas of impact. This column is designed to be completed by experts in each particular use area.

During this study, the table was begun by first listing major components of the table determined from a review of literature. The table was further refined through discussion sessions with groups of experts on the physical system and each social use area. These experts represented state and federal agencies, universities, and private companies and organizations. The meetings had a twofold purpose. First, they were designed to expand the information contained in Table 1; and second, the meetings were used to aid the identification of data and research needs related to Great Salt Lake and to assign priorities to these needs. Research needs became apparent during the meeting from the general discussion of Table 1 and the specific discussion of the information needs contained in the last column of the table. The specific views of each participant in the meetings on research needs and priorities were obtained by having the participant complete a research needs questionnaire, a sample of which is contained in the Appendix. The information obtained from these meetings and questionnaires was used as basic knowledge in completing Task I of this study.

The procedure followed in this study proved to be an effective method of extracting information from experts in particular fields. By setting out the social use objectives and the desired system characteristics in the table, it was easy for the experts to participate in the identification of research needs. Further, these meetings indicated the need for a forum for the open exchange of information between researchers. The Great Salt Lake Division could greatly aid the research effort on the lake by sponsoring seminars where research information, ideas, and needs can be freely disseminated.

Table 1. Identification of problems associated with possible uses of Great Salt Lake.

MAIN LAKE

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic or areas of influence
I. Lake Brine Industry System					
A. Mineral extraction industries	1. Access to high TDS[a] brine concentration	a. Use north arm brines	Higher cost to south arm salt producers	M. E. Industries	Cost to pump or relocate plants vs. benefits. Microclimate of relocation sites
		b. Limit or control extraction	M. E. Industries will be limited in extraction or expansion	M. E. Industries	Depletion factor, rate of accumulation, and percent removable
		c. Use deep south arm brines	Higher cost to salt producer	M. E. Industries	Problems which may arise from using the deeper brine such as supply, pollution pure product–cost to pump
		d. Breach the R. R. causeway	Construction cost	Transportation	Cost and benefits of breaching the causeway
			Alters the salinity conditions of both the north and south arm	Brine shrimp M. E. Industries	The affect breaching the causeway would have on TDS[a] concentration and brine stratification
	2. Good ionic makeup	a. Limit or control extraction of specific ions	same as I.A.1.b.		The effect on phase chemistry of removing one ion and returning the rest to the lake The effect of salt precipitation in the north arm at low lake levels
	3. Minimal high water damage to dikes and other facilities	a. Control high water levels			
		1. Upstream storage	Change the nature of the stream	Wildlife, Recreation	
		2. Pump to west desert	Floods land and may eliminate the present uses of the land	Wildlife, Department of Defense	What affect would pumping brine into the west desert have on the distribution of TDS[a] and stratification in the north and south arms? What affect would it have on the circulation pattern? Legal and environmental impact questions.

[a]TDS is total dissolved solids.

Table 1. **Continued.**

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
					Effect of returning brine to north or south arm.
		3. Breach the causeway	Same as I.A.1.d.		Present land use and the benefits from these uses. The affect breaching the causeway would have on the concentration of salt within the north and south arms. Would breaching the causeway affect the two layer system in the south arm? The elevation changes in the north and south arms if the causeway was breached.
		4. Raise existing dikes	Construction costs	Wildlife Recreation M. E. Idustries	Cost of dike maintenance at various lake stages.
		5. No action			Cost (damages) vs. lake elevation.
		b. Restrict development in the flood plain	No relief for established facilities	Recreation Wildlife M. E. Industries	Land use planning
		c. Invest in alternative methods to solar evaporation			Feasibility
	4. Production to meet market demands	a. Salt production	May deplete the resource	M. E. Industries Brine Shrimp	Rate of depletion, rate of accumulation, and percent recoverable. Cost vs. benefit of sustained yield
	5. No pollution problems	a. Regulation of pollution input to the lake	Government regulation of potential pollutors of the lake	Industry Recreation Oil Development	Pollutants which create a problem for salt companies
B. Brine Shrimp Industry	1. Maintain conditions favorable to high egg production	a. Control the lake level	Creates a specific habitat which may affect the écosystem	M. E. Industries Brine Shrimp	The effect on the ecosystem of a specific lake (or TDS[a]) level. Conditions which cause good winter eggs to be produced.

[a]TDS is total dissolved solids.

Table 1. **Continued.**

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
		b. Dike a portion of the lake and farm brine shrimp eggs	Dikes may alter the circulation patterns	M. E. Industries	Feasibility. Alternatives to collecting eggs.
	2. Adequate supply of food	a. Insure adequate nutrient supply	Associated algae production	Recreation	The role in algae production of nutrients input to the lake and recycled nutrients in the lake. The effect on nutrient levels in the lake of meet-EPA stream standards.
C. Oil and Gas	1. Access to lake and drilling platforms	a. Road and dike construction	Alters lake habitat and circulation patterns	M. E. Industries Brine Shrimp	Present circulation patterns. The circulation patterns which would result from dike construction.
	2. Maximum oil production	a. Appropriate location of drilling platforms	Interference with other uses	Wildlife, Recreation, M. E. Industries	Land use planning
	3. No (or minimum) effect on other users of the lake	a. Appropriate locations of drilling platforms	Same as I.C.2.a.		Size of buffer zones required between drilling areas and other users of the lake.
		b. Minimum oil spills	Increased costs. Government regulation.	Oil Development M. E. Industries Wildlife, Recreation, Brine Shrimp	Effects which a single or chronic oil spills would have on wildlife, recreation, M. E. Industries, and the lakes ecosystem. Methods to prevent and clean up spills
	4. Minimum aesthetic affect	a. Appropriate location of drilling platforms	Same as I.C.2.a.	Recreation, Wildlife	Land use planning Buffer zones required.

Table 1. Continued.

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
II. Recreation and Tourism					General need to identify existing and potential recreation operations, projected damages, and the optimum use intensity.
A. Tourism	1. Facilities: motels, restaurants, visitor centers, and recreation opportunities	a. Construction	Limits other uses of the lake. Sanitation problem (waste disposal).	Wildlife, M. E. Industries	Where. The economic and envirmental affect of possible alternatives.
	2. Easy access to historic and scenic areas	a. Road and dike construction	Alters the lake habitat and lake circulation	Wildlife, M. E. Industries	
	3. Low insect problem (Brine fly, deer fly, etc.)	a. Alter habitat	May adversely affect other insects. May disrupt a food chain.	Brine Shrimp Wildlife	Best method of control. Extent of problem (time and space)
		b. Chemical or biological agents	(same as a.)		
	4. Aesthetic appeal	a. Clean air	Government regulation		Land use planning
		b. Scenic locations	Limits areas which may be used or other uses once area is established.		Land use planning
	5. Stable water level	a. Control the inflow	Requires upstream storage of water.		
B. Boating	1. Facilities - mooring harbors, and boat ramps	a. Construction	Same as II.A.1.a.		What facilities will be needed in the future?
	2. Fresh water bodies	a. Dike construction	Alters the lake habitat and lake circulation		Possible ecologic effects.
	3. Safety	a. Navigational aid (Including charts) and hazard warnings			What are the hazards? Navigation charts of the lake.
		b. Search and rescue	Government regulation		
	4. Low insect problem	Same as II.A.3.			
C. Water contact sports	1. Facilities	a. Construction	Same as II.A.1.a.		
	2. Low health hazard (coliform and virus)	a. High TDS[a] concentration	May favor specific components of the ecosystem	Brine Shrimp Wildlife	The survival rate of coliform and virus at various TDS levels.

[a]TDS is total dissolved solids.

Table 1. Continued.

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation	Some social use areas which may	Information needed to understand the system characteristic of areas of influence
		b. Low coliform and virus count in the inflows	Government regulation		The distribution of coliform bacteria, virus, algae, and BOD in the lake. How are water quality constituents transported through the lake?
	3. Low insect population	Same as II.A.3.			
	4. Low algae population	a. Limit or control nutrient input to the lake	Government regulation		The major source of nutrients in the lake (recycle or inflow) Contributions which benthic deposits make to the nutrient supply.
		b. Remove algae from the recreation areas	Disposal problems		
	5. No odor problem	a. Reduce benthic decay rates by maintaining a high TDS level	May favor specific components of the ecosystem	Brine Shrimp	The variation of the benthic decay rate with TDS[a] concentrations.
		b. Control BOD inflow to the lake	Government regulation		How much DO is used by BOD inflow compared to DO uptake by the benthic deposits?
D. Camping and picnicing	1. Facilities	a. Construction of facilities	Waste transport and disposal		
	2. Easy access	Same as II.A.2.			
E. Hunting	1. Productive marshland	Same as III.A.1.			
F. Bird watching	1. Productive marshland	Same as III.A.1.			
	2. Easy access	Same as II.A.2.			
III. Wildlife					
A. Waterfowl	1. Productive marshland	a. Adequate flow of water through the marshlands	Regulating the lake level	Recreation	The flow that is necessary for proper food production and minimum disease hazards.

[a]TDS is total dissolved solids.

Table 1. Continued.

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
		b. Water level management dikes	Requires a specific maximum lake level to protect dikes from damage and salt water intrusion into the marshland.	Wildlife	The lake levels which will cause damage to the marshlands. The costs vs. benefits of coping with high water elevations in the lake.
		c. Low TDS[a] inflow to the marshland from streams	May require low flow augmentation and thus affect other uses of fresh water		The TDS[a] inflow levels. The TDS[a] levels the marshland can tolerate.
		d. Adequate dissolved oxygen to protect against botulism in duck			What other water quality constituent effect a productive marsh?
		e. Lake fluctuation to enhance the marsh below the managed marshlands	Lake fluctuation is not desirable for recreational development.	Recreation	The relation between lake fluctuation and productive marshalnds. The effect on unmanaged marshlands of a stable lake elevation.
		f. Construct protective dikes to protect management dikes	Alters the lake habitat and lake circulation		Possible ecologic effects
	2. Controlled intrusion of people	a. Controlled access and enforcement of rules	Limits use of the marsh		
		b. Land use planning	Buffer zones may restrict other potential users		
B. Rookeries (islands)	1. Controlled intrusion of people	a. Establish buffer zones around the Rookeries	Limits other use of lake especially boating. Government regulation	Boating Oil Development	The buffer zone required during the nesting period.
		b. Limited access-such as present access to the north arm.	Same as a.		
		c. Prohibit use of islands during the nesting period.	Government regulation		
C. Other wildlife (pheasants fur–bearers, etc.)	1. Productive marshlands	Same as III.A.1			
IV. Transportation across and around the lake	1. Minimum distance (cost of transportation)	a. Build roads and dikes	Alters the lake habitat and circulation patterns	Brine Shrimp M. E. Industries Recreation and Boating	Need capability to predict the habitat change and circulation pattern changes which will occur.

[a]TDS is total dissolved solids.

Table 1. Continued.

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
		b. Use water transports	May require breaching of the causeways	Transportation Recreation	Need capability to predict the habitat change and circulation pattern changes which will occur.
		c. Construct pipelines	Interfered with other uses	M. E. Industries Wildlife, Recreation	
	2. Minimum damage from waves and high water to roads and causeway	Same as I.A.3.			
	3. Maximum positive aesthetic affect	a. Appropriate location	Interference with other uses	M. E. Industries Wildlife, Recreation	
V. Hydrologic (Physical system)	1. Water supply to the state	a. Upstream development of reservoirs, canals, and other facilities	Would reduce inflow to the lake which could adversely affect uses of the lake.	All	The types of water developments possible and the long-term impacts they would have on the level and the TDS[a] concentration of the lake.
		b. Near shore development of storage reservoirs	Restricts other uses of flooded land	All	Same as above Land use planning
			Would reduce inflow to the lake	All	
	2. Minimum water quality problems	a. Control the input of pollutants	Government regulation		The point sources of pollutants to the lake.
		b. Control the distribution of pollutants which enter the lake	Would limit where discharges could be made		The present distribution of pollutants to the lake. The mechanisms which transport the pollutants through the system. The distribution of pollutants which result from input at a specific location.
	3. Viable ecosystem	a. Insure proper conditions for life in the lake	May restrict uses of the lake which create adverse conditions	All	The components of the ecosystem, how they interact, and how the ecosystem reacts to changes in the lake level, TDS[a] concentrations and nutrient and pollution input to the lake.

[a]TDS is total dissolved solids.

Table 1. **Continued.**

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
		b. Control the input of toxic materials	Government enforcement		The level of various toxic material which would harm the ecosystem. The distribution and transport of toxic materials in or entering the lake.
	4. Minimum high or low water damage	a. Control the lake's fluctuation (both high points and low points)			The present components of the lake's water balance (evaporation, precipitation, inflow, and exchange between the two arms) An elevation vs. damage curve The feasible alternative to control the lake's fluctuation.

Table 1. **Continued.**

FARMINGTON BAY

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
I. Recreation and Tourism					
A. Power Boating	1. Sufficient area and depth	a. Control the outflow of the lake	Alteration of the biological habitat	Wildlife, Brine Shrimp, Recreation	The required depth and surface area for various use intensities. The surface area to be expected under various inflow conditions. The component of the water balance.
	2. Fresh water (low TDS[a])	a. Control outflow	Same as I.A.1.a.		The TDS[a] to be expected under various inflow conditions.
		b. Control the inflow of lake brine	Same as I.A.1.a.		The input of lake brine under present conditions and methods to control this input.
		c. Control the inflow of high salinity water from the rivers (selected inflow by diversion)	Restricts the flow through the marshlands	Wildlife, Recreation	The required quantity and quality of flow through the marshlands to maintain a productive environment. The quality of the present inflow.
	3. Minimum safety hazards	a. Provide navigational charts			
		b. Minimum floating debris	Collection problems		
	4. Supporting facilities	a. Dredge harbors	Disturbance of benthic deposits		Facilities required under various use intensities.
		b. Construct breakwaters			
	5. Low algae content	a. Control point and non-point sources of nutrient input	Government regulation		The present point and non-point sources of nutrient input.
		b. Control disturbing the benthic deposits	Restrict use by power boating or other uses which create turbulent conditions	Recreation	The present extent of benthic deposits. The present natural disturbance of the deposits by wind and wave action.

[a]TDS is total dissolved solids.

Table 1. **Continued.**

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
					The extra disturbance which will be caused by power boating.
		c. Introduce catfish or other life form to remove algae	Requires a low TDS[a] condition be maintained	Brine Shrimp	The salinity level which could be tolerated.
	6. Minimum odor problem	a. Maintain a maximum volume for assimilative capability	May require the use of high salinity stream flow	Recreation	
		b. Reduce benthic decay by maintaining a high salinity environment	Limits the recreational uses	Recreation	What is the relation between TDS[a] concentrations and benthic decay. Is a stable salt water wedge present in the bay? Could one be developed?
		c. Aerate artifically	Could produce other ecologic effects		
		d. Control disturbing the benthic deposits	Same as I.A.5.b.		
	7. No insect problem	a. Control program i Water management ii Habitat modification iii Biological or chemical agents	May disrupt important food chains or destroy the wrong insects	Wildlife	Proven methods of control.
B. Sail Boating	Same as power boating except fresh water is not required.				
C. Camping and Picnicking	1. Supporting facilities	a. Construction of campgrounds swimming areas, etc.	Waste disposal	Recreation, Wildlife	Waste disposal alternatives
	2. Good access	a. Road dike construction	Alters circulation patterns and habitat	All	The affect dikes will have on the circulation patterns and TDS[a] concentrations.
			Restricts access by boats	Recreation	
D. Water contact sports	1. Low algae content	Same as I.A.5.			
	2. Minimum odor problems	Same as I.A.6.			
	3. Low health hazard (Pathogenic organisms)	a. Control coliform bacteria and virus input	Government regulation Could limit near shore users	Recreation	The present sources of coliform bacteria and virus.

[a]TDS is total dissolved solids.

Table 1. **Continued.**

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristics of areas of influence
		b. Maintain a high salinity environment	Restrict uses (power boating)		The salinity level under present conditions and methods to increase this level. The relation between the survival of pathogenic organisms and TDS[a] concentrations.
E. Fishing	1. Sufficient dissolved oxygen	a. Control BOD input	Government regulation Could limit near shore users	 Recreation	Present source of BOD
		b. Control benthic uptake	Limits uses which disturb these deposits	Recreation	The distribution of DO within the bay if it is allowed to freshen.
	2. Low TDS[a] concentration	a. Control contribution of TDS[a] from streams and lake	Alters the habitat	Wildlife	Present contributions of TDS from lake sources
F. Hunting	1. Productive habitat	Same as II.A.3.			
	2. Good hunting conditions	a. Isolate from other users	Restricts uses	Recreation	The characteristics which are good for hunting.
	3. Easy access	a. Construction of roads	Alters habitat		
II. Wildlife					
A. Marshlands	1. Low or restricted human intrusion	a. Restricted access-land and water	Limits other uses of the bay	Recreation	Possible land use patterns which create the least conflicts.
		b. Proper land use planning			
		c. Establish buffer zones in which no adverse recreational use is allowed (power boats, motorcycles, etc.)	Government regulation	Recreation	
	2. Low health hazard to wildlife	a. Sufficient flow through the marshlands	Restrict other uses of fresh water	Water supply	Flows required to maintain a productive marsh.
	3. Productive habitat	a. Sufficient flow through the marshlands	Same as II.A.2.a.		

[a]TDS is total dissolved solids.

Table 1. **Continued.**

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristics of areas of influence
		b. Sufficient marshland area	Restricts the high water level in the bay	Recreation	The relationship between productive marsh lands and elevation and salinity of the bay.
		c. Minimum high water damage to the dikes	Same as II.A.3.b.		

Table 1. Continued.

SOUTH SHORE

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
I. Recreation and Tourism					Identification of existing and potential recreational opportunities and associated demands
A. Develop the south shore recreational potential	1. Facilities-boat harbors, motels, camping, etc.	a. Construction of facilities	Other uses may be limited	M. E. Industries Wildlife	Optimum use intensity (best mix of recreational uses) Land use planning
			Waste disposal		Method to dispose of solid and sewage wastes
	2. Easy access	a. Road construction	Alters existing habitat	Wildlife	
	3. Easy access to other scenic and historic spots	a. Road and dike construction	Alter habitat and lake circulation	M. E. Industries Wildlife	
	4. Aesthetic appeal	a. Minimal air pollution b. Visual quality	Government regulation May limit type of development and location of recreational and industrial facilities	Near Shore Ind. Recreation M. E. Industries	Land use planning
	5. Low insect population	a. Control program i Water management ii Habitat modification iii Biological or chemical agents	May disrupt the food chain Could kill the wrong insects	Wildlife Brine Shrimp	The present extent of the problem (time and space) Long term ecological effect of the possible control measure.
	6. Low algae population	a. Control nutrients input to the lake	May limit the food chain	Brine Shrimp	The present sources of nutrients and the distribution of nutrients and algae. The transport mechanisms (circulation patterns) in the south shore area.
			May limit south shore development if there is not proper disposal of waste from recreational area		

Table 1. **Continued.**

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
	7. Low Health hazard	a. Control the input of virus and coliform bacteria	Government regulation		The present sources and amount of input of virus and coliform bacteria
			Require proper disposal of wastes from south shore development	Recreation	The transport mechanism in the south shore area.
		b. High TDS[a] brine			The relationship between virus or coliform kill and the TDS[a] concentration
	8. Safety	a. Navigational aids and search and rescue capability	Government regulation		
	9. No odor problem	a. Control BOD input	Government regulation		The present sources and amount of BOD input. The transport mechanisms in the south shore area. The reaeration rate of DO.
		b. Control the benthic decay			Extent of benthic deposits and the benthic decay and dissolved oxygen uptake rates.
	10. Stable water level (minimum fluctuation)	a. Regulate the inflow and outflow	May have a long-term affect on the ecosystem	Brine Shrimp	Feasibility of possible methods.
	11. Minimum high water damage	a. Control high water levels		All	Economic and physical feasibility of each alternative.
		i Upstream storage	Changes the nature of the stream		Social, economic, and environmental effect of each alternative.
		ii Pump to the west desert	Floods and thus eliminate present uses of the land		Effect of TDS[a] concentration in each arm.
		iii Breach the causeway	May reduce the concentration of the north arm brine		
		iv Restrict development in the flood plain	No aid to established facilities		

[a]TDS is total dissolved solids.

Table 1. Continued.

Possible use	Desired system characteristics related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of area of influence
II. Lake brine Industries					
A. Mineral extraction	1. Sufficient evaporation ponds	a. Construction	Other uses may be limited	Recreation	Land use planning

Table 1. **Continued.**

NORTH ARM

Possible use	Desired system characteristics related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of area of influence
I. Lake Brine Industries					
A. Mineral extraction	1. High TDS[a] concentration	a. Maintain the present two arm system (don't breach the causeway)	A specific (high salinity) ecosystem will exist in the north arm	Brine Shrimp	The component and viability of the ecosystem.
	2. Good ionic make-up	a. Maintain the present two arm system	Same as I.A.1.a.		
		b. Limit or control the extraction of specific ions	M. E. Industries would be limited in extraction or expansion	M. E. Industries	Depletion factor, rate of accumulation, and percent removable.
	3. Minimum high water damage	a. Control high water levels		All	Economic and physical feasibility of each alternative social, economic, and environmental effects of alternative.
		i Upstream storage	Changes the nature of the stream		
		ii Pump to the west desert	Floods and thus eliminates present uses of the land		
		iii Breach the causeway	May reduce the TDS[a] concentration of the north arm brine		Effect on the TDS[a] concentration in each arm.
		iv Restrict development in the flood plain	No aid to establish facilities		
B. Brine Shrimp	a. Maintain condition favorable to high egg production	a. Control the lake level	Create a specific habitat which may affect the ecosystem	M. E. Industries Brine Shrimp	
		b. Breach the causeway	May alter the TDS[a] concentration of both the north and south arms.	M. E. Industries	Would breaching the causeway produce conditions favorable for egg production?
II. Recreation and Tourism					
A. Boating	1. Easy access	a. Road construction	Easy access to bird rookeries in the north arm may be detrimental to the birds	Wildlife	Effect of human intrusion on nesting birds
		b. Breach the causeway			

[a]TDS is total dissolved solids.

Table 1. Continued.

Possible use	Desired system characteristic related to use	Some possible methods of achieving the desired system characteristic	Areas which may be negatively influenced by implementation of the method (impact areas)	Some social use areas which may be affected	Information needed to understand the system characteristic of areas of influence
III. Wildlife					
A. Rookeries (island)	1. Controlled intrusion of people	a. Establish buffer zones around rookeries	Limits other use of lake especially boating	Boating Oil Development	The buffer zone required during the nesting period.
		b. Limited access-maintain limited acess to the north arm	Same as a.		
		c. Prohibit use of islands during the nesting period	Government regulation		

CHAPTER III

IDENTIFICATION OF RESEARCH NEEDS AND PRIORITIES

The first task of the project dealt with identifying the research necessary to understand the components of the physical and social use systems and the interactions which occur between these systems. From the previous discussion it has been established that all interactions between social uses are linked through the physical system. Therefore, it is not surprising that much of the research identified during this study deals with establishing a basic understanding of the physical system and developing the ability to predict the consequences of any alterations of the system.

Research needs are summarized under two principal geographic divisions; the lake system and Farmington Bay. The geographic subareas included in Table 1 were useful for discussing the lake but research needs identified for the north arm and south shore were found to be encompassed in the research needs identified for the entire lake system. Within each geographic division, research needs are discussed according to social uses and the physical system which is composed of hydrologic and biologic components.

Research needs for a social use system are investigations which must be conducted to understand the use system itself or the impact links between the social use system and the physical system. An example of information needs within a social use system is the amount of land required for evaporation ponds to produce a given amount of salt at a specific salinity of the brine. A related information need for the impact link would be the resulting salinity of both arms of the lake if the railroad causeway was breached to relieve high water damage in the south arm. The ability to predict the salinity in each arm comes from an understanding of the physical system. In the following discussion of the social use systems, the information needed to properly understand the impact links between the physical and social use system is identified, but the specific research necessary to predict the impact is found in the discussion of the physical system.

From a management point of view, research involving the physical system cannot stand alone but must be initiated by the need to properly understand the impacts between the physical and social use systems. Thus, physical system research needs evolve directly from the information needs identified for each social use system. It cannot be over emphasized that proper management decisions depend on a sound understanding of the physical system. All the consequences of a management decision which require alteration of the physical system must be considered in the decision. A management decision such as pumping brine to the west desert to relieve high water damage in the lake must be made with an understanding that salinity concentration or stratification changes might occur in either arm of the lake. Failure to completely understand the consequences of altering the physical system could create a situation where the solution to one problem creates other unforeseen problems.

Tables are included in the text in which three priorities (A, B, or C) are assigned by groups to research needs within each social use area and the physical system. Research priorities were assigned by evaluating:

1. The social demand (need).

2. The degree to which the information is basic to understanding the social use system or the physical system.

No attempt was made at this time to assign research priorities between the social use areas. Since priorities were assigned within each social use area the overall priority of a specific research need will be easy to establish once alternative development schemes in the comprehensive plan are adopted and specific development goals for the lake system are set.

There are a number of state and federal agencies with jurisdiction and interest in Great Salt Lake and several universities in the state which have the capability to conduct the research necessary in formulating and comparing alternative components of the comprehensive plan. Research entities which can possibly perform the research identified in this report are listed for each research need. The capability of these entities was estimated from the known nature and jurisdiction of the agencies and the research that agencies or individuals have performed in the past. Table 2 lists the

Table 2. Agencies, universities, and counties concerned with Great Salt Lake.

STATE

Directly involved	Indirectly involved
Department of Natural Resources (DNR)	State Planning Coordinator's Office (SPCO)
Division of Water Resources (DWR)	Committee on Water Pollution (CWP)
Division of Parks & Recreation (DPR)	Utah Industrial Development Division (UIDD)
Division of Wildlife Resources (DWLR)	Bureau of Outdoor Recreation (BODR)
Division of Oil & Gas Conservation (DOGC)	Attorney General's Office (AG)
Utah Geological & Mineral Survey (UGMS)	Department of Agriculture (USDA)
Division of State Lands (DSL)	Bureau of Economic and Business Research (UUBEBR)
Division of Water Rights (DWR)	Division of Provo-Jordan River Parkway Authority (DPJ)
Division of Health (DH)	
Department of Transportation (UDOT)	

FEDERAL

Directly involved	Indirectly involved
Bureau of Land Management (BLM)	National Parks Service (NPS)
Army Corps of Engineers (ACE)	Department of Transportation (USDOT)
Environmental Protection Agency (EPA)	Department of Commerce (USDOC)
Fish and Wildlife Service (FWS)	Bureau of Mines (BOM)
Bureau of Reclamation (BOR)	Department of Defense (USDOD)
U. S. Geological Survey (USGS)	National Oceanic and Atmospheric Administration (NOAA)
Soil Conservation Service (SCS)	

UNIVERSITIES	COUNTY PLANNING COMMISSIONS	MULTI-COUNTY
University of Utah Engineering Exp. Station (UUEES)	Salt Lake	Golden Spike Empire
Utah Water Research Laboratory (UWRL)	Davis	Wasatch Front Regional Council
Institute for the Study of Outdoor Recreation and Tourism at Utah State University (ISORT)	Weber	Mountain Lands Association of Governments
Brigham Young University (BYU)	Tooele	Bear River Association of Governments
	Box Elder	

agencies involved with the lake. In the tables of research needs the abbreviations found in Table 2 are used to identify the agencies. University associations are identified for individuals listed with the research needs.

Many of the state agencies already systematically conduct research which is directly or closely tied to Great Salt Lake while the resources of other agencies could be mustered to support research in specific areas in the future. The specific areas of involvement of the various state agencies are outlined in the following paragraph.

The Division of Water Resources, Parks and Recreation, Wildlife Resources, Oil and Gas Conservation, State Lands, Water Rights, and the Utah Geological and Mineral Survey, are all under the Department of Natural Resources.

The Division of Water Resources is charged with the authority to authorize studies, investigations, and plans for the full development and utilization of the water and power resources of the state and for the formulation of a state water plan.

The Division of Parks and Recreation establishes and coordinates programs for the development of recreational areas within the state. They are presently charged with the recreational development of Antelope Island and the south shore area.

The Division of Wildlife Resources is responsible for management of wildlife throughout the state, including the management of 65,000 acres of developed marsh lands around the lake.

The Division of Oil and Gas Conservation has jurisdiction over all oil and gas well drilling in the state. The Board of Oil and Gas Conservation has adopted rules and regulations for drilling of oil wells on Great Salt Lake.

The Utah Geological and Mineral Survey is charged with the survey of the geography and the mineral occurrences of the state. The survey has had more than 15 years of experience of basic and applied research on the lake including 10 years of sampling and analyzing the lake brines.

The Division of State Lands has jurisdiction and control over all state owned lands. Additionally, the State Land Board is charged with selling the minerals of Great Salt Lake on a royalty basis.

The Division of Water Rights through the State Engineer allocates all waters which are used for mineral production. The State Engineer is also charged with the allocation of water in the basins tributary to Great Salt Lake.

The Division of Health in the Utah Department of Social Services is charged with the authority to development programs for the prevention, control, and abatement of pollution of waters of the state. The Division is also charged with the adoption of water quality standards.

Research Needs for the Entire Lake System

Mineral Extraction Industry

Extraction of salt from Great Salt Lake was established by the early Utah settlers soon after their arrival in 1847. This group is responsible for pioneering the use of solar evaporation to remove salt from the lake brine. Solor evaporation is still the most practical way to extract minerals from the lake brine.

Common table salt (sodium chloride) was the first mineral to be removed from the lake and still accounts for the largest tonnage of salt each year. Production of additional minerals including sodium sulfate, magnesium chloride, and potassium sulfate from the lake brine has also been established.

There are presently six salt companies extracting minerals from the lake. Morton, Hardy, National Lead Industries, and the Solar Division of American Salt operate with south arm brine. Two companies, namely, Lake Crystal and Great Salt Lake Minerals and Chemicals, extract minerals from the north arm brine.

The chemical feasibility of extracting minerals from Great Salt Lake is well established and documented. Both the production of individual companies and the royalties paid by the entire industry to the State of Utah are documented in Searle et al. (1976). This publication is a compilation and summary of information which was gathered by the Utah Legislative Council in support of planning on Great Salt Lake The publication contains current information on many aspects of the lake system.

A major concern of the extraction industry is access to concentrated brines. Since the completion of the railroad causeway this has been a problem for the south arm salt producers. The determination of future salinity trends, ionic makeup of the lake brines, and the distribution of salinity in different parts of the lake were identified as major research needs. The key to understanding future salinity trends in the lake is a sound knowledge of the present water and salinity balance of the lake and its subdivisions; specifically, the north and south arms. Unfortunately, many aspects of these balances are not yet completely defined.

Methods of supplying the south arm salt producers with a more concentrated brine were investigated by Whelan and Stauffer (1972). Their study looked mainly at equalizing the concentration of brines in the two arms. Their suggestions included removing 1500 feet of the railroad fill, pumping south arm brines into the north arm, and diverting the Bear River into the north arm. Any scheme to equalize the brine concentration produces a trade off between increasing the production capabilities of the south arm producers and decreasing the capabilities of the north arm producers. Whelan and Stauffer also investigated the possibility of pumping north arm brine through a pipeline to the south arm producers. They discounted the use of the deep south arm brine because it is apparently contaminated with organic matter, heavy metals and obnoxious odors. They also assumed that diverting the inflow of the Bear River and breaching the causeway would not alter the present lake character of a completely mixed north arm and a stratified south arm. Projects which alter the lake to this degree might cause the north arm to stratify or increase the stratification of the south arm.

An immediate concern of the mineral extraction industry is damage to facilities due to the present high level of the lake. A high priority research need is to identify both short and long term methods to alleviate this danger. Any solution of the high water problem which requires an alteration of the lake system has the potential of affecting the future salinity distribution in the lake. Therefore, a potential trade off exists between alleviating high water damages and altering production capabilities by changing the present salinity distribution. A desirable requirement of any proposed management scheme is an ability to predict the changes which would take place in the salinity distribution as a result of particular system alterations so that any adverse affect on salt production could be anticipated and minimized. A predictive ability cannot be gained until an understanding of the present hydrologic system is better established.

At present, there is little conflict between the lake ecosystem and the mineral extraction industry. A shift in the ecosystem which would cause the population of algae to substantially increase could create a situation in which the mineral extraction industry would have difficulty in extracting a pure product. Potential conflicts of this type need to be defined.

The list of research needs identified for the mineral extraction industry is given in Table 3. Many of the items deal with understanding the present physical system and developing the ability to predict the consequences of altering the system.

Table 3. Research needs identified for the mineral extraction industry.

Research Needs	Possible Information Source
Group A	
Methods of controlling high water damage (flooding) in both the short and long-term.	DWR, ACE, UWRL, UDOT
An accurate lake level frequency curve.	DWR, UWRL
State of art prediction of future extreme high and low lake elevations.	DWR, UWRL, H. Willett (MIT)
Future salinity trends of both the north and south arms under present lake conditions and the effects of any alterations of the present system especially breaching the causeway.	DWR, UWRL, J. Glassett (BYU)
Economic impact of the mineral extraction industry on the state and how it would be altered if the physical system is changed.	UUBEBR, UWRL, Salt Companies, UGMS
Economic analysis of mineral extraction as affected by lake salinity levels	UUBEBR, UWRL, Salt Companies, UGMS
A better understanding of the present water and salinity balance, specifically:	
a. The change in ionic makeup of the brine, if any, occurring in each arm as a function of time and how the precipitation of salt in the north arm affects the ionic makeup.	UGMS
b. A better definition of the two directional flow through the railroad causeway fill and culverts.	USGS
c. Accurate evaporation, precipitation, and groundwater inflow data.	USGS, DWR
d. The rate of mixing between the lower and upper south arm brines.	J. Glassett (BYU), G. Watters (USU), A. Lin (U of U)
e. Future volume and salinity trends of the lower south arm brine layer.	UGMS
f. Conditions that would cause the north arm to become density stratified.	J. Glassett (BYU), G. Watters (USU), A. Lin (U of U)
Group B	
The concentration and distribution of heavy metals in the lower south arm layer.	UGMS
Feasibility of using the lower south arm brine for salt production.	UGMS
Circulation and resulting horizontal distribution of salt within each arm.	UGMS, G. Watters (USU), A. Lin (U of U)
Group C	
The micro-climate of future extraction sites.	USGS, D. Dickson (U of U)
The rate of accumulation and depletion of each ion.	UGMS
The effect on phase chemistry of the extraction of salt and salt precipitation in the north arm.	UGMS
Methods of algae control near pond intakes.	F. Post (USU), UGMS
Ecologic conditions which would interfere with the extraction of salts.	UGMS, Salt Co.

Brine Shrimp Industry

The Sanders Brine Shrimp Company was responsible for establishing the use of brine shrimp from the lake for commercial purposes. This company harvests what are termed winter eggs from the shore of the lake, cleans them, and packs them for marketing. The eggs are hatched by the consumer for use as tropical fish food or feed for commerically grown edible shrimp. It is well established that the brine shrimp reproduce through both summer eggs (soft shelled) and winter eggs (hard shelled). The soft shelled eggs hatch within hours of being laid, but the winter eggs must first be dried before they will hatch. For a yet unexplained reason the hatch of harvested winter brine shrimp eggs has dropped steadily from 75 percent prior to 1967 to about 5 percent in 1975. Unless this trend reverses it could bring an end to this commercial venture on the lake. The royalities which have been paid to the state for brine shrimp egg harvesting are found in Searle et al. (1976).

Since little is known about the conditions that affect the brine shrimp reproductive cycle it is not possible to pinpoint the reason for the reduction in hatchable eggs. The small amount of data on the population of brine shrimp in the lake as a function of time makes it impossible to presently ascertain if the reduced egg hatch is associated with a shift in the reproductive cycle in the brine shrimp or a reduction in brine shrimp population due to some type of adverse conditions. Brine shrimp play an important role in the lake ecosystem and it is important to both the brine shrimp industry and the maintenance of a viable lake ecosystem to understand the cause of the reduced egg hatch.

Research needs of the brine shrimp industry logically focus on the need to understand the conditions favorable to the production of winter eggs having a high proportion of hatch. The research needs are summarized in Table 4.

Oil and Gas Development

Exploration for oil in and around Great Salt Lake has received attention at various times since the turn of the century. The presence of oil was established with the discovery of natural oil seeps at Rozel Point. Attempts to produce oil within the lake have resulted in only marginal success to the present time. Recent leases have been granted to American Oil Company (AMOCO) making it the only oil company with rights to explore for oil within the boundaries of Great Salt Lake. Seismic exploration of the lake bed by AMOCO established the presence of formations considered favorable for exploratory oil drilling. However, there is no definite indication that significant production of oil is possible.

The Dow Chemical Company (1973) prepared a report for the Utah Division of Water Resources on the feasibility of locating an industrial complex in the Wastach Front Region. The study was based on the assumption of manufacturing 14 chemical products mainly from Utah crude oil and minerals extracted from Great Salt Lake. The report is favorable on the

Table 4. Research needs identified for the brine shrimp industry.

Research Needs	Possible Information Source
Group A	
The optimum environmental and ecosystem conditions for hatchable winter egg production. This should include the variation of egg production with changing food supply and environmental factors such as salinity and brine temperature.	Post (USU), Porcella (USU)
The variation of brine shrimp population with time.	Post (USU), UGMS
Group B	
The role of the brine shrimp in the lake ecosystem.	Post (USU), Porcella (USU)
Identification of the nutrient supply and environmental conditions necessary to sustain brine shrimp in the lake.	Post (USU), Porcella (USU)
Group C	
A study of alternatives to the shore collection of eggs including alternative methods of egg production such as brine shrimp farming.	Brine Shrimp Industry

possibility of locating such a complex near Great Salt Lake. The discovery of a large quantity of oil beneath the lake could give the necessary inpetus to such a major development.

The main concern created by oil drilling is the possibility of oil spills, either single spill or some type of chronic pollution. Due to the wide extent of oil exploration throughout the world many of the potential oil spill hazards which exist for Great Salt Lake have been researched for other geographic areas. Studies such as Baker (1971) have shown that chronic oil pollution destroys salt marsh vegetation even at low pollution levels. Nelson-Smith (1973) reported that crude oil had no adverse effect on adult brine shrimp. While studies of these types provide a wide base of knowledge certain aspects of pollution from oil spills need to be considered specifically for Great Salt Lake.

A chronic oil spill is potentially more dangerous to the lake than a single spill due to the adverse effect it could produce on the lake ecosystem. The effect of a constant supply of hydrocarbons to the aquatic community has not been studied. Information of this type is important since a constant supply of hydrocarbons could create a shift in species dominance and disrupt the unique ecosystem of the lake.

The single event spill represents a potential hazard to all social uses of the lake. Such a spill could contaminate the marsh lands below the diked areas, the recreational beaches, and the intakes to the mineral extraction ponds. The key to controlling damage from this type of spill lies in the ability of providing clean up before the spill reaches key use areas. Lake circulation data would provide an understanding of the movement of an oil spill occurring at any point in the lake and would aid in identifying areas of the lake where spills would be the greatest hazard to other social uses. With this information, the decision-maker could determine if the potential hazard is great enough to restrict drilling in certain portions of the lake.

The state has already eliminated some potential conflicts between oil and gas development in the lake and other uses by restricting drilling in the vicinity of shore lines, islands, and marshes. This provides a buffer zone for recreational and wildlife uses. Possible conflicts between drilling and other uses such as boating should be identified.

The research needs identified for oil and gas development are listed in Table 5.

Recreation and Tourism

Resorts and beaches. Great Salt Lake for many years provided major resort facilities for the tourists and local residents that visited the lake. The late 1880s and early 1900s saw the establishment and eventual failure of many resorts around the lake. Black Rock, Garfield Beach, Lake Point, Lake Park, Syracuse, and Saltair all flourished as major resort areas at one time during this period, but all eventually failed. Saltair was perhaps the most popular with swimming facilities, a dance pavilion, and an amusement park. Saltair survived with varying degrees of popularity from 1893 until 1968 when it was once again closed and later destroyed by fire.

The continuous fluctuation of the volume of the lake was a common enemy of the resorts. The bottom of the lake has a very gentle slope which results in a large change in surface area for a small change in lake volume. The location of the shore line varies drastically between dry and wet years. During periods of decreasing lake stage the shore line would recede, leaving the resorts high and dry. Saltair lost most of its popularity during the low lake periods of the 1930s and the 1960s when the shore line receded several hundred yards from the pavilion.

The main recreational facilities presently found on the lake are at Silver Sands Beach on the south shore of the lake. These facilities provide the opportunity to swim, boat, or tour the lake. The use of the lake for boating has grown recently, mainly due to the use of fiberglass craft which are impervious to the effects of the salt brine. An active group of sail boaters has reestablished the old Salt Lake Yacht Club Charter.

The State of Utah obtained the north end of Antelope Island and established it as the Great Salt Lake State Park. A highway between Syracuse and the park which was severely damaged several times due to increasing water levels, has been rebuilt to a higher elevation and is presently open to traffic.

Great Salt Lake apparently has the potential to again serve the State of Utah as a major recreation and tourist center. Unlike many other uses of the lake, the development of the lake for recreational purposes is still in the formative stages which will allow the decision-maker to insure the systematic long-range development of this use.

Because the recreational potential of the lake has not yet been fully realized, many of the study needs center on identifying potential recreational uses and the associated use intensities. The physical and economic impacts of such uses must also be considered. The research needs specifically deal with identifying present and potential uses, use patterns, use intensities, and use sites; identifying the facilities desired by present and potential users of specific

Table 5. **Research needs for oil and gas development.**

Research Needs	Possible Information Source
Group A	
The effects of a chronic oil spill on the lake ecosystem; specifically, on species dominance and food chain links.	Post (USU)
Identification of methods to control a single spill.	Oil companies
Group B	
Development of the ability to predict the fate of an oil spill through circulation data and computer model development.	UGMS, A. Lin (U of U), G. Watters (USU)
Group C	
Identify potential conflicts between oil and gas drilling and boating.	DPR, Yacht Club

sites; and identifying the economic potential of recreational development on the lake.

Many of the previous and ongoing studies designed to identify the above items have dealt with the south shore area and Antelope Island since these areas have been obtained for recreational development by the state. McCool and Becker (1974) performed a superficial point survey of several of the recreational attractions located within the immediate vicinity of Great Salt Lake. The survey estimated the total use of the major recreational attractions around Great Salt Lake, determined the recreational activity patterns, described the characteristics of recreational visitors, and determined visitor expenditures. The authors' major purpose was descriptive and they recognized the need for more intensive studies on these subjects.

The Institute for the Study of Outdoor Recreation and Tourism in cooperation with the Utah Division of Parks and Recreation performed a comprehensive study of the south shore area to determine the recreational use and development desires of users of the area and the Wastach Front population. The Institute is currently conducting a repeat of the south shore study and is applying a similar methodology to Antelope Island. The Golden Spike Empire is sponsoring research with the Institute aimed at identifying ways to keep tourists in the area who visit the lake and providing experiences which will make them return for future visits. Their efforts are centered away from the south shore of the lake and focus primarily on the Antelope Island State Park.

Still lacking is a thorough study of use and expenditure patterns, an inventory of potential recreational sites, and a projection of future use patterns and demands. Recreational facilities development on the lake must cope with its continuous fluctuation. This aspect of recreational development needs to be investigated so that the development which occurs on the lake will not be adversely influenced by the extreme variation of the location of the shore line between wet and dry years. Wind tides coupled with the present high water conditions caused extensive damage to the marina at Silver Sands Beach in the spring of 1976. This damage and damage to the Antelope Island causeway point to the need to research both short and long-term solutions to the high water flooding problem. This should be coupled with an investigation of establishing a maximum lake elevation where flood control measures would be put into effect.

The south shore area, the state park on Antelope Island, and Farmington Bay are presently being considered as sites for expanded recreational development. Many factors other than society's desire for recreation must be considered in developing recreation on the lake. Consideration must be given to factors such as health and safety, access, insect control, impact on other users, and aesthetics.

A major water quality concern for recreational use is the control of pathogenic organisms in areas used for water contact sports. Research leading to the elimination of this potential health hazard is needed to better understand the sources of the organisms and their distribution and mortality rate once they enter the lake. Recreation development itself is liable to create water quality problems in the lake unless the disposal of sewage and solid wastes is properly managed.

Yet to be defined are the salinity conditions in the lake which are considered desirable for recreation. The main consideration would appear to be maintaining a high enough salinity so that the unique experience of "floating like a cork" would not be lost.

Boating. In recent years the sail boating has increased significantly. This has created a need for navigational aids, hazard warnings, and equipment necessary for search and rescue. The Utah Geological and Mineral Survey (UGMS) has prepared a navigational chart of the south arm of the lake. The UGMS participates in search and rescue but their capability in this capacity is not adequate for the present extensive use of the lake. In addition, the Utah Department of Transportation (UDOT) is capable of conducting a wide variety of studies involving the movement of water traffic and the locations of terminal and docking facilities on the lake.

Noxious insects. The problem of abundant noxious insects must be addressed in planning recreational development of the lake. The principal insects which may require control are the brine fly, mosquito, deer fly, horse fly, and gnat. The non-biting brine fly is a problem due to the vast numbers which cover both the water surface and beaches in the recreational areas. Noxious insects can be controlled through water management in the marsh lands, the use of chemical or biological agents, or by altering their habitat. Research needs to be conducted on the best way to control insects in specific areas with the minimum effect on the ecology of the lake.

Marsh lands often provide the necessary environment for producing mosquitos. Methods of mosquito control on marsh lands through the proper regulation of water levels were described by Rees et al. (1966). In this series of studies it was shown that water management techniques and practices effectively used in mosquito abatement often improved the marshes for waterfowl and other wildlife.

Other ecologic factors which would affect the recreational uses of the lake need to be defined. For example, at what concentrations of algae in the lake would swimmers and boaters find the conditions objectionable and seek alternative recreational sites. Table 6 contains a list of research needs identified for the recreational use system.

Wildlife

Wildlife is perhaps the best understood use of the lake resources. Both the Utah Division of Wildlife Resources (DWLR) and the U. S. Fish and Wildlife Service (FWS) have sponsored extensive research in the wildlife area. Rawley et al. (1974) provide a detailed discussion of the various aspects of the wildlife resources in the vicinity of Great Salt Lake.

The islands of Great Salt Lake and the marsh lands which are found around the shore of the lake provide nesting and rest areas for a variety of migratory birds. The California gull, white pelican, Caspain tern, great blue heron, and double-crested cormorant migrate inland from the Pacific Coast to nest on the islands of Great Salt Lake. During the spring and summer these birds mainly use the smaller islands for nesting, having abandoned the use of the larger islands.

An extensive network of marsh lands is found around the shores of Great Salt Lake. These marsh lands provide a vital link in the waterfowl flyway extending from Canada to Mexico. Much of the marsh land is controlled by federal and state agencies and private organizations. The Utah Division of Wildlife Resources operates eight waterfowl management areas at the mouths of streams entering Great Salt Lake. The U. S. Fish and Wildlife Service (FWS) operates the Bear River Migratory Bird Refuge at the mouth of the Bear River. The rest of the marsh lands are managed mainly by private organizations such as hunting clubs.

Wildlife provides major recreational benefits from hunting, fishing, and bird watching. The waterfowl management areas around the lake provide the major areas of activity. A summary of the number of annual hunters and visitors to the marsh lands is given in Rawley et al. (1974). They report that an average of 151,000 hunter trips are made to the marshes annually with an average expenditure per trip of over $40. The marshes have an even more significant value to the preservation and perpetuation of waterfowl. The marshes act as a nesting area and a vital flyway link for birds which provide hunting throughout the North American Continent.

Presently the main concern of the wildlife system is the damage created by the current high elevation of the lake and the potential dangers if the lake were to rise still higher in the future. The waterfowl management areas are composed of diked areas in which the water level is regulated, and unregulated areas which are principally below the diked areas. The high water already has flooded major portions of the unregulated marshes and threatens to cause major damage to the dikes. Occasional flooding of the area below the dikes is considered favorable since it rejuvenates the vegetation which provdes better waterfowl feed. However, extended periods of inundation are detrimental. Damage to the marsh land diking systems could destroy the ability to regulate the water level in the marsh lands and create expensive repair problems. Understandably, high priority research items are an investigation of methods to alleviate potential short and long-term flood damages and the development of a lake elevation frequency curve. Any solution of the high water problem which includes upstream storage of water should consider methods of improving the inflow to the marsh lands by storing mass spring flows and augmenting summer low flows. A project with this ability would benefit the marsh lands by stabilizing the inflow and reducing the salinity of low flows by dilution.

Table 6. Research needs identified for the recreation and tourism system.

Research Needs	Possible Information Source
Group A	
Methods of controlling high water damage (flooding) in both the short and long-term.	DWR, ACE, UWRL
Methods of modifying extreme low levels and effects on recreation.	DWR, ACE, UWRL
Present recreational lake use patterns and the economic potential of resident and non-resident visitors.	ISORT, DPR, UDOT
Present and potential recreational uses, use sites, and use intensities.	ISORT, DPR
The facilities desired by present and potential users of specific sites such as Antelope Island State Park.	ISORT, DPR, UDOT
The economic potential of recreational development.	ISORT, DPR, UUBEBR, UDOT, UWRL
Recreational expenditure patterns.	ISORT, DPR
The present length of tourist visits to the Great Salt Lake vicinity and how to hold them in the area longer.	ISORT, DPR, UDOT
Methods of noxious insect control in recreational areas.	D. Rees (U of U)
Types of facilities which can cope with the fluctuating lake levels.	DPR, UDOT
The health hazard from pathogenic organisms in the recreational beach areas.	DH
Search and rescue equipment needed for the lake.	UGMS, Yacht Club
Group B	
An accurate lake level frequency curve.	DWR, UWRL
Methods to dispose of sewage and solid wastes from recreational facilities.	DPR
Where hazard warnings should be located and what hazard warnings are needed.	UGMS, Yacht Club, UDOT
The amount of land the state should own for proper access to the lake.	DPR, UDOT
The range of salinities considered desirable for recreational use.	DPR
Group C	
The sources and availability of utilities for recreational facilities.	DPR, UDOT
Methods of stabilizing the water level fluctuation in recreational areas.	DWR, DPR, UWRL
Identification of ecologic and water quality factors which would affect recreational uses of the lake.	DPR

Low lake levels are also a problem since they allow land access to the islands by predators and humans which can disrupt nesting birds. The Utah Division of Wildlife Resources is presently looking at methods of limiting access to the islands during these low lake level periods. McDonald (1974) attributes the preservation of the white pelican colony on Gunnison Island to the limited access to the north arm. Methods of eliminating the conflict between man and birds need to be investigated. The solution should include public education and methods of enforcing no trespassing limits for the islands during the nesting season. Since some of the islands are privately owned the benefits of public ownership should be studied.

While the impact of intrusion by people onto the islands is established, their intrusion into waterfowl areas, which may be outside the managed marsh lands, needs to be documented. The Division of Wildlife Resources is presently investigating this problem. Because this represents a potential conflict between recreational and wildlife uses of the lake all modes of intrusions, including boats and hikers, should be considered.

During the early 1900s avian botulism killed thousands of ducks on Great Salt Lake and the occurrence of the disease is observed yearly. The Utah Division of Water Resources (1974) summarized the lake characteristics which would be favorable to avian botulism as, a sizable population of invertebrates the carcasses of which provide the medium for toxin, constant drying, and reflooding of extensive beach areas, and hypersaline water. While at present there doesn't appear to be any practical way to alter these characteristics of the lake and reduce botulism deaths, consideration must be given during project planning on the lake to insure that conditions are not produced which enhance the possibility of outbreak of botulism.

Any disruption of the ecosystem by users of the lake can create an adverse affect on wildlife. Understanding of the ecology of the lake system is basic to the proper management of the wildlife system. The relationship between the marsh land ecosystem and the lake ecosystem needs to be established. Table 7

Table 7. Research needs identified for the wildlife use system.

Research Needs	Possible Information Source
Group A	
Methods of controlling high water damage (flooding) in both the short and long-term.	DWR, ACE, UWRL
Methods of dealing with low lake levels.	DWR, ACE, UWRL
Methods of enforcing restrictions on human access to island rookeries during the nesting season.	DWLR, UDOT
Economic analysis of the wildlife use of the lake system.	UUBEBR, UWRL, DWLR
The relation between the marsh land and lake ecosystems.	DWLR, FWS
Possibility of acquisition of more land for marsh land.	DWLR
Possibility of acquisition of privately owned lake islands.	DWLR
Impact of human intrusion into waterfowl areas.	DWLR, FWS
Group B	
The role of the lake ecosystem in the waterfowl food chain.	DWLR, FWS
Energy flow in the marsh land ecosystem.	DWLR, FWS
Methods of stabilizing the spring and summer inflows to the marsh lands.	DWR, UWRL
Group C	
Quality of groundwater inflow to the marsh lands.	USGS, DWR

contains a listing of the research needs identified for the wildlife system.

Transportation

The development of transportation on the lake is dependent on a need to serve other social use goals. The construction necessary to facilitate land transportation has produced substantial impacts on the physical lake system. The magnitude of these inputs is evident from the disruption of the circulation patterns in the lake produced by the railroad causeway and the freshening of Farmington Bay due to the presence of the Antelope Island causeway. The major effect of the railroad causeway has been the disruption of the brine concentrations in both arms and the resulting effect this produced on the mineral extraction industry. The effect of the Antelope Island causeway has not yet been fully evaluated. The positive or negative nature of the freshening of the bay will be influenced by the future uses of the bay proposed in the comprehensive plan.

The essential problem lies in the fact that during the planning of these projects the consequences of alterations of the physical system were not adequately considered. Although it was foreseen that the present conditions could possibly result from the construction of these causeways, the magnitude of the effects on the physical system and ultimately other social uses of the system were not evaluated.

Any construction in the lake has the potential of changing the lake conditions. The most dramatic alterations have resulted from the construction of the railroad and Antelope Island causeways. These have altered the hydrology, circulation patterns, salinity, and ecology of the lake. Similar alterations could occur from the construction of dikes, channels, and other facilities to serve any social use of the lake. Again, proper management of the lake requires the ability to predict the consequences of altering the physical system. The ability to evaluate these impacts depends on a thorough understanding of the present lake system and the development of predictive capabilities.

The expense of maintaining the railroad and Antelope Island causeways during the present rising lake stage has made the study of solutions to high water control a top priority research need. Increases above the present lake stage also would threaten Interstate 80 and the Western Pacific railroad route at the south end of the lake.

Before the railroad developed as an efficient means of transportation, shipping on the lake was an important means of transportation. Water transportation may be an effective alternate to the construction of causeways. This is especially true for recreational transport to the lake islands. The Transportation Subcommittee of the Great Salt Lake Interagency Technical Team is presently investigating the feasibility of various methods of water transportation on the lake.

The location of a transportation route has a large impact on the development of an area. The road to Antelope Island has already created interest in developing motels and restaurants along the route. Access routes to the lake must be developed with consideration of the associated development they will foster. An extensive listing of research needs identified for the transportation use system is given in Table 8.

Physical System

Understanding the physical system is fundamental to the proper management of any system. Through this understanding the impacts of a management decision which requires alteration of the physical system can be evaluated and, thus, the negative impacts minimized. This allows the maximum benefits to society to be realized from the limited resources of the system. The need to understand and predict potential impacts creates the necessity for research on the physical system.

Two problems exist concerning Great Salt Lake. First, the future of the lake under present conditions is not known. The construction of dikes and causeways, principally the railroad causeway, has changed the character of the lake by altering the circulation patterns, salinity, hydrology, and ecology. The information necessary to predict the future hydrologic and biologic characteristics of the lake has not yet been accumulated. This research is necessary in order to understand if the previous alterations to the system will produce conditions which will limit present or potential uses of the lake. If future trends were to indicate adverse conditions, the decision-makers could take steps to eliminate the adverse conditions.

Secondly, the capability to predict the impacts on both the physical and social use systems of altering the present system has not yet been developed. Understandably, the development of this capability depends on researching many of the same topics needed to understand the future trends of the present system.

Identification of the impact links between the physical system and the social use systems indicates the factors which must be addressed in building an understanding of the physical system. From the discussion of the social use systems it was established that some of the impact links are understood while others need to be researched. For example, the salinity of the lake is a physical system parameter with impacts on the mineral extraction industry. A research need identified for the brine shrimp use system was how the salinity of the lake affects the production of winter brine shrimp eggs. The impact the salinity of the lake has on the social use systems creates the need for an ability to predict future salinity trends under either present or altered conditions. Research on the physical system necessary to develop this predictive ability thus is needed.

In the following discussion the physical system is divided into a hydrologic and biologic component.

Table 8. Research need identified for the transportation system.

Research Needs	Possible Information Source
Group A	
Methods of controlling high water damage (flooding) in both the short and long-term.	DWR, UWRL, ACE
Economic analysis of various transportation uses associated with the lake.	UUBEBR, UDOT
Feasibility of alternatives to causeway construction for access to the islands.	UDOT
The impact of causeway construction on the physical system, especially, circulation patterns, salinity trends, and the ecosystem.	USGS, DWR, UGMS, UWRL, A. Lin (U of U) J. Glassett (BYU) G. Watters (USU)
Group B	
The need for a route around the entire lake.	UDOT
The future demands of auto and bicycle access to the lake, especially, for recreation.	UDOT, DPR
Alternatives to auto access to the lake.	UDOT
Group C	
The need, advisability, and facilities necessary to provide boat access to the north arm and Willard Bay.	UDOT, DWLR, DPR

Hydrologic System

The hydrologic system, as depicted in Figure 5, was divided into three areas, the watershed, the near shore, and the lake.

The lake watershed. The Great Salt Lake drainage area or watershed is composed of major drainages, the Bear, Weber, and Jordan River basins, and a number of minor drainage basins. Components of the Great Salt Lake watershed systems have been the subject of various studies due to the importance of this resource in Utah's water development. The Utah Water Research Laboratory and the Utah Division of Water Resources have performed a series of water budget studies of the Bear, Weber, and Upper Jordan drainage areas (Hyatt et al., 1969; Haws et al., 1970; and Haws and Hughes, 1973). Simulation model studies of the hydrology and salinity within the Bear River basin were performed by Hill et al. (1970 and 1973). A model study of the Upper Jordan River drainage was carried out by Wang et al. (1973). A 1974 study by the Utah Division of Water Resources estimated the effect of different levels of upstream water development on future lake stages.

Under studies at the Utah Water Research Laboratory, the high resolution QUAL model (Texas Water Development Board, 1970) and the intermediate resolution USU RM model (Utah State University River Model - Grenney et al., 1974) were used to provide simulation models of waste load allocation on the Bear, Weber, and Jordan Rivers. These models cover the Weber-Ogden system from Park City and Kamas to Great Salt Lake, the Jordan River from the Jordan Narrows to Great Salt Lake, and the Bear River from the Utah-Idaho border to Great Salt Lake.

Several studies of the smaller drainage areas of Great Salt Lake also have been performed. A water budget study of the Great Salt Lake Desert area, similar to the water budget analysis of the major rivers, was prepared by Foote et al. (1971). The water resources of Salt Lake County were discussed in Hely et al. (1971) and later simulated in a computer model (Israelsen et al., 1973). Future water use in Utah Valley was modeled by Huntzinger (1971). A water resource allocation model of the entire State of Utah, including Great Salt Lake, has been developed at the Utah Water Research Laboratory (Keith et al., 1973).

Additional research needs which were identified for the watershed area were determining the effects the lake has on the climate within the Great Salt Lake drainage basin. Such studies should address the effects on precipitation and air temperature of inadvertent cloud seeding as storms pass over the lake. These research items are included in Table 9.

The near shore area. From a hydrologic viewpoint the near shore area can be considered as a strip of land around the perimeter of Great Salt Lake which contains the marsh lands. The water requirements for waterfowl marsh lands in the vicinity of Great Salt Lake were studied under an extensive project which began in 1959 as a cooperative effort of the Utah State Division of Fish and Game, the Utah Water Research Laboratory, and the USU Cooperative Wildlife Unit. The investigation took place on the Howard Slough management area and the data gathered were used to develop a procedure for determining the monthly and seasonal water requirements for marsh lands. The results of the study are summarized by Christiansen and Low (1970). This report presents a method for calculating marsh land water requirements based on the salinity of flow, the evapotranspiration (consumptive use) from the marsh land, and the precipitation on the marsh land. The study not only provided a means for estimating water requirements of marsh lands, but also through the development of the necessary background information and data, provided insight into the tolerance of marsh plants to salinity and the evaporation losses to be expected within marsh lands.

The research needs for the near shore area are included in Table 9 and consist of accumulating information on the lake elevations which will cause flooding of the marsh lands, methods of equalizing the spring and summer inflows to the marsh lands, and the quantity and quality of groundwater inflow.

The lake. Great Salt Lake itself is an important component of the Great Salt Lake system. The unique characteristics of the lake provide an unusual combination of resources which support a variety of social use activities. However, use of the lake can severely alter its characteristics as the construction of the railroad causeway has shown. The hydrologic processes within the boundaries of the lake determine its character under any degree of alteration imposed by man.

Principal considerations of users of the lake resources regarding the hydrologic system are lake elevations and salinities to be expected in the future and how they would be affected by alterations of the present physical system. Both the lake level and salinity are affected by the inflow and outflow from the lake and the exchange between physical divisions of the lake; namely, the north arm, the south arm, and to a lesser degree Farmington Bay. The inflow and outflow of water and salt from a system constitute the water and salinity balances, respectively. Since water is the transport mechamism for salt, the two balances are closely tied.

Table 9. Research needs identified for the hydrologic system.

Research Needs	Possible Information Source
Group A	
Methods to control high water damage (flooding) in both the short and long-term.	DWR, ACE, UWRL
Establishment of a reliable lake elevation frequency curve.	DWR, UWRL
A state of the art prediction of future high and low lake elevation extremes.	DWR, UWRL, H. Willett (MIT)
A better definition of the present water balance including data on:*	
1. The spatial variation of evaporation across the lake.	USGS
2. The spatial variation of precipitation across the lake.	USGS
3. Total groundwater inflow to the lake and its spatial variation (group B priority).	USGS
4. Flow through the railroad causeway fill.	USGS
5. Flow through the Antelope Island fill.	USGS
A better definition of the present salt balance including data on:	
1. Flow through the railroad causeway fill.	USGS
2. Monitoring of the vertical location of the interface between the south arm brines.	UGMS
3. The rate of mixing between the two south arm brines.	J. Glassett (BYU), A. Lin (U of U), G. Watters (USU)
4. Salinity of groundwater inflows (group B priority).	USGS
The forces creating the mixing mechanism between the two south arm brines which also leads to why the south arm is stratified.	A. Lin (U of U), G. Watters (USU), J. Glassett (BYU)
Data on the present circulation patterns including point velocity measurements.	UGMS, NOAA
Modification to the circulation patterns which would result from alterations to the physical system such as breaching the railroad causeway, pumping brine to the west desert, or constructing additional dikes and causeway in the lake.	G. Watters (USU)
Testing of the USGS causeway flow equations for current conditions. This requires fill flow information and may lead to altering the flow equations.	USGS
Study the mixing of north and south arm brines to prove or disprove that they would mix if the causeway were breached.	J. Glassett (BYU), A. Lin (U of U), UGMS, UWRL
Future salinity and stratification trends of the lake brines under altered conditions such as breaching the railroad causeway or pumping brine to the west desert and returning the concentrated brine to the north or south arm.	USGS, DWR, UWRL J. Glassett (BYU)
Conditions which would cause a precipitated salt layer to be covered with a sediment which would restrict redissolving as the lake rose.	UGMS, UWRL
Relationship between the hydrology and salinity balance of Farmington Bay and the south arm.	USGS, DWR, UWRL
Group B	
How the precipitation of salt in the north arm affects the ionic makeup of the lake brines.	J. Jurinak (USU), UGMS
Vapor pressure, temperature, and wind near the lake (for use in calculating evaporation).	Weather Bureau, USGS
Verification of existing methods or the development of calculating evaporation from the lake. This requires evaporation data from points near or in the lake.	USGS
Group C	
The relationship between Great Salt Lake and the climate of the basin including precipitation and temperature.	
Methods of equalizing the spring and summer inflows to the marsh land.	DWLR, DWR, FWS
The contribution that condensation of fog makes to the water budget.	

* The USGS basic data collection program also should be continued.

With the lake divided into distinct areas by the construction of causeways, the water and salinity balance for the entire lake is quite complex. The potential evaporation rate is different in each area due to differences in salinities. The spatial variation of inflows and the rate of flow through the causeways influence the surface elevation and salinity of each of the areas. Under present conditions the surface elevation of the south arm is always greater than the north arm while the north arm is more saline than the south arm.

The components of the water balance must be understood and predictable under various lake conditions to provide the foresight necessary to enable predictions of how alterations of the present physical system will affect future lake levels. Because of the close tie between the water and salinity balance an understanding of the water balance is necessary in predicting future lake salinity trends. The converse of this is true when dealing with major divisions of the lake such as the north and south arms. The water balance for either arm of the lake is composed of the inflow and outflow to the lake and the exchange of brine between the two arms through the causeway. Flow through the causeway is a function of both the surface elevation difference across the causeway (water balance) and the difference in salinity (salt balance).

Evaporation, perhaps because it is the only outflow from Great Salt Lake, has been the subject of a number of studies. In 1932, T. C. Adams established a method of estimating the evaporation from the Great Salt Lake by correlating pan evaporation of salt and fresh water. The work done by Adams has been referred to in most of the subsequent studies of evaporation from Great Salt Lake.

Harbeck (1955) investigated the effect of salinity on evaporation from a theoretical basis and used the results obtained by Adams to verify his findings. Dickson, Yepsen, and Hales (1961) performed laboratory measurements of the vapor pressure of Great Salt Lake brine at various concentrations and temperatures. Dickson (1962) and Dickson and McCullom (1965) used vapor pressure, wind speed, temperature, and humidity data collected in the vicinity of Great Salt Lake to estimate evaporation using the eddy flux technique. Their results indicated evaporation from Great Salt Lake was greater than predicted in earlier studies.

The main limitation of using these methods is that sufficient evaporation data are not available from the lake for verification. The U. S. Geological Survey (USGS) is gathering basic data on evaporation at six stations around the lake which should help fill this void. As part of the same project, the USGS is also gathering basic data on surface inflows, precipitation, and radiation. This data gathering project is scheduled to end in September of 1976 to 1977.

Precipitation, surface inflows, and groundwater inflows are inputs to the lake. Precipitation on the surface constitutes a major inflow to the lake. Except for the current USGS data gathering project, research on the distribution of precipitation over the lake at this time has not progressed much beyond the preparation of isohyetal maps, by E. L. Peck, which include the Great Salt Lake regions. The contribution which condensation of fog makes to the water budget has not been studied.

The USGS has a program of monitoring the quality and quantity of flow in the major streams in the state. In their project mentioned above, the monitoring program has been expanded to measure the quality and quantity of major surface inflows nearer the lake and the miscellaneous flows which were previously ungaged.

Before Farmington Bay was separated from the south arm by the Antelope Island causeway, the south arm directly received over 95 percent of the surface inflow to the lake. Thus, the major inflows to the north arm are precipitation and south arm brines. This inflow pattern has created a head difference across the causeway, with the south arm elevation being greater than the north arm. The Antelope Island causeway affects the flow of the Jordan River into the south arm. A culvert was constructed in the causeway to allow for flow between the bay and the south arm, but any impact this may produce on the hydrology of the south arm, is not yet known.

The contribution which groundwater makes to the inflow to Great Salt Lake has not been well established. Lofgren (1954) estimates the groundwater inflow to be 30 percent of the total inflow. More recent investigators have placed the groundwater contribution at 6-10 percent of the total annual inflow. Many of the estimates of total groundwater inflow to Great Salt Lake have come from water budget studies which are made by balancing inflow, outflow, and storage change in the lake. Major components in a water budget study of Great Salt Lake are evaporation and precipitation on the lake. The accuracy of estimating groundwater inflow using water budget studies are affected by the fact that neither evaporation nor precipitation on the lake is well defined.

Groundwater conditions in Utah are investigated by the Utah Department of Natural Resources and the U. S. Geological Survey. Hely et al. (1971) discuss the groundwater conditions in Salt Lake County. Foote et al. (1971) use the data available on groundwater conditions in the Great Salt Lake Desert to estimate the average annual groundwater inflow to the lake from this area.

During 1970-1972, the U. S. Geological Survey in cooperation with the Utah Geological and Mineral Survey carried out an investigation to establish (1) the net movements of dissolved solids load through the railroad causeway for the 1971 and 1972 water years, (2) salt load movement through the causeway for simulated rising and falling lake stages, and (3) the effects on salt movement patterns of enlarging the present culverts through the causeway. The project included field measurements of flow through the causeway. Flow through the causeway was found to occur through the semi-permeable fill and through two 15 foot wide concrete culverts in the causeway. A flow northward was observed in the upper portion of the culverts and fill. Beneath this flow was a southward flow in both the fill and culverts. The fill flow accounted for approximately 80 percent of the total flow. The results of the USGS study are reported by Waddell and Bolke (1973). A major contribution of this study was the development of a procedure for predicting the flow through the culverts and fill for various head and density differences across the causeway. The equations were developed mainly from regression analyses based on fill and culvert flow data gathered for the study.

Two additional models of flow through the causeway have been developed. Lin and Lee (1972) developed a Hele-Shaw model of seepage flow through the causeway and suggest that the model study, when coupled with field investigations, should provide all the information needed to assess the impacts of the causeway. Cheng and Hu have submitted a report for publication in the Journal of the Hydraulics Division of the American Society of Civil Engineers in which they present a mathematical model of a two-fluid flow system through a homogeneous porous media. Results of the numerical solution are correlated with that of a Hele-Shaw experiment.

The future elevation trends of the lake are not yet well established. Knowledge of the elevation fluctuation is important in planning the uses of the lake, especially for uses such as recreation which must cope with the continually changing location of the shore line. Thus, there is a need to establish a reliable lake elevation probability curve for present lake conditions. The Utah Division of Water Resources (1974) produced such a curve based on the 1901 to 1973 period. The main concern expressed during meetings with experts on uses of the lake was that this base period was not a true representation of historic lake levels.

The continued rise of the lake since 1963 has produced lake elevations which have damaged recreational, wildlife, and mineral extraction users of the lake. If the lake continues to rise it will cause extensive damage to these and other users. For this reason, finding the short and long-term means of alleviating high water damage is presently the top priority research need. Consultants hired by the Great Salt Lake Division (Austin, 1976) indicated there is a good probability the lake elevation will rise above the present level in the near future. The work by these consultants was viewed as preliminary and an in depth state of the art investigation of future trends of lake elevation was identified as a need.

The Great Salt Lake Division is presently looking for possible solutions of the flooding problem including:

1. Pumping brine to the west desert to increase evaporation.

2. Pumping brine into the north arm to decrease the south arm elevation.

3. Breaching the railroad causeway to decrease the south arm elevation.

4. Storage and use of water upstream to decrease inflow.

5. Export of water from the basin to decrease inflow.

The ultimate solution to both the short and long-term flooding problem may be a combination of several of the above measures. The effectiveness of these measures in controlling the lake elevation can be evaluated through an understanding of the water balance.

Proper management of the lake requires that the impact on social uses caused by implementing these solutions be understood so that the benefits of flood relief can be weighed against any adverse effects to users of the lake. The main impact would come possibly from changing the salinity characteristics of the lake. The Corps of Engineers is presently studying flood damage as a function of lake elevation.

Equally as important as extremely high water levels are extremely low levels. In 1963 the concern was that the lake would completely disappear. At the low level experienced in 1963 uses of the lake were affected due to the shore line receding from recreational facilities, land access to island rookeries, and the precipitation of salt changing the characteristics of the brine. Although not of immediate concern, research should be conducted on the possibility of future extreme low lake levels. An additional consideration is the loss of salt from the system at such times due to sediments being deposited over a precipitated salt crust. A layer of material such as decaying algae could impair the redissolving of the salt crust as the lake rose and essentially remove the salt from the lake. The loss of salt from the lake in this manner has not been addressed but may represent a real concern.

Consideration must be given to how the solution of either a high or low water elevation problem will affect the lake when a wet or dry cycle is reversed. This is possible when the response of the components of both the water and salinity balance can be predicted under varied hydrologic conditions.

Mineral extraction is the main social use influenced by the lake salinity. However, the salinity of the lake also has an impact on recreation, the brine shrimp industry, and the ecosystem, but identifying these impacts represents research needs.

The future salinity of the lake cannot be separated from the water balance. The annual inflow of total dissolved solids is small compared to the total load in the lake. Therefore, the surface and groundwater inflows combine with the precipitation to dilute the lake brines. Evaporation removes water from the lake and concentrates the brine. The salt balance for the north and south arms of the lake thus is principally a function of the exchange of brines through the railroad causeway, the vertical mixing of salt in the south arm, and the exchange of salt with the lake bed.

The chemical makeup of salinity inflow to Great Salt Lake has been investigated mainly by the USGS and Utah Geological and Mineral Survey (UGMS). Hahl and Mitchell (1963) present a compilation of data collected from July 1959 through June 1962 to aid in the definition of the chemical composition of streams, drains, and springs discharging into Great Salt Lake and, additionally, to define the chemical composition of the lake brine. Hahl and Langford (1964) continued the study and report on conclusions drawn from the above data.

During the 1964 water year more detailed data were obtained on surface inflow at sites closer to the lake shore. Hahl (1968) used these data to estimate the salt inflow at the lake shore for water years 1960, 1961, and 1964. The data for 1960 and 1961 were collected during low inflow and low lake stage years. The fact that data for high flow years were not included may affect the estimate of salt inflow to the lake which Hahl obtained. The present USGS basic data gathering project includes monitoring the quality of surface inflows. Determining the salinity of groundwater inflows represents a research need.

Mineral extraction accounts for the major output of salt from the lake. Since a royalty must be paid on salt extracted from the lake the yearly output is well documented (Searle et al., 1976). A small amount of salt leaves the lake each year by wind transport but the amount is apparently very small.

Prior to the construction of the railroad causeway the concentration of the brine in the lake was directly related to the lake stage (Glassett, 1974). Under present conditions (Figure 6), the north arm contains a well mixed concentrated brine. South of the causeway the lake is vertically stratified with a relatively dilute brine overlying a more concentrated brine. The lower brine represents about 10 percent of the total volume of the south arm. No data are available to establish if the lake was stratified before the causeway construction.

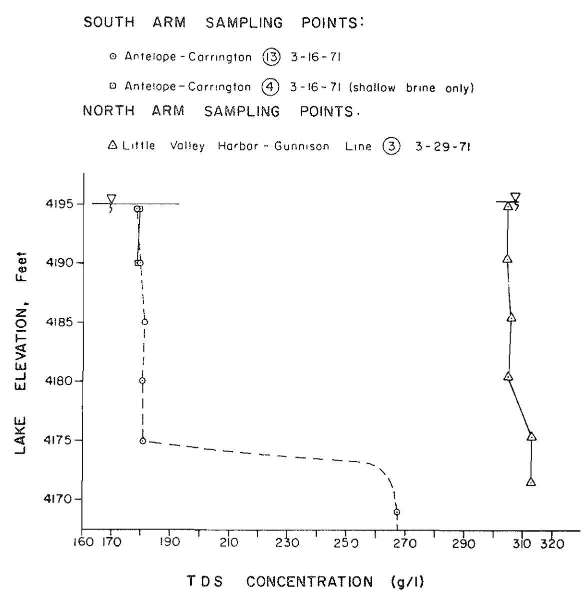


Figure 6. **Typical variation of total dissolved solids with depth for the south and north arm brines.**

The Utah Geological and Mineral Survey (UGMS) has had, since 1966, an ongoing program of sampling the brine and determining its ionic composition. The UGMS sampled on an irregular basis until 1973 when a quarterly sampling program was instituted. Presently when a station is sampled, samples are taken at the surface and at each 5 foot interval to the bottom. A complete set of data giving the total dissolved solids concentration on an ionic composition basis is available from the open files of the UGMS. Three reports have been published by the UGMS which analyze the chemical and physical variation of the brine from 1963 to 1973 (Hahl and Handy, 1969; Whelan, 1973; and Whelan and Petersen, 1975).

The concentration of the north arm brine is dependent on the exchange of brine through the causeway and the exchange of salt with the lake bottom. The UGMS data have shown the north arm brine to be well mixed. A salt layer which was present on the bottom of the north arm since the railroad causeway was completed had essentially redissolved by the spring of 1976 (UGMS, 1976). Waddell and Bolke (1973) and Jones et al. (1976) developed essentially the same equation for the redissolving of salt which would predict this to occur.

The salinity balance for the south arm is complicated by the vertical stratification and the mixing which occurs between the two brine layers. The lower brine apparently receives the inflow from the north arm through the causeway while the surface inflows to the lake enter the upper south arm brine. Flow northward through the railroad causeway is apparently upper layer dilute brine.

The future salinities of the north and south arms are dependent on the water balance for each arm, the exchange of brine through the railroad causeway, and the mixing and stability of the two south arm brine layers. Attempts have been made to predict the future salinity trends in the north and south arms of the lake. Glassett (1974) predicted the upper south arm brine will become more dilute each year. Waddell and Bolke (1973) included their equations of flow through the causeway in a preliminary water and salinity balance model of the lake. Using this model they found that the net movement of dissolved solids load through the causeway reversed under various rates of rising or falling lake stages. Jones et al. (1976) developed a water and salinity balance model of the lake which included Waddell and Bolke's causeway flow equations and allowed for the diffusion of salinity between the two south arm brine layers. They concluded the south arm upper brine had reached a point where the concentration varies above a fixed equilibrium. Both Waddell and Bolke (1973) and Jones et al. (1976) assumed the volume of the lower south arm brine was fixed. Glassett of Brigham Young University is presently formulating a method to predict the future chemical composition of the lake brine.

Flow through the railroad causeway is essential to understanding the salinity balance for each arm of the lake. Concern was expressed during meetings for the project that the flow equations developed by Waddell and Bolke (1973) may not accurately represent the present flow situation. The concern may be justified since the culverts are often plugged which partially or completely restrict the flow. Large quantities of material have been added to the fill to combat high water damage which may have altered the fill flows. The USGS continues to monitor the culvert flows but data are not being gathered on the fill flows.

Mixing of the two south arm brine layers and the stability of the lower brine layer are important components of the south arm salinity balance. Jones et al. (1976) estimated the average rate of mixing between the two layers from UGMS salinity data. Glassett is developing a model for predicting the amount of diffusion and mixing between the two brine layers.

Understanding the mechanisms which cause the south arm to be stratified and the forces which produce mixing of the two layers is important to predicting future salinity trends of the lake and, thus, the proper management of the lake. Understanding the origin of the lower south arm brine layer and why it persists would lead to an understanding of how changing the present system would affect the stratification of the south arm or perhaps cause the north arm to stratify.

The forces which cause mixing between the two layers must be understood to properly predict the consequences of altering the physical system. The mixing processes, which may be created by winds across the surface of the lake or turnulence created by the lake circulation, determine the salinity transport between the two layers under present or altered conditions. Proposed solutions to the present high water problem provide good examples of why we must have an understanding of the hydrologic systems and an ability to predict the consequences of altering the present system. Two proposals, pumping brine to the west desert and breaching the causeway, could change the characteristics of the present physical system.

Pumping a large quantity of brine to the west desert would be designed to reduce the volume of the south arm but in turn would, to some extent, change the water and salinity balance. However, the major impact on the salinity balance would probably be created by the return of the concentrated brine to the lake from the desert. Two factors must be considered in returning the brine to the lake; first, would the return brine mix with the lake brine or stratify, and second, what would be the effect on the salinity balance of returning the brine to the north or south arm. Consideration of both of these factors requires an understanding of the physical system advanced enough so that the effects on the salinity balance and stratification of the lake can be assessed. Any consequential alteration of the salinity balance would, of course, affect social uses of the lake.

Breaching the causeway would alter the exchange of brine through the causeway and thus the water and salinity balances of both the north and south arms. Again, the major consideration would be whether the brines would mix or cause stratification of the north arm or further stratification of the south arm. A layer of the less saline south arm water on the surface of the north arm would have the effect of increasing evaporation rates from this water surface.

The horizontal distribution of salinity in the lake is a function of the circulation patterns. No data are presently being gathered on circulation. Jones et al. (1976) developed a model which could predict the distribution of water quality constituents if circulation data were available. Watters and Kincaid of Utah State University are presently involved in a project which will have the ability to predict steady state circulation patterns in the lake. Verification of their model for Great Salt Lake is dependent on the gathering of data on general circulation patterns, point measurements of velocity with depth, brine temperatures, and any fluctuations of the interface between the south arm brines. Work on understanding the mechanisms which produce the present circulation patterns should lead to an ability to predict how the circulation would be changed by the construction of additional dikes and causeways in the lake.

The ionic makeup of the lake brines is being studied by the UGMS. The UGMS brine sampling program provides a record of the ionic makeup of both arms of the lake. Jurinak of Utah State University has developed a model which is capable of predicting the ionic makeup of the north arm at various lake levels. He is working on including heavy metals into the model. His goal is to develop a general model applicable to the entire lake.

Biotic System

The total number of species which inhabit the waters of Great Salt Lake is limited due to the harsh environment created by the high brine concentration. Organisms found in the lake include bacteria, green and blue-green algae, diatoms, protozoa, corixid, brine shrimp, and brine flies. In addition, forms typical of fresh water are found in the lake on occasion, but it is believed that these are extraneous forms which have been carried in with freshwater and probably survive only short periods of time. An excellent discussion of the present knowledge on life form in and around the lake is found in Rawley et al. (1974).

Much of the biological work on the lake was done in the 1930s. Flowers (1934) found four species of blue-green algae and two species of green algae. Kirkpatrick (1934) cultured lake waters in the laboratory in an attempt to separate native from extraneous algae forms. She reported 13 species of algae as well as some protozoa. Patrick (1936) identified 24 genera and 62 species of diatoms from lake bottom samples. Eardley (1938) reviewed the literature on life in the lake and listed the brine shrimp, three flies, five protozoa and 13 species of algae. ZoBell et al. (1937) worked on the bacterial flora of the lake. This type of work performed prior to the construction of the railroad causeway probably still applies to the south arm.

Stephens and Gillespie (1972) identified the basic components of the south arm ecosystem. They identified two energy flow sytstems with only minor interactions: A planktonic system consisting of algae, brine shrimp, and several protozoa and bacteria; and a benthic sequence consisting of the blue-green algae, detritis, and the brine fly larvae. The only outflow from either system occurs when birds feed on brine shrimp and brine flies and when adult brine flies leave the lake. The authors express concern that the toxic effect of many substances presently inflowing to the lake may reach concentrations where they effectively eliminate the flora and fauna of Great Salt Lake.

Porcella and Holman (1972) studied the nutrients in Great Salt Lake and the influence of these nutrients on algal growth. The relation between food supply (algae) and the growth of brine shrimp also was studied. The study results indicate the relation between inorganic nutrients, algae, and brine shrimp. They concluded that inorganic nitrogen is apparently the limiting factor for growth.

Forthcoming publications by Stube, Post, and Porcella (1976) of Utah State University contain information on the ecosystem and nitrogen cycle of the north arm. Stube's work indicates a relatively simple ecosystem in the north arm composed of four groups; the algae, the bacteria, the brine shrimp, and the brine fly. He provides information on the biomass of each group, the interactions between groups, and the importance of organic matter and ammonia as nutrients.

Research on the lake ecosystem is encouraging. The remaining research centers on quantitatively defining the interactions between organisms, organisms and the environment, the water quality-ecologic relationships, and the various factors which can disrupt the ecosystem. The growth rates of organisms and the rate of grazing of one organism on another need to be made and the effect of environmental factors such as salinity and temperature on these rates need to be identified. Society can influence the system by supplying nutrients and toxicants. The nutrients supply energy to the system which in abundance can produce dominance by a specific organism or species and disrupt the entire ecosystem. Toxicants may repress growth, cause death, or interfere with reproduction at any level of the ecosystem. The effects of proposed alterations of the present system cannot be assessed until a knowledge of the effects on the ecosystem of changing the salinity of the lake, or adding nutrients, toxicants and other pollutants is available.

The brine shrimp and brine fly are two main organisms of concern to other users of the lake. The cause of the reduced brine shrimp winter eggs hatch needs to be studied. The reduction may be related to a shift in the reproductive process of the brine shrimp or may indicate a possibly more severe problem of a decline in the brine shrimp population. Related to this, research needs to be performed on the tolerance (survival) of brine shrimp at various salinity levels and the conditions which cause the shrimp to produce viable winter eggs. Eliminating the brine shrimp could create serious water quality problems because they filter algae from the lake.

The brine fly is very important as waterfowl feed but must be controlled in certain recreational areas. A research need is to identify the dominant species and population of flies produced at various salinity levels. Collins of the University of Ontario and the University of Utah is involved in a three year study of the most important species of brine fly in the lake. If the interactions between the brine fly, the ecosystem, and the lake enviroment can be defined methods of control which do not severely disrupt the ecosystem can be identified.

Presently the major social uses of the lake affected by its ecosystem are the brine shrimp industry, recreation, and wildlife. Possible impacts between the ecosystem and the mineral extraction industry and recreation, besides the noxious insect problem, need to be identified so that the effect of disrupting the present ecosystem on these uses can be understood. For example, dominance of the ecosystem by algae could create a situation where their concentration would discourage swimming in the lake. A complete list of research needs identified for the biotic system is given in Table 10.

Water Quality Aspects

The hydrologic characteristics of Great Salt Lake amplify the water quality considerations. Being a terminal lake there are few outflows for pollutants carried into the lake and the continual buildup of pollutants must be addressed. The ultimate level of various pollutants which the ecosystem and lake users can tolerate is thus important. Because of the diversified uses and the unique hypersaline conditions, it has been difficult for the state to determine a set of water quality standards for the lake.

The water quality of the lake inflows is monitored by the USGS, the Environmental Protection Agency, and the State Division of Health. Thus, the quality of the inflow to the lake is fairly well documented. Currently there is not systematic gathering of water quality data within the lake except for total dissolved solids and its ionic components. A few short term data collection projects are reported in the literature which were concerned mainly with obtaining information on other water quality parameters of the lake. Lin et al. (1972) reported on detailed vertical profiles of temperature, dissovled oxygen, conductivity, and pH values measured at 17 south arm stations during the summer of 1972. This was the first detailed study of the vertical variation of these parameters. The authors reported typical values of dissolved oxygen for the upper brine layer as 3.5 ppm to 1.5 ppm and "invariably" zero for the lower brine layer.

The Kennecott Copper Corporation in cooperation with the UGMS has taken an initial look at heavy metals pollution of the south arm and their findings will be available as a forthcoming report. This study charted the present inflow of heavy metals from all the streams, established the concentration of heavy metals in the brine and sediments at 12 locations in the lake, and looked at the chemical fate of heavy metals in the lake. The results of this study should provide direction for future research and data needs on heavy metals.

As part of the Weber River 208 Water Quality Study, data are being gathered on the water quality of streams in the study area, the changes of water quality which occur in the marsh lands, and the distribution of water quality parameters in the lake. Water quality data are being gathered in Farmington Bay and near the Antelope Island and south shore recreational beaches. Researchers involved with this study realize they are only touching the surface of the entire lake pollution problem but hope the study will indicate the extent of the water quality problem and help in identifying what is most important to study in the future.

This type of data gathering needs to be expanded to the entire lake so that present and potential water quality problems can be identified and research in the water quality area given direction. Due to the present lack of information regarding biological and chemical processes in the system, it is difficult to

Table 10. Research needs identified for the biotic system.

Research Needs	Possible Information Source
Group A	
A quantitative definition of interaction between organisms and organism growth rate.	F. Post (USU), D. Porcella (USU)
Population dynamics for the lake ecosystem.	F. Post (USU), D. Porcella (USU)
The relationship between lake salinity conditions and the ecosystem.	F. Post (USU), D. Porcella (USU)
The toxic effect of pollutants at various concentrations (buildup in the lake) on the ecosystem.	F. Post (USU), D. Porcella (USU)
Methods to control brine flies and other noxious insects.	D. Rees (U of U), N. Collins (U of U)
Cause of reduced brine shrimp winter egg hatch and relation to brine shrimp population.	F. Post (USU), D. Porcella (USU), Saunders Brine Shrimp Co., Salt Lake City, Utah
Group B	
Define the relationship between the lake's aquatic community and the marsh land community.	UWRL
Brine fly life cycle and species dominance at various salinity levels.	N. Collins (U of U)
Impact of oil spills on the ecosystem.	Oil Companies
Energy flow system for the marsh land ecology.	UWRL
The effect on the ecosystem of increasing the nutrient input to the lake.	UWRL

predict the water quality impacts between the physical system and the social use system. However, general considerations based on uses of the lake can be identified.

Recreational use areas should be free of pathogenic organisms and odors produced by the anaerobic decay of unstabilized organic material. Pathogenic or disease organisms originate from human wastes and enter the lake via inflows or human contact. Research needs related to pathogenic organisms include studies of the survival of coliform bacteria and human virus at different salinity concentrations, the present distribution of these organisms in recreational areas, and their sources.

Anaerobic decay occurs when organic materials are decomposed in the absence of oxygen. A product of anaerobic decomposition is hydrogen sulfide gas which has a distinctive rotten egg odor. Anaerobic decay occurs in the benthic deposits of most lakes. The low oxygen content of the lake brines increase the likelihood of anaerobic conditions developing. The complete process of organic material decay in the salt lake needs to be studied. Such studies should include identifying the present sources of organic material and their distribution in the brine and bottom sediments, the aerobic and anaerobic decay rates, and the dissolved oxygen supply in the lake.

The main requirement of the mineral extraction industry is a high salinity brine. The south arm salt companies, however, have discounted the use of the deep south arm brine because they do not feel a pure salt can be produced. The lower brine is known to be fetid by hydrogen sulfate gas which probably could be solved by aerating the brine. The water quality parameters which make the brine unusable need to be identified. This water quality problem is especially important if future trends of the lake showed the volume of the lower south arm brine was going to increase significantly.

Any construction in the lake has the potential of altering the water quality. Construction of facilities to support recreation and mineral extraction may disturb the benthic deposits and adversely affect the water quality. This potential impact should be understood. The construction of dikes and causeways may change the long term circulation patterns in the lake and impact on the distribution of pollutants. Because the physical transport of pollutants plays a major role in their distribution research should be conducted to define the present circulation patterns and to develop a method of predicting any changes in circulation patterns which would result from construction in the lake.

The ecologic balance of the lake could be upset by pollution. Heavy metals, pesticides, and herbicides could disrupt the ecosystem at various points. Research must be conducted to understand the potential effect of these and other pollutants on the viability of the ecosystem.

Nutrients directly affect the lake ecosystem. When the system is not overloaded nutrients can be very beneficial to the ecosystem, while excessive nutrients could overload the system and disrupt the ecosystem. Determining the role of nutrients in the ecosystem and the concentration which would overload the system represent research needs.

Water quality standards are difficult to set for the lake because with the hypersaline conditions ordinary fresh water standards do not apply. However, it is important that reliable methods of water quality analysis be researched and standard methods for water quality analysis be established so that results of water quality studies on the lake can be compared. The chemists at Kennecott have done some work along this line.

The research needs identified for the water quality aspects of the physical system are listed in Table 11. The research needs are not listed in priority groups because this is not appropriate until the extent of the lake pollution problems are identified.

Research Needs for Farmington Bay

Farmington Bay is a shallow portion of the lake lying east of Antelope Island. The bay is separated from the main body of the lake by causeways between the mainland and the north and south ends of Antelope Island. The exchange between the lake and the bay is thus limited and the bay has the potential of becoming a freshwater body. Recreational and wildlife uses of the bay have been proposed. However, the water quality of the bay will have a large and perhaps controlling impact on the future uses of the bay.

Background

Several attempts have been made to construct a permanent fill from Syracuse to the state park on the north end of Antelope Island. The causeway has been severely damaged several times due to the rising lake stage but has been rebuilt to a higher elevation and survived the high water during the spring of 1976.

A private causeway connects the mainland to the south end of Antelope Island. Several sections of this road were lost during the spring of 1976 which allowed the water in Farmington Bay to flow into the lake around the south end of the island. Because the causeway sits on a strip of high ground, this flow will probably be eliminated if the lake recedes much below its present level.

The Antelope Island causeway is the main impediment to circulation between the bay and the lake. The free flow exchange across the causeway passes beneath a 30 meter clear-span bridge situated near the island. Salinity observations made in the bay when predecessors to the present causeway were intact indicated the bay would tend to freshen with the Antelope Island causeway in place and flow restricted around the south end of the island (Coburn and Eckhoff, 1972, and Meide and Nicholes, 1972).

The bay has serious water quality problems which must be addressed in considering the use of the bay. The water quality is affected by the past as well as the

Table 11. Research needs identified for the water quality aspects.

Research Needs	Possible Information Source
Identification of the present and potential water quality problems; especially heavy metals, pesticides, herbicides, pathogenic organism, and organic material in the form of biochemical oxygen demand.	DH, UGMS
Field and laboratory investigations of biological and chemical reactions which occur in the lake including possible formation of toxic heavy metal compounds.	DH, UGMS, UWRL, U of U
The length of survival of pathogenic organisms in the lake brine at various salinity concentrations.	DH, UWRL, U of U
The aerobic and anaerobic decay rates.	UWRL, U of U
The water quality parameter which makes the lower south arm brine unusable for salt production.	UGMS
The effect of pollutants on the lake ecosystem.	DH, Post (USU), UWRL, U of U
Methods of water quality analysis for the hypersaline conditions.	DH, EPA, Kennecott Copper Corp.
The salinity level at which fresh water standards apply.	DH, UWRL, U of U
The effect of construction in the lake on water quality by disturbing the benthic deposits or altering the circulation pattern.	DH, UWRL, Watters (USU)
Any changes in water quality which occur in the marsh lands.	DH, UWRL, DWLR
Projected waste inflow to the lake.	EPA, DWR

present water quality inflows. Prior to 1965 raw sewage from Salt Lake City was discharged into the Jordan River and carried into the bay. Since 1965 the water quality of the Jordan River has been improved but the river still transports a significant amount of pollution into the bay. Additional problems were created by the construction of the Salt Lake Sewage Canal which discharges into the bay. As a result, bottom sediments are high in unstabilized organic materials. The range of potential impacts of the organic layer, other pollutants in the bay, and the pollutants presently carried into the bay have not been defined.

Planning the future use of Farmington Bay requires that the interactions between proposed uses of the bay and the physical system, especially water quality, be addressed. Thus, the desire for particular uses of the bay must be identified along with the physical system characteristics which are necessary for those uses. Associated research must be conducted on the physical system to identify present characteristics; such as water quality, salinity, and elevation; and to gain insight into how these characteristics might change in the future. This will allow the extent of conflicts between desired and actual system characteristics to be assessed. The desire to accommodate a particular social use may lead to additional research if conflicts between desired and actual system characteristics exist and it appears to the decision-maker that altering the physical system will eliminate the conflict. The understanding of the physical system will allow the feasibility of altering the physical system to accommodate particular uses to be tested and the impact of altering the system on social uses of the bay and the lake to be assessed. While potential conflicts cannot be assessed until the physical system and social uses of the system are defined, discussing suggested uses of the system will emphasize the need for research on both the physical and social use system.

Farmington Bay provides a good example of the importance of timing and coordination between research on the physical system and social uses of the system. An example of research timing using Farmington Bay is given in a later section of this chapter.

Social Use Systems

Recreation and wildlife have been suggested as potential uses of Farmington Bay. A research need is to identify any other potential uses of the bay. The Great Salt Lake State Park provides access to the bay and is a natural hub for proposed recreational development. Salt water recreational activities can be accommodated from the north and west portions of the park. With adequate opportunities for salt water recreation coupled with the tendency of the bay to freshen, Farmington Bay has been suggested as a possible area for freshwater sports.

Research needs related to the potential recreational uses of the bay deal with identifying the recreational opportunities and associated facilities desired by potential users of the bay and the use intensities which would result if the facilities and conductive environmental conditions were provided. The Institute for the Study of Outdoor Recreation and Tourism is currently conducting a survey concerning the state park on Antelope Island which identifies development desires. A study of this type should be conducted to identify the public's desire for fresh water or other types of recreational activities on Farmington Bay.

Power boating, water skiing, sail boating, and swimming are the main activities associated with freshwater recreation. Swimming, no matter what the salinity of the water, requires a situation with a low health hazard from pathogenic organisms, algae concentrations low enough not be objectionable, minimum odor problems, and the control of noxious insects.

Power boating would require the salinity level of the bay to be below a concentration which would damage motors. Predicting the probability of the bay being below a specific concentration requires an understanding of the present water and salinity balance of the bay. Both water skiing and power boating could be curtailed if an over-abundance of algae, floating debris, or noxious odors persisted in the bay.

Because of the shallow nature of the bay, power boating could impact on the physical system by disturbing the benthic deposits which would add to the unstablized organic load of the water. This could result in the development of anaerobic conditions and associated odor problems.

Freshening of Farmington Bay is not a factor in the use of the bay for sail boating. However, algae, floating debris, and noxious odors would have to be considered undesirable system characteristics for this use. In addition, even at the present higher than average water-levels, mud bars and shallow water depths in the bay are a problem for power boats. In this respect, sail boating would be even more difficult than power-boating and the problem would be worse at lower water levels.

The physical system of Farmington Bay could also have an impact on recreational development around the lake. The production of noxious odors or noxious insects in the bay could detract from the recreational value of the state park on Antelope Island and perhaps even the south shore area.

Thus, physical system characteristics desirable for the recreational uses include; a low health hazard from pathogenic organisms, low algae concentrations, minimum odor problems, control of noxious insects, and a minimum of floating debris. Identifying the remaining system characteristics desirable for recreational uses such as salinity levels and water depths are some of the research needs.

Waterfowl is presently the major user of Farmington Bay. The Farmington Bay Bird Refuge and many private hunting clubs are located at the mouth of the Jordan River. Presently, the main concern of the wildlife system is the damage created by high water. Solutions of the high water problems for the entire lake should alleviate high water damages in the bay. However, the hydrologic interactions between the bay and the lake should be established to assess the effectiveness of elevation control measures for the main body of the lake in controlling the elevation of the bay.

Physical system characteristics for waterfowl use of the bay deal mainly with the surface elevation. The desired surface elevation for waterfowl is at or below 4196 feet (Rawley et al., 1974). This elevation allows the marsh lands to expand below the diked areas. Since botulism has been associated with anaerobic conditions and water level fluctuations, these would have to be considered undesirable system characteristics for the use. Research should be performed to identify additional system characteristics required for wildlife use.

Intrusion of people into waterfowl areas creates a conflict between the recreational and wildlife use systems. If the water quality of the bay will allow development of both uses research may be appropriate on determining ways to avoid or reduce such conflicts. The control of the lake elevation below 4196 could have an impact on recreational uses of the bay. Researching the effect on recreation of holding the lake at a specific elevation would not be appropriate until it was determined if the characteristics of the present physical system were suitable for or could be manipulated to accommodate recreational uses. However, this does indicate that, like planning, research is an ongoing task. If it were determined that the physical characteristics of the bay could accommodate both recreation and wildlife uses, further research on each social use would be appropriate so that the impact, and thus the trade offs, of altering the system to accommodate a particular use could be assessed. Research needs identified for the social uses on Farmington Bay are given in Table 12.

Physical System

The proper understanding of the physical system provides the background required to test the feasibility of proposed uses of the bay, to ascertain how the bay might be altered to accommodate particular uses, and to assess the impacts between the physical system and the social use systems.

Hydrologic System

The componets of the water balance for Farmington Bay are the surface and groundwater inflows, precipitation, evaporation, and exchanges with the south arm of the lake. The main surface inflow to the bay is the Jordan River whose quality and quantity are documented. A current USGS basic data gathering project should help further in defining the surface inflows, precipitation, and evaporation from Farmington Bay. Identification of the groundwater inflow to the bay represents a research need.

Free flow between the bay and the south arm of the lake occurs beneath a 30 meter clear span bridge in Antelope Island causeway and around the south end of Antelope Island. The flow at the south end of the island will be eliminated if the lake level recedes or if the causeway is rebuilt. However, this flow should not be ignored and the future of the causeway should be established. Depending on the future of the causeway it may be appropriate to gather flow data.

Flow through the present Antelope Island causeway has not been studied. A two directional flow was observed through the culvert of an earlier causeway

Table 12. Research needs identified for the social uses of Farmington Bay.

Research Needs	Possible Information Source
Group A	
Identify any potential uses of the bay in addition to recreation and wildlife.	All state agencies
Physical system characteristics necessary for both fresh and salt water recreational uses.	DPR
Physical system characteristics necessary for wildlife uses.	DWLR, FWS
Present physical system characteristics, particularly water quality.	Weber 208 Study, DH, UGMS
Recreational opportunities and associated facilities desired by potential users of the bay and the use intensities which would result if these facilities were provided. The study should include the public's desire for freshwater recreation in Farmington Bay.	DPR, ISORT, UDOT
Economic analysis of various social uses of Farmington Bay.	UUBEBR, UWRL, BYU, UDOT DNR, DWR, DPR, DWLR, DSL, UGMS, DH

(Coburn and Eckhoff, 1972). South arm brine was observed to flow into the bay beneath the outflow from the bay to the lake. The culvert flows are not being gaged. The causeway is assumed to be impermeable but no measurements have been made.

The salinity balance for Farmington Bay may be as complex as that for the south arm of the lake. Salt enters the bay in the surface inflow, groundwater inflow, and any inflow to the bay through the Antelope Island causeway or breaches in the causeway at the south end of the island. Salt flows out of the bay through the causeways. Data gathering concerning the quantity and salinity of groundwater inflows and flows through the causeway represent research needs.

Sudweeks (1965), Carter (1971) and Coburn and Eckhoff (1972), all reported a two layer salinity stratification in the bay. Data on stratification of the bay under present conditions have not been gathered but these previous data would indicate the bay is now or probably will become stratified. The stability of the volume and concentration of the lower brine layer and the rate of mixing between layers will have to be determined in order to assess the importance of the lower layer and the brine inflow to the bay from the south arm in the salinity balance. The research needs identified for the hydrologic system are given in Table 13.

Biotic System

The salinity balance for Farmington Bay is important to the future ecosystem of the bay. As the bay freshens a multitude of organisms which could not survive in the lake brine will be able to exist in the bay. The future salinity will contribute to determining which organisms will prosper. The ecosystem will directly influence future uses of the bay. An over abundance of algae or coliform bacteria would discourage or eliminate boating and swimming as potential recreational uses. Understanding the future salinity trends of the bay is important to understanding the future ecology of the bay.

The experts in biology which attended the meetings on research needs (see the appendix) felt enough information was available to assess which organisms could survive in Farmington Bay at various salinity levels. The main research needs for the biotic system deal with identifying the future population of organisms, species dominance, and the interaction between the ecosystem and pollutants presently in the bay or pollutants which will be added in the future. The future population of specific organisms will be influenced by the supply of nutrients to the system from external and internal sources, such as the benthic deposits, and the level of toxic materials such as heavy metals, pesticides, and herbicides.

The freshening of Farmington Bay could increase the population of brine flies. The salinity conditions which develop in the bay may be more favorable to their production. Since the bay is close to the major recreational use areas on Antelope Island and the south shore, a research need is to look at the species and population of brine flies which will be produced in Farm-

Table 13. Research needs identified for the Farmington Bay hydrologic system.

Research Needs	Possible Information Source
Group A	
The quantity and salinity of the two directional flow through the Antelope Island causeway.	USGS
The relationship between the hydrologic system of the bay and the entire lake.	DWR, UGMS
The salinity stratification of the bay. If the layer is present, research the stability of the lower layer, and the rate of mixing between the two layers.	USGS, Glassett (BYU), UWRL
Methods to control high water (flooding) in the bay in both the short and long-term.	DWR, ACE, UWRL
Group B	
The quantity and salinity of groundwater inflow.	USGS
The quantity and salinity of the flow around the south end of Antelope Island.	USGS
Group C	
Permeability or flow through the Antelope Island causeway fill.	USGS, DWR

ington Bay at various salinity levels. The biotic system research needs are listed in Table 14.

Water Quality Aspects

Water quality is presently the top priority research need for the physical system. The present and future water quality of the bay will influence and perhaps eliminate certain potential uses. The initial need is to assess the extent of the current water quality problem. As part of the Weber River 208 Water Quality Planning Study preliminary data are being gathered on the present water quality of the bay. The data gathered for the study will hopefully indicate the extent of the water quality problem and help in identifying areas where further study is needed. The future water quality of the bay will be influenced by the salinity. For example, the survival of coliform bacteria and the concentration of dissolved oxygen both decrease with increasing salinity.

Potential uses of the bay also indicate what water quality parameters should be investigated to assess the impact on social uses of the present or future water quality. Recreational swimming, no matter what the salinity, requires the bay or swimming area to be relatively free of pathogenic organisms. Meide and Nicholes (1972) studied the occurrence of coliform bacteria in the bay. They proposed that the unstabilized organic material deposited in the bay harbor coliform bacteria and provide nutrients for the bacteria which contribute to the potential health hazard. The present distribution of coliform bacteria, the link with the sludge deposits on the bottom, and their survival at various salinity levels of the bay should be researched.

The present nutrient levels in the bay may be sufficient to create an over abundance of algae which would detract from swimming, water skiing, and power or sail boating. The potential impact the supply of nutrients has on the bay identifies data on the inflow and present distribution of nutrients as a data need.

The potential for anaerobic decay and the associated production of noxious odors could impact on recreational uses of the bay and the Great Salt Lake State Park. The bottom sediments by themselves provide the potential for anaerobic conditions to develop. This problem may be accentuated by the increased rate of decomposition in fresher water, the additional stress put on the dissolved oxygen supply by inflowing organic wastes, and the resuspension of organic wastes from the bay bottom. The bottom sediment can be disturbed by natural wind mixing, power boating, or the feeding habits of carp.

Anaerobic conditions and resuspension of bottom sediments could also impact on the waterfowl use of the bay. Anaerobic conditions have been associated with avian botulism. The resuspension of bottom sediments contributes to the development of anaerobic conditions and the associated turbid conditions limit the production of waterfowl feed.

Determining the extent and composition of the bottom sediments represent research needs. Preliminary samples (Carter, 1971) indicate the sediments are rich in organic materials. Methods to bring the organic load of the bay in line with proposed uses may create the need to investigate methods to remove organic material from the bay, such as by the use of carp or catfish.

If properly managed, Farmington Bay has the potential to protect the water quality of the lake. The relationship between the lake and the bay therefore, should be established.

Table 14. Research needs identified for the Farmington Bay biotic system.

Research Needs	Possible Information Source
Group A	
Population dynamics and species dominance for the bay ecosystem at various levels.	Winget (BYU), Bauman (BYU), Post (USU)
Interaction between nutrient levels in the bay and population dynamics.	Winget (BYU), Bauman (BYU), Post (USU)
The toxic effects of present and future levels of heavy metals, pesticides, and herbicides	Porcella (USU), Adams (USU)
The species and population of brine flies which will be produced in the bay at various salinity levels.	Collins (U of U)
Algae baseline study.	Winget (BYU), Post (USU) UWRL
Future salinity trends of the bay.	DWR, USGS, UWRL
The effect on the ecosystem if the bay freezes.	UWRL

The research needs listed in Table 15 for the water quality aspects of the system deal mainly with identifying the present water quality characteristics of the bay. This is an important research need for Farmington Bay and should involve at least a year of monitoring the inflow and distribution of the important water quality parameters. Sampling for a minimum of a year is required to properly describe the seasonal variation in the water quality parameters. The water quality parameters listed in the table are tentative. The results of the water quality sampling of the bay for the Weber River 208 study should reveal further water quality parameters which are important to monitor in an extended sampling program.

When this is coupled with research on the social uses to identify the system characteristics favorable for specific uses the result may require the initiation of further research. The logical sequence of research after the identification of the characteristics of the present physical system, the possible social uses of the bay, and the physical characteristics of the system desired for each possible use that have been identified are outlined in the next section.

Research Needs and Priorities in the Comprehensive Plan Development

The development of a comprehensive plan for a complex system such as Great Salt Lake involves an iterative process between the decision-maker and research on the physical and social use systems. Through this iterative process a multitude of potential use combinations are narrowed down to a single flexible plan. The final plan is arrived at by eliminating infeasible uses and selecting a mix of the feasible uses which will maximize the benefits to society from the limited resources of the system. Flexibility is required for the final plan because changing lake conditions in the future and shifts in use patterns may create the need to reexamine and perhaps alter the comprehensive plan. For example, methods to alleviate high water damage were not a consideration in 1963 when the lake was at an all time low.

Farmington Bay will be used as an example in the following pages to provide insight into the development of a comprehensive plan for a real system. The discussion should in no way be viewed as a recommended management plan for the bay since it involves many assumptions about the characteristics of the physical system.

Alternative plans for using the resources of the system create the need for research on both the physical system and social uses of the system. Research must be conducted to establish the public's desire for proposed uses, the feasibility of the system to support the uses, and the impacts on other uses if alteration of the physical system is required to facilitate a particular social use.

The first step in the planning process is to identify the potential uses of the system. This constitutes the initial step in developing alternative management

Table 15. Research needs identified for the water quality aspects of Farmington Bay.

Research Needs	Possible Information Source
Group A	
Assess the extent and spatial variation of the current water quality problems by sampling the water and bottom sediment. The following water quality parameters definately should be included: Biochemical oxygen demand, dissolved oxygen, chemical oxygen demand, temperature, pH, the major nutrients, heavy metals, pesticides, herbicides, and pathogenic organisms.	Weber 208 Study, DH, UGMS
The present inflow of the above water quality parameters especially from the Jordan River.	DH, USGS, EPA
Identify the aerobic and anaerobic decay rates for the bay at various salinity levels.	DH, UWRL
Future salinity trends of the bay.	DWR, UWRL
The relationship between algae growth and nutrient supply in the bay.	UWRL
The relationship between the water quality of the bay and the lake and how the bay could be managed to protect the water quality of the lake.	UWRL
Group B	
The feasibility of using biological methods such as the harvest of carp or catfish to remove organic material from the bay.	DWLR, FWS
The effects of power boating on the water quality of the bay.	DPR, UWRL, UDOT
The effects of the introduction of carp on the water quality of the bay.	DWLR, FWS

plans for the system in that only the potential uses deemed feasible will be considered further. Recreation, especially fresh water activities, and wildlife have been suggested as potential uses of Farmington Bay.

Mineral extraction has not been suggested as a potential use due to the low salinity and the lack of desire by industry to use the bay for this purpose. For discussion purposes, recreation and wildlife will be considered the only potential uses identified for the system. Alternative development plans then involve only recreational and wildlife uses.

This does not indicate that both uses will be included in the final recommended plan. Rather, it indicates that with the present knowledge of the system both uses appear feasible. This may not be the case as more data become available on characteristics of the physical system. If the water quality of the bay is as poor as expected, fresh water recreational uses may not be feasible unless a way is found to upgrade the conditions. The vital point is that in the planning process the consideration of a use continues until the decision-maker deems the use infeasible or not desired by the public.

Table 16 illustrates the role of research in the comprehensive plan development. The table is divided into three levels corresponding to the hierarchical structure depicted in Figure 4, namely, the decision-making process, the social use systems, and the physical system. The time axis in Table 16 is broken into time periods which may represent one to several months. The time periods are used only to indicate that the various stages of planning may require different lengths of time and that specific research and decisions must be carried out in a logical and systematic order.

Basic research on the physical system can be justified before specific alternative development plans are developed. Certain baseline information will help in determining the feasibility of the system to accommodate a proposed use and provide insight into further research needs once alternative development plans are proposed. As indicated in the previous discussion of research needs for the bay, basic research is needed to describe the present hydrologic, biotic, and water quality aspects of the physical system. Basic considerations of wildlife and recreational uses of the bay indicate the general physical system characteristics which must be considered. Once alternative recommended plans are available, greater insight into research needs and priorities is provided.

Not yet considered are the social demands for particular uses of the system. As indicated in Table 16, research on the social uses is necessary in the early stages of the planning process. Research at this stage deals with assessing the public's desire for the recreational and wildlife facilities, the use intensities which would be made of the facilities if developed, and the physical system characteristics required for each proposed use.

The information gathered on the proposed social uses serves two purposes. First, it establishes the desire of the public for specific developments and, second, the information aids the development of alternative management plans for the system. The research on the social use systems may indicate to the decision-maker that, as with mineral extraction, the desire for the proposed uses indicates that the use should be dropped from further consideration. For example, it may be determined that the demand for power boating was insignificant with the public preferring to use Willard Bay or upstream reservoirs. Further research involving power boating on the bay would thus be eliminated.

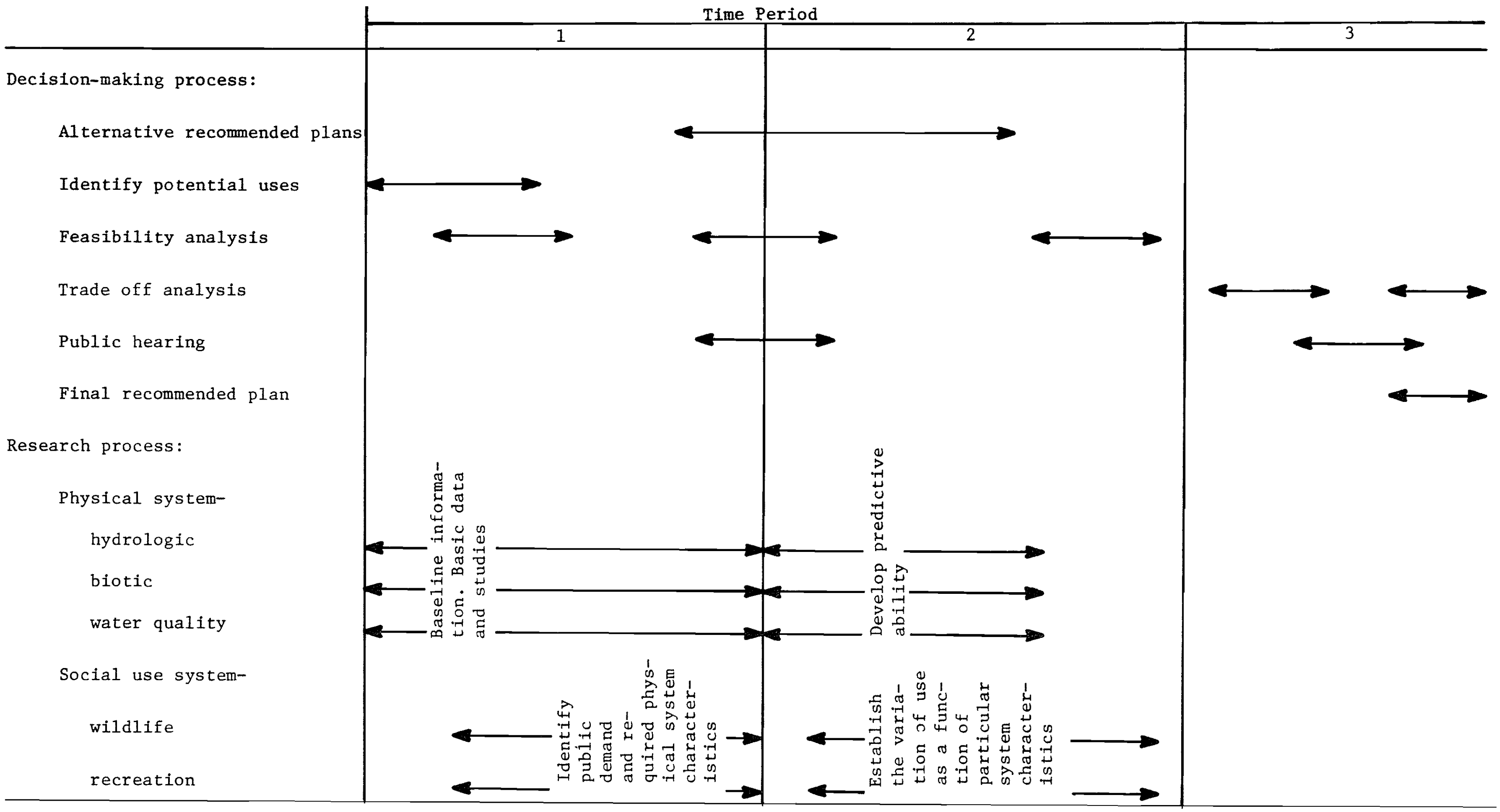
Elimination of a proposed use due to the lack of demand by society would eliminate the need to gather some of the baseline information. The converse is true if the baseline information indicates to the decision-maker that a proposed use is not feasible. For example, if the baseline data indicated the ionic makeup of the salinity was such that salt water fish could not survive in the bay, research on the social desire for a salt water fishery would be unnecessary.

The overlap between research on the physical feasibility and public demand for facilities creates the situation where ongoing research may become useless. This situation is difficult to avoid since the future of proposed uses of the system depends on both demand and feasibility. However, proper timing eliminates situations where research becomes useless because it was not properly sequenced. Such a situation would occur if research on conflicts between power boating and wildlife were undertaken before the demand for boating on the bay was established.

For discussion purposes, suppose both wildlife and recreational uses were feasible. That is, the decision-maker concluded that the public desired both marsh land development for waterfowl and recreational development to facilitate power boating, water skiing, and swimming. Additionally, assume that from the baseline data on the physical system it appeared to the decision-maker that conflicts between present system characteristics and required social use characteristics could be eliminated by altering the system.

At this point further research would be improper without considering alternative recommended plans. The alternative plans may already be formulated before this point and have given guidance in the baseline data gathering.

Table 16. The timing of research in comprehensive planning.



For a given alternative development plan a set of research needs and priorities can be identified. The research needs and priorities are not necessarily the same for different alternative development plans. A plan to enhance the waterfowl use of the bay by controlling the water level would require research on the hydrologic system. Similarly, a plan to enhance recreational uses would require research in the water quality area.

A management policy is imposed upon the physical system in order to produce a particular set of conditions. While such conditions might be desirable in terms of a particular social use, the same conditions might represent disadvantages to other social uses. The ability of a management plan to produce a given set of conditions and the ability to predict the impact these conditions will have on other social uses creates the need for research on both the physical and social use systems. For this reason, a predictive ability for the physical system must be developed so that future hydrologic, biotic, and water quality trends can be forecast under either present or altered physical conditions. Research on the social use systems at this stage would involve establishing how the use of the system would vary with changing system characteristics. An example would be developing the relationship between power boat use on the bay and the water depth, salinity, algae concentration, and level of noxious odors.

The research needs and priorities at this stage are dependent on the alternative plans proposed and the methods suggested to achieve the goals of the alternative plans. All the plans require the development of a predictive ability to assess how proposed alterations of the system effect the physical system characteristics and thus impact on the social uses. Figure 7 illustrates how the development of the predictive ability draws on the baseline information while identifying additional research needs. As indicated in the figure, an alternative plan may create the need for additional basic research or specific research necessary in the development of a predictive ability for the physical system. The complexity of the predictive ability necessary to evaluate the impact of alternative plans depends on both the complexity of the plan and the potential impacts on the system.

The final management plan is selected by means of some form of optimizing process which involves evaluating the trade offs between proposed uses under alternative development plans. The final plan is usually selected because it provides the optimal resource use from the system. For this reason, the decision-maker should not be hasty in selecting an alternative plan just to identify research priorities and get the needed research underway. Rather, he should proceed with a set of alternative plans with often varied research needs and priorities while initiating the necessary research so that the final plan represents a mix of feasible uses which maximize the use benefits to society.

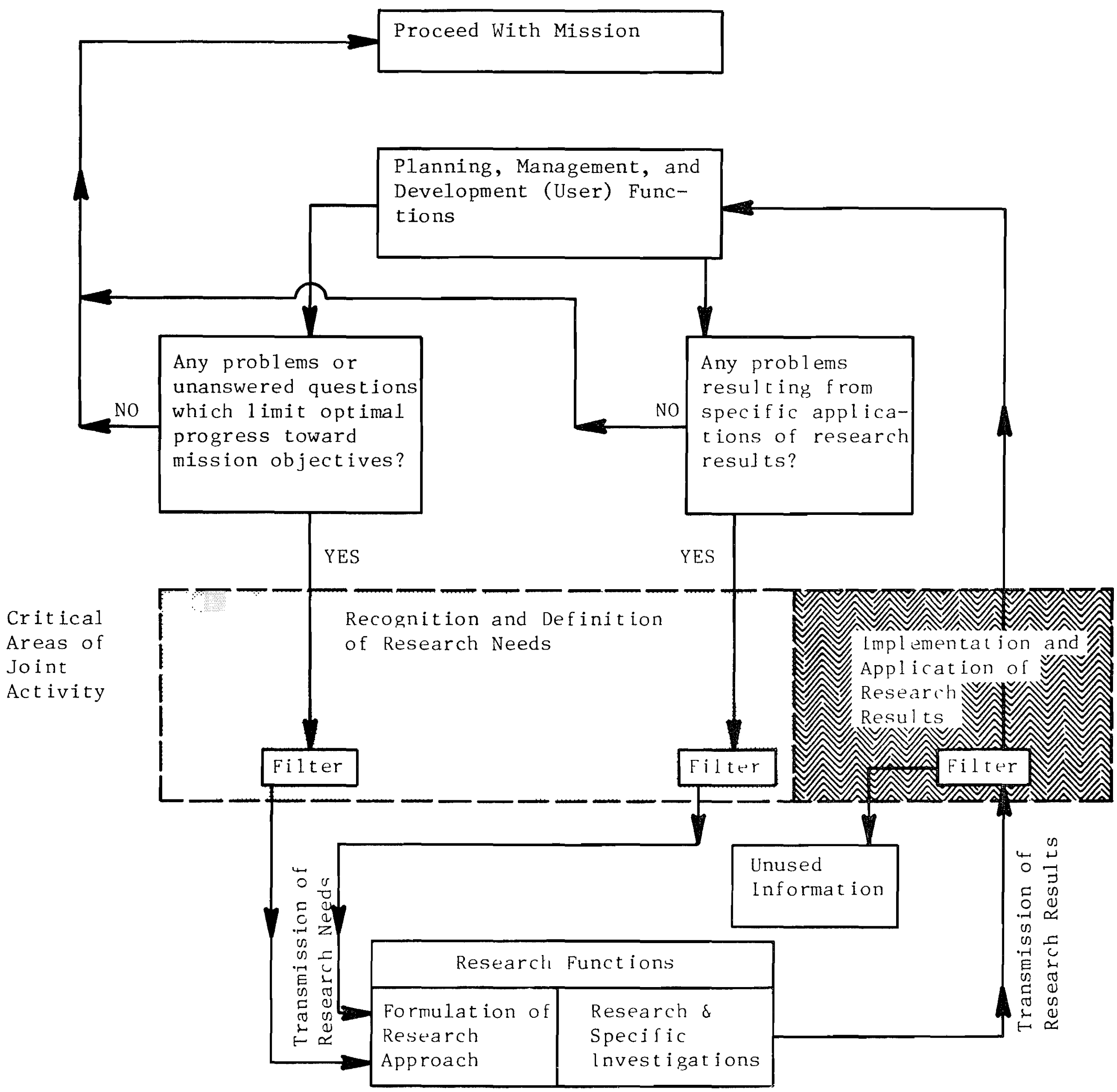


Figure 8. A schematic diagram depicting the communication channels between the research and application functions in society (after Bagley et al., 1973).

It is, of course, possible for research to be conducted in the absence of the management (user) and coordination (linkage) contexts. This situation is depicted by considering only the lowest box in Figure 8. This practice usually leads to an explosion of information which contains much duplication and which is not prioritized in terms of user needs. An example of this kind of proliferation is the past history of research relating to the Great Salt Lake. However, in spite of this so-called proliferation of research, because it was not coordinated in a management sense, much information still is needed with respect to any specific management plan which might be adopted for the lake system.

A Research Coordination Plan

As indicated by Table 2, many federal, state, and local agencies and several universities have pursued active research and data collection programs on Great Salt Lake. The organizations are concerned with various aspects of resource management, and will continue to assume important roles in the search for additional needed information about the lake system. The problem is to develop a plan for coordinating the research efforts of these (Table 2) and other groups, such that information is obtained which is consistent with management needs. The plan should provide for the establishment of research needs and priorities which are consistent with a management policy for the lake. The plan also should include a mechanism for altering research needs and priorities in terms of changing social conditions, desires, and practical considerations based on research findings.

Figure 9 shows in schematic form a plan which is proposed for the Great Salt Lake Division to coordinate research efforts relating to the Great Salt Lake. The Great Salt Lake Division of the Department of Natural Resources within the state government is shown by this diagram as consisting of three major sections or units. The policy and administrative section is labeled as A, with those parts which are responsible for (1) planning and (2) research coordination being shown as sections B and C, respectively. The double arrows between sections A and B and between sections A and C are intended to suggest the two-way exchange of information between the executive and (1) the planning and (2) the research and coordination components of the Great Salt Lake Division.

As suggested by Figure 8, the key to a successful research integration program is efficient information exchange. The channels of information flow envisioned for the plan to coordinate research efforts relating to the Great Salt Lake are shown by Figure 9. This system will function in accordance with the following procedure. The Planning Section (B) will formulate a management plan(s) for the resources of the lake system. This plan will be based on board policies and directions which are received from Section A (see channel $A\text{-}B_p$ of Figure 9). Research needs and priorities evolve from the recommended or adopted management plan(s), and these are transmitted to the Administration and Policy Section (Section A) through channel $B\text{-}A_N$. In turn, policies and research needs and priorities (as received from Section B and approved by Section A) are transmitted to the Research Coordination Section (Section C) through Channel $A\text{-}C_p$. Advisory information, such as progress and status reports, is transmitted from Section C to Section A through the channel designated as $C\text{-}A_R$.

To this point the functions of the system depicted by Figure 9 are entirely "in-house" in that they involve only the Great Salt Lake Division. Under this arrangement the flow of information as depicted between Sections A, B, and C is easily coordinated and controlled. However, the primary objective of the plan is to coordinate the efforts of outside research groups and funding sources, shown as Sections D and E, respectively, by Figure 9. This objective is met by providing for the extensive flow of information between Sections C and D, and C and E. The primary driving functions or stimuli for this information flow are (1) an awareness of research needs and priorities (which itself depends upon information received from Section C), and (2) the availability of funds. The second condition requires that funding sources (such as the Office of Water Resources Research, the National Atmospheric and Oceanographic Administration, the Corps of Engineers, the U. S. Geological Survey, and others) be aware of current research needs and priorities, and be willing to grant research funds accordingly. It is recognized that some organizations (such as the U. S. Geological Survey) will conduct "in-house" research, and thus perform a dual role as both funding source and research entity.

As indicated by Figure 9 research needs and priorities are transmitted to Funding Sources (Section E) and Research Groups (Section D) through Channels $C\text{-}E_N$ and $C\text{-}D_N$, respectively. Requests for further information, proposal abstracts, and entire proposals, if needed, are conveyed from the Research Groups (Section D) to the Research Coordination Section (C), and this flow is shown as $D\text{-}C_I$. The flow of evaluation requests, summaries of funded research, and other needed information from Section E to Section C is shown as Channel $E\text{-}C_I$.

As suggested by the diagram of Figure 9, the usual role of the Great Salt Lake Division under this concept will be to coordinate rather than to fund research efforts. However, it is expected that research activities in some specific areas of particular interest to the division will be supported directly by that agency. In these cases research proposals will be submitted dir-

CHAPTER V

SUMMARY

The primary purposes of this report are to indicate the following two research items in connection with the management of the water resource system of the Great Salt Lake:

1. Research needs and priorities.

2. A research coordination strategy.

With reference to the first of these two items, research needs are identified by the report in terms of (1) various management, or use, categories (such as lake industries), and (2) the need to understand the physical characteristics of the lake system itself. Research needs are identified in each category as information (including data) or understanding gaps. In cases where there seems to be sufficient information, a research need is assumed not to exist. Research needs identified in this way are listed in the last column of Table 1.

The problem of categorizing research needs in terms of priorities is a difficult one. Ideally, prioritization is accomplished within the framework of a particular management plan. However, management plans are altered by changing social values and the results of research itself. Thus, the problem of determining research needs, and particularly of priorities, must be approached concurrently with that of developing a management plan or strategy. First, a fairly broad set of possible management plans is considered. This set is narrowed by eliminating first those plans which seem to be infeasible on the basis of present knowledge, and perhaps considering additional information.

For example, on the basis of present knowledge it probably is possible to eliminate the use of Farmington Bay as a fresh-water recreation area. Further reduction in the number of management plans is accomplished by obtaining additional information by means of research. It might seem that many research results are discarded in this process, but the eliminated management alternatives could not have been adequately assessed (and realistically eliminated) without the vital information provided by research.

As might be expected, in the early stages of assessing a broad spectrum of management alternatives, many of the research needs are somewhat superficial in nature. However, as the number of possible management alternatives are reduced, and particularly in the "operational" phase when perhaps only two or three alternatives might remain as options, research needs become much more specific and definitive, and priorities become clearly identified.

In the case of the Great Salt Lake system, the development of a management plan is still in the early stages, so that research needs cannot be prioritized in terms of a specific plan. However, the various research needs identified by Table 1 are grouped into three broad categories in terms of what is seen as being their priority levels for providing planners with the needed information to proceed logically with the development of a management plan, which of necessity will be dynamic in terms of changing social needs and priorities. The grouping of research needs into three priority categories is shown by Tables 3 through 15.

In order for research to develop information about the lake system in accordance with management needs and priorities, a research coordination procedure is proposed. The objective of this procedure is to coordinate research between various funding sources and research organizations and groups. Under this plan "input" from the Great Salt Lake Division will play an important role in the selection of specific research projects, but the direct involvement of the division is avoided in the detailed processes of proposal evaluation and the awarding and supervision of specific research contracts. The proposed procedure is illustrated by Figure 9.

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APPENDIX

GREAT SALT LAKE MANAGEMENT MEETINGS HELD TO DISCUSS RESEARCH NEEDS AND PRIORITIES

A. Lake Industries, May 26, 1976
B. Recreation, Tourism and Transportation, June 8, 1976
C. Wildlife and Biota, June 15, 1976
D. Physical System, June 22, 1976
E. Legal, Sociological, Environmental, and Water Quality, June 29, 1976
F. Water Quality and Its Impacts
G. Sample Questionnaire

MEETING TO DISCUSS THE GREAT SALT LAKE MANAGEMENT - May 26, 1976
(Lake Industries)

Name	Organization
Doug Stewart	Great Salt Lake Division
Max Wall	Div. of State Lands
Lloyd H. Austin	Div. of Water Resources
James R. Palmer	American Salt Company
W. R. McCormick	N. L. Industry, Magnesium Div.
G. S. Cochetas	Great Salt Lake Minerals
Philip J. Smith	BYU
Joe Glassett	BYU
Calvin G. Clyde	Utah State University
Gail Sanders	Sanders Brine Shrimp Company
Kenneth A. Allen	Sanders Brine Shrimp Company
Owen W. Burnham	Great Salt Lake Division
Craig T. Jones	Utah Water Research Laboratory
J. Paul Riley	Utah Water Research Laboratory

MEETING TO DISCUSS THE GREAT SALT LAKE MANAGEMENT - June 8, 1976
(Recreation, Tourism, and Transportation)

Name	Organization
Calvin G. Clyde	Utah Water Research Laboratory
Gerald L. Smith	Utah State University
Owen Burnham	Great Salt Lake Division
Bill Becker for John Hunt	Utah State University
Joe McBride	Department of Transportation
Jack Myers	Southern Pacific Transportation Co.
Les Abbey	UDOT
Reed Searle	Legislative Research
Ed Rawley	Wildlife Resources
Ken Millard	Consultant-Div. BE Co, T. Co.
Jerry Lyco	Great Salt Lake Yacht Club
Michael J. Mardoe, Commodore	Great Salt Lake Yacht Club
Max Wall	Division of State Lands
John Harkness	Western Pacific Railroad
Graham F. Shirra	Ogden-Weber Co. Planning 208
W. Sands Brooke	Salt Lake City, UT
Norm D. Nuttall	Salt Lake City, UT
Doug Stewart	Great Salt Lake Division
Scott Carter	Davis Co. Planning
Harold W. Christiansen	Great Salt Lake Yacht Club
Craig T. Jones	Utah Water Research Laboratory
J. P. Riley	Utah Water Research Laboratory
Miss Sandra Fergusson	Golden Spike Empire

MEETING TO DISCUSS THE GREAT SALT LAKE MANAGEMENT - June 15, 1976
(Wildlife and Biota)

Name	Organization
Calvin G. Clyde	Utah Water Research Laboratory, USU
Craig T. Jones	Utah Water Research Laboratory, USU
J. Paul Riley	Utah Water Research Laboratory, USU
Chris Anderson	University of Utah
Robert C. Garrison	U. S. Fish and Wildlife Service
Ned I. Peabody	U. S. Fish and Wildlife Service
D. W. Thurgood	Utah Wildlife & Outdoor Recreation Fed.
Donald A. Smith	Utah Div. Wildlife Resources
Ed Rawley	DWR
Owen Burnham	Great Salt Lake Division
Richard W. Baumann	BYU
Robert Winget	BYU, CHES
Glen C. Collett	Salt Lake City Mosquito Abate. Dist.

MEETING TO DISCUSS THE GREAT SALT LAKE MANAGEMENT - June 22, 1976
(Physical System)

Name	Organization
Calvin G. Clyde	Utah Water Research Laboratory, USU
Craig T. Jones	Utah Water Research Laboratory, USU
Lloyd H. Austin	Div. of Water Resources
George E. Pyper	USGS Water Resources
Charley Kincaid	Utah State University
Abe Van Luik	Utah State University
Gary Z. Watters	Utah State University
J. W. Gwynn	UGMS
Max Wall	Division of State Lands
David A. Westnedge	National Weather Service
Don R. Dickson	University of Utah