Glen Canyon
Environmental Studies

Proposal to the

National Science Foundation
Research Applied to National Needs (RANN)

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

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Date Submitted: April 1, 1972

One PROPOSAL submitted to

NATIONAL SCIENCE FOUNDATION
RESEARCH APPLIED TO NATIONAL NEEDS (RANN)

entitled

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

with

Budget Requests from Seven Participating Institutions
found on Subsequent Pages

1. Dartmouth College
2. John Muir Institute
3. University of Arizona
4. University of New Mexico
5. University of Rochester
6. University of California, Los Angeles
7. Northern Arizona Society of Science & Art, Inc.

Plus Four Associated Universities contributing Personnel
but not requesting Budgets

1. Boston College
2. University of California, Santa Barbara
3. University of Santa Clara
4. Western Washington State College

Plus One Law Firm contributing Personnel
but not requesting Budgets

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ABSTRACT

The project entitled "Collaborative Research on Assessment of Man's Activities in the Lake Powell Region" has been in formal existence for one year. Its abbreviated title is the "Lake Powell Project". This document is a proposal to renew this research for a two-year period at an expanded level of effort. The project is a consortium of 7 institutions combining expertise in a wide range of natural sciences and social sciences and it is proposed to apply this expertise in an assessment of man's effect upon one of the most dynamic regions of the United States.

The Lake Powell region was for many years a static and undeveloped area. However, with the great national need for energy resources, water resources and recreational facilities, this region is experiencing sweeping changes that will drastically alter its former pastoral equilibrium. In addition, it is a region with various Indian tribes constituting a major portion of the population that will undergo great pressures on their mode of living.

The consortium of institutions participating in the Lake Powell Project seeks to establish the natural framework of the region, evaluate the recent changes that man has wrought, and determine how these changes have, in turn, affected man.

In the first year of the Project, it was found that many past decisions on development of the region would have benefitted from more accurate and objective appraisals of the natural framework of the region. It is intended that the results of the research in this proposal will influence the decisions to be made by providing better information about changes in the natural environment around the Lake Powell region. This information will be communicated to the public as well as the decisionmakers of the region, by a well-considered plan.

ACKNOWLEDGMENTS

The final form of this proposal was prepared from original subproject proposals and budgets submitted by senior investigators and from notes and material resulting from the writing groups of the Denver Workshop of the Lake Powell Project held January 16-19, 1972.

This document was prepared in completed form at the Institute of Geophysics, University of California, Los Angeles, under the direction of Priscilla P. Dudley, Executive Secretary, Lake Powell Project, and Jeni M. Varady, Editorial Assistant, Journal of Geophysical Research. The manuscript could not have been completed without the invaluable assistance of the following individuals:

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Jean Sells	Drafting

Orson Anderson

NOTE

A revision of pages 5-36 of the January proposal was completed at UCLA on March 31, 1972.

Orson Anderson
3/31/72

I. GENERAL PROBLEM: PROBLEM, GOALS, TASKS, AND CONCEPTUAL FRAMEWORK

A. STATEMENT OF THE PROBLEM

There is a need for wise development of natural resources in the nation, particularly in semiprimitive areas. The societal *problem* which prompts this proposed research is how to develop water resources and deal with effects and ramifications of this development in the arid Southwest.

B. GOALS AND TASKS

In addressing the societal *problem*, the investigators of the Lake Powell Research Project chose the following *goals*:

1. To study the problems inherent in water resource management with regard to water allocation, water quality, power production, recreation, and aesthetic values of the environment.

2. To evaluate the expected consequences of alternative water management decisions upon the Lake Powell region.

3. To study the decisionmaking process in the development of water resources and to disseminate information pertinent to future decisions.

4. To create a quantitative systems analysis model which is designed for use in the first three goals.

The specific *tasks* which must be completed in order to achieve the objectives of the studies of:

1. The Water Cycle of the Lake Powell Region

   a. Projection of quantity of water as input to the Lake. A determination of the water available from natural causes and man's activities upstream but independent of the Lake Powell impoundment.

   b. The reallocation of water within the natural water cycle as a result of the impoundment. Perturbations in the local cycle created by man.

2. Useful Water Lifetime and Quality of the Impoundment

   a. The changing biological, physical, and chemical systems of Lake Powell, arising from natural causes and from man's ongoing activities at the Lake.

b. The biological interaction of the Lake and the shore.

c. Biological-physical interactions of heavy metals in Lake Powell.

d. Effect of siltation upon lifetime.

3. Impact of the Impoundment and Resulting Activities on Water Utilization in the Lake Powell Region

a. Effects on recreational availability.

b. Economic effects on the Indian Nations.

c. Economic effects on recreation, power production, and irrigation.

4. Impact of the Impoundment and Resulting Activities upon the Quality of Life in the Lake Powell Region

a. Effect upon the health and welfare of the residents of the Lake Powell region.

b. Effect upon the social structure of the Indian Nations in the region.

c. Effect of resultant air quality upon the Lake Powell recreational area. Measurement of baseline atmospheric data in order to evaluate future atmospheric-Lake interactions.

5. The Role of Institutional Decisions on Water Development in the Lake Powell Region

a. The legal decisions related to upper basin water development.

b. The political institutions involved in the decisions for the impoundment and the present water management structure.

c. The effect of institutional environmental impact statements on water management decisions.

6. The development of a methodology for correlating all the research components essential to achieve each of the objectives. This methodology is necessary to expose the interactions between the research components involved. Without these interactions, the realization of the objectives cannot be comprehensive.

C. CONCEPTUAL FRAMEWORK

1. An Interdisciplinary Approach

Environmental research can be classified into three major categories according to the methodological approach taken by the researchers involved. These are (a) single-discipline approach, (b) multidisciplinary approach, and (c) interdisciplinary approach.

Historically, most research has been confined within the framework of one particular discipline, augmented occasionally by consultants from other disciplines. For simplicity and reference, we will refer to this category as the Single-Discipline Approach. Realization of the multidimensional nature of many environmental problems necessitated changes in methodology and brought about a multifaceted attack. This Multidisciplinary Approach involves many independent research investigations, each of which concentrates on one aspect of the total problem.

In the Multidisciplinary Approach, final research results are in essence stapled together to provide a comprehensive, though not integrated, answer to the total problem which was the focal point of the research. In our judgment, this approach represents a clear advance over the Single-Discipline Approach, in that it gives explicit recognition to the fact that most environmental problems cannot be adequately treated from a standpoint of only one discipline, however capable the researchers in these disciplines might be. Secondly, this approach does yield a product which is a result of concurrent research efforts, and in final form it will be summarized into a single exposition.

In contrast to the two previous approaches (i.e., Single-Discipline and Multidiscipline), the Lake Powell Project has made an effort to carry the development to a further stage of integration, the Interdisciplinary Approach: that is, a truly interdisciplinary project in which all the subprojects are functionally linked to the major goals as they have been developed by a steering committee made up of senior investigators from a broad spectrum of disciplines.

We stated earlier that realization of the objectives of the Lake Powell Research Project requires an understanding of the interrelationships among the critical factors involved in those changes. It should be clear that realization of the second goal will be even more complicated in terms of interrelationships among social, economic, medical, physical, biological, and legal factors. In order to accomplish the two objectives, we have to achieve an actual integration of the different disciplines involved and not simply a reporting of the results of independent investigators. This integration can only be achieved through

personal interchanges among the researchers involved, each of whom comes to the Project with a different conceptual approach to the problems under investigation. A continuous and complete involvement of each investigator in the total Project is essential. This involvement results in the modification of each investigator's conceptual approach to bring it into conformity with the general objectives of the Project. Anyone who has dealt with independently minded scientists who have clearly developed ideas as to where their best interests lie realizes the difficulty in achieving this modification of thought.

This integration was not a painless process. It has involved countless hours of discussions, arguments, and memos. After compromise eventual resolution of major differences occurred within the framework of a steering committee representing all Project disciplines.

It is this integrative research effort which we categorize as an Interdisciplinary Approach. This approach eliminates the independent and separate character of each discipline's research as occurs in the multidisciplinary framework and substitutes for them an interaction among the various disciplines involved from the earliest stages of the research, so that the entire research project proceeds every step of the way under a common conceptual framework as to what the end result of the Project is to be.

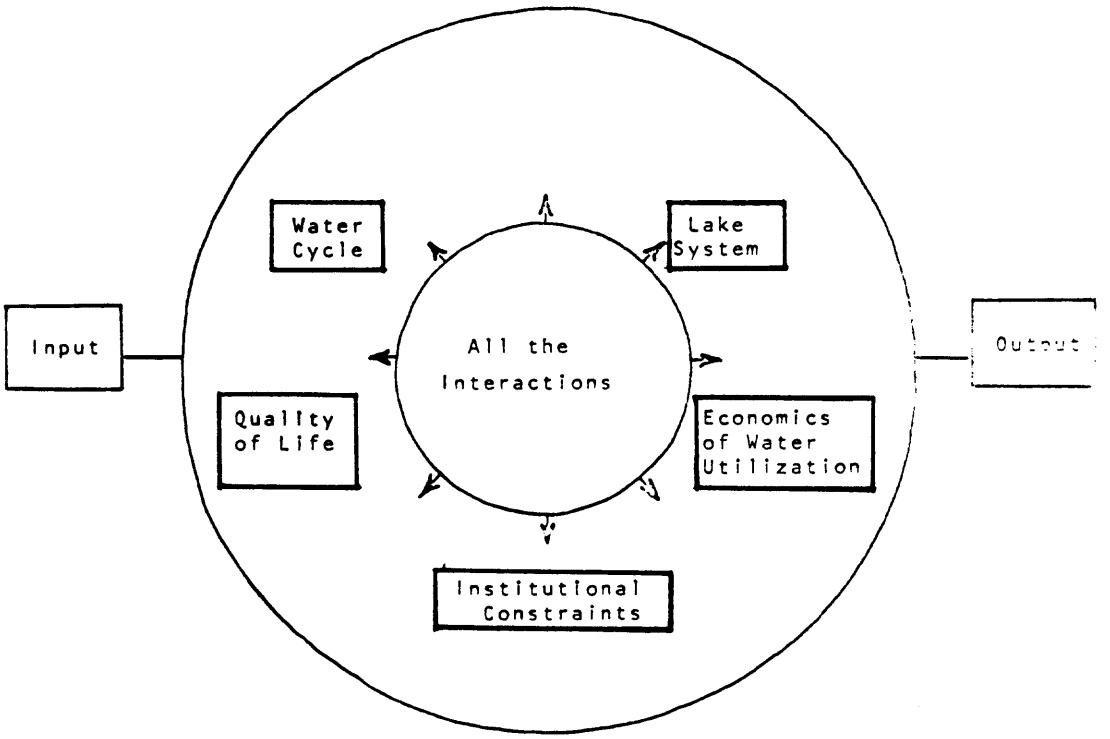
2. Systems Analysis Methodology

A systems analysis methodology will be used in order to execute the Interdisciplinary Approach. The system will incorporate five tasks, while the total system corresponds to the sixth task. A schematic description of the system is given on the following page.

Each subsystem is composed of several research components closely interrelated by virtue of the contribution to the role of the subsystem in the general system. There are two physical subsystems (1 and 2), one environmental subsystem (3), one socio-economic subsystem (4), and one subsystem (5) dealing with institutional constraints (e.g., legal, political, and environmental).

A number of additional subsystems could have been arbitrarily incorporated, but the above five were chosen as a logical balance in order to best achieve the Project goals. Each of the subsystems chosen is directly connected to water management questions. The air quality research component, while apparently not directly connected to water management, is of such a special nature in its contribution to the subsystem concerned with the quality of life in the Lake Powell region that it does in fact have an impact on water management. During the first year of the Project, a number of research components were added to the system

Systems Analysis Model



1. Water Cycle
   a. Streamflow Trends
   b. Lake Evaporation
   c. Bank Storage
   d. Geochemical Tracers

2. Lake System
   a. Biological Limnology
   b. Physical Limnology
   c. Lake Geochemistry
   d. Environmental Hazards (Heavy Metals)
   e. Sedimentation
   f. Lake-Air Exchange

3. Quality of Life
   a. Air Quality
   b. Epidemiology
   c. Anthropology (Social)
   d. Shoreline Ecology

4. Economics of Water Utilization
   a. Economic Anthropology
   b. Economics

5. Institutional Constraints
   a. Legal
   b. Political Science
   c. Tribal
   d. Environmental

Input
a. Environmental Questions
b. Water Management Questions
c. Water Policy Questions

Output
a. Environmental Consequences
b. Water Management Alternatives
c. Institutional Consequences

Figure 1

in order to satisfy the research goals, while others were curtailed and one was eliminated. Mechanisms for the addition, elimination, and curtailment of research components are described in the management section concerning the Steering Committee.

The responsibility of developing the systems analysis model is distributed in the following manner. The principal investigators in charge of the research components in each subsystem will collectively construct a model for their subsystem. The construction of each subsystem model will be guided by the systems analysis group to ensure the compatibility required for the general system. Another function of the systems analysis group will be to initiate the formulation of interrelationships to describe the interactions within each subsystem and between the five subsystems. Relationships will be quantified and expressed in a mathematical formulation whenever possible. The subsystem parameters will be estimated by the appropriate researchers in each case. The responsibility for developing the overall systems model which incorporates the subsystems and the interaction between them rests with the systems analysis group.

The cost of developing the overall model and its application for problem analysis are included in the systems analysis budget. The major cost of developing the subsystem models in terms of manpower and computing services was not charged to the systems analysis budget, but was allocated to the specific research components and is reflected in their corresponding detailed budgets.

3. <u>Examples of Questions To Be Answered Utilizing the Overall Systems Model</u>

What will be the consequences of:

a. A change in Lake level

b. An extended drought

c. A legal change in water allocation

d. Additional thermal power plants

e. New major road construction to the Lake shores

f. Programs to limit evaporation losses

g. Programs to recover "bank storage" water

h. Increased water quality standards

i. Increased air quality standards

j. Restrictions on recreational use

k. Building additional dams upstream but close to Lake Powell

l. Continued large annual losses into "bank storage"

m. Rapid siltation in restricted zones

n. Early eutrophication of the Lake

o. Heavily polluted skies over Lake Powell

p. Heavily polluted water in Lake Powell

q. Increased use of environmental impact statements.

4. Milestones for Development of the Integration of the Project

We expect four major stages in the development of the integration of the Project, which will parallel the data collection phases of the subprojects. Data collection will likely continue throughout the lifetime of the Project. The development of the systems analysis model is planned to take place in four stages, each of 6 months' duration.

- Stage One

  a. Development of the relationships in each component and preliminary estimates of their parameters

  b. Search for interaction within each subsystem

- Stage Two

  a. Development of interrelationships between the components in each subsystem, and preliminary estimation of their parameters

  b. Search for interactions between subsystems

- Stage Three

  a. Refinement of estimates for the relationships and interrelationships within each subsystem

  b. Preliminary estimates for interrelationships between subsystems

c. Construction and testing of the overall model using the preliminary estimates of the system parameters

o <u>Stage Four</u>

a. Incorporating the refined estimates in the overall model

b. Using the model to answer questions of the types illustrated above.

II. IMPLEMENTATION

A. BACKGROUND AND EVOLUTION OF THE STUDY

1. The Beginning

The initial idea for this Project occurred when Anderson, one of the Coordinators of the Project, read newspaper reports of statements of the Bureau of Reclamation officials in Salt Lake City that large amounts of water were "missing" from Lake Powell, and were presumed to have gone by infiltration into the banks around the Lake. After field trips to the Lake, which seemed to substantiate these reports, he proposed to the Ford Foundation a hydrology study of the Lake shores to locate this missing water, but the project proposal was turned down. Comments made in that rejection led to the realization of the need for a group of researchers from various disciplines with greater breadth than could be found in any one institute or department. A group of researchers representing a number of major disciplines was organized for a workshop of 1 week's duration on Lake Powell, in the summer of 1969. This workshop was financed by an NSF project of Dr. Vincent Schaefer of SUNY, Albany. Out of this workshop came the awareness that the problem of infiltrated water going into bank storage was only one in a large class of problems associated with the impoundment of Lake Powell. A second proposal was submitted to IRRPOS of the NSF, and it again was rejected. So another Lake Powell workshop was organized for the summer of 1970. A smaller group was gathered and a harder look was taken at how a consortium could work on problems associated with Lake Powell. Finally, a proposal was submitted to IRRPOS in the spring of 1971 by Dartmouth College, the University of New Mexico, UCLA, the John Muir Institute, and Prescott College. All but the one from Prescott College were funded. It was the consensus of those who were funded that the absence of work in the social sciences was a serious defect, and conscious efforts were made to recruit social scientists from early in May of 1971.

2. The Evolution of the Steering Committee

In the first proposal which was funded, Anderson was named as Coordinator with overall responsibility for the Project. One of his first concerns was the traditional problem of management: the balance between executive action and policy decision. He sought advice in this problem from Dr. William Ackermann, who has scientific expertise in man-made lakes. Anderson appointed Ackermann as a consultant to the Lake Powell Project. Early in 1971, Ackermann advised Anderson that a Steering Committee should be formed. At that time, the Project was organized around four institutions, and it seemed logical to form a Steering Committee by asking representatives of each institution to be on the Steering Committee. The members of the Steering Committee took as their responsibility those policy issues which involved the Project on finance, publicity, and publications.

The Steering Committee existed by mid June, but did not function until July 3. Prior to its first meeting (July 3, 1971), Anderson made the decision to have a representative from social sciences on the committee, even though there was not at the time a funded institution doing social science work on the Project, in order to have a social science component on the Project as soon as possible. In addition, a remote sensing program was in fact being pursued in conjunction with but funded separately from the Project. Two were added.

When the first Steering Committee met, it consisted of six members and the Executive Secretary (ex-officio). At that meeting, an agenda for the work of all Lake Powell Project personnel was discussed and policy relating to publicity was established. At this point, the Steering Committee assumed responsibility for policy matters. The first policy decision was that all publicity and all publications of Project personnel were to be channeled through one person, and it was resolved that no individual could speak as a representative of the Lake Powell Project without first clearing his statement with Coordinator Anderson. This is in contrast to an individual's right as a citizen to speak on matters of concern to him as an individual. It was agreed by the Committee that the Project would deny responsibility for news reports based upon comments made by individuals, if such comment had not passed through the one person designated for Project publicity.

At the end of the field season in 1971, two new members were added to the Steering Committee from social science fields. Dr. Jerrold E. Levy was accepted by the Steering Committee as the Co-Coordinator who was held responsible for the balance of effort in the Project regarding social sciences.

In November of 1971, a meeting of the principal investigators funded by the Project and prospective investigators for work described in this proposal met in Albuquerque and reorganized their relationships to the Steering Committee and the Coordinator's Office. It was decided to deemphasize the funding institutions as focal points and to focus on the disciplines of specialities needed for the Project as a whole. The disciplines and specialities were organized into a number of subprojects, and the senior investigators of each subproject prepared budgets and proposals to be submitted in January. All Project personnel met in Denver in January 1972 to prepare this proposal. By this time, the principal economist of the Project was added to the Steering Committee.

Perhaps the most significant development during the Denver meeting was the assumption of responsibility by the Steering Committee for all decisions relating to budgets and future growth of the Project. This was a new and significant departure

since previous budgets and research topics had been proposed and incorporated into the Project in a kind of ad hoc way. The assumption of control of budget was not without considerable trauma, and the evolution of the Steering Committee and its relationships to the Coordinator's Office is by no means complete. It is important to recognize, however, that the Steering Committee has accepted as its responsibility the rational control and growth of the Project, and that members have begun to understand how to talk with one another about issues and priorities related to the total Project, with individual subprojects being evaluated in relationship to the whole.

The Steering Committee also assumed the authority for the determination of any additional disciplines and specialities and their level of effort which might be added to the Lake Powell Project.

The Senior Investigators came to the Denver meeting with proposals for 17 subprojects. The sum for the budgets of the 17 subprojects plus the budget of the Coordinator's Office totaled $1,662,000 for 2 years. In order to determine the relevancy of each subproject to the overall objectives, the Steering Committee decided upon the statements of Problem, Goals, Objectives, and Tasks of the overall Lake Powell Project. The Steering Committee then voted that it would establish the level of proposed funding for the total project. It did so by evaluating each one of the specific proposals and determining the level of the budget for each subproposal according to its relevance to the general goals of the Project. In this task, the necessity for early inauguration of work and interconnection of the subparts was taken into account. In this way, the Steering Committee established the budget for each of the subprojects and assigned it to the Senior Investigator of this subproject. The total budget approved by the Steering Committee for 2 years amounts to $1,281,800 (see the following page). The amount submitted is found on page 66.

The Project in the early months was almost entirely run by the Coordinator's Office. By the time of the Denver meeting the financial and research issues were sufficiently serious and numerous that the distinction between administration and policy was uncertain, and new adjustments between authority of the Coordinator's Office in day-to-day operations and long-term policy of the Steering Committee needed to be resolved. The issue is complicated since the members of the Steering Committee are dispersed from one coast to the other, and can only meet a few times a year. The problem is structural in nature, and the Committee members are determined to deal openly with the flow of authority, as the Project evolves.

January 18 PM, 1972

The following table is the budget that was approved by the Steering Committee for each subproject of the Lake Powell Project. It will be submitted to the National Science Foundation by the Coordinator's Office in such a form so that none of these amounts are exceeded by any one subproject.

Biological Limnology	174,000
Shoreline Ecology	50,000
Heavy Metals	50,000
Streamflow Trends	38,000
Lake Evaporation	57,000
Bank Storage	51,000
Physical Limnology Lake Geochemistry Sedimentation	181,500
Impact Analysis Studies	52,000
Systems Analysis	61,000
Economics	71,000
Plume Measurements	0
Background Air Quality	117,000
Epidemiology	27,000
Anthropology	130,000
Law	70,000
Coordinator's Office, UCLA	122,300
Coordinator's Office, UA	30,000
Total	1,281,800

The total amount cut by the Steering Committee is $380,200.

Orson Anderson

Gerald E. Lacy

3. The Evolution of the Systems Analysis Plan for the Project

The present Lake Powell Project started out last June without a systems analysis plan, but with a belief that a good plan could be designed and implemented. At the workshop held on Lake Powell in July 1971, Dr. Shaul Ben-David opened up the question of an overall plan, and commenced discussions with the individual senior investigators which eventually led to the definition of the first set of objectives for the Project.

Later in July, Dr. Ben-David and Dr. F. Lee Brown composed a memorandum which began to address the problem of a systems analysis plan. At this time, the objectives were somewhat open because of the uncertainty about the limits of the societal problem we would address as a Project. For instance, there were some who believed that the Project should include most aspects of the Black Mesa strip mining operation, and there were others who thought the Project might be concerned with the problem of thermal power generation in the Four Corners area. By the time of the Albuquerque meeting in November 1971, the Project objectives were fairly well restricted to those of water management, and the systems analysis model began to evolve. Figure 2, on page 18 shows the systems model agreed upon at Albuquerque among the senior investigators present. This figure is a refinement of an earlier diagram proposed by Dr. Ben-David in his July 1971 memorandum to the Coordinators. At this stage of the development, three basic subsystems had been conceived, but they were still based upon discipline orientation, a classification of subsystems of the overall system which was later abandoned. Nevertheless, it was at this point that the need for the systems analysis group as a separate subproject was clearly seen, and the differences between law, political science, and impact analysis studies were defined. The Coordinators assigned senior investigators to write proposals for each of these three subprojects so they could be considered at the Denver meeting by the Steering Committee.

Using the information obtained by the discussions behind Figure 3, the Steering Committee defined the problem, goals, objectives, and tasks which were stated in our original proposal. Using these tasks, the Steering Committee then modified and in some cases seriously curtailed subprojects. The result of these exercises led to new insights on the systems analysis plan, but these insights were illuminated at discussions subsequent to the submission of the proposal. Dr. S. Ben-David and Coordinator Anderson then redefined the systems model in terms of (a) natural science subsystems, (b) interrelations arising from economics, recreational values, and aesthetic values, and (c) boundary conditions arising from institutional constraints. This model was approved by the Steering Committee and is shown in Figure 1, page 9.

A Stage of Development of the Systems Analysis Model

November 1971

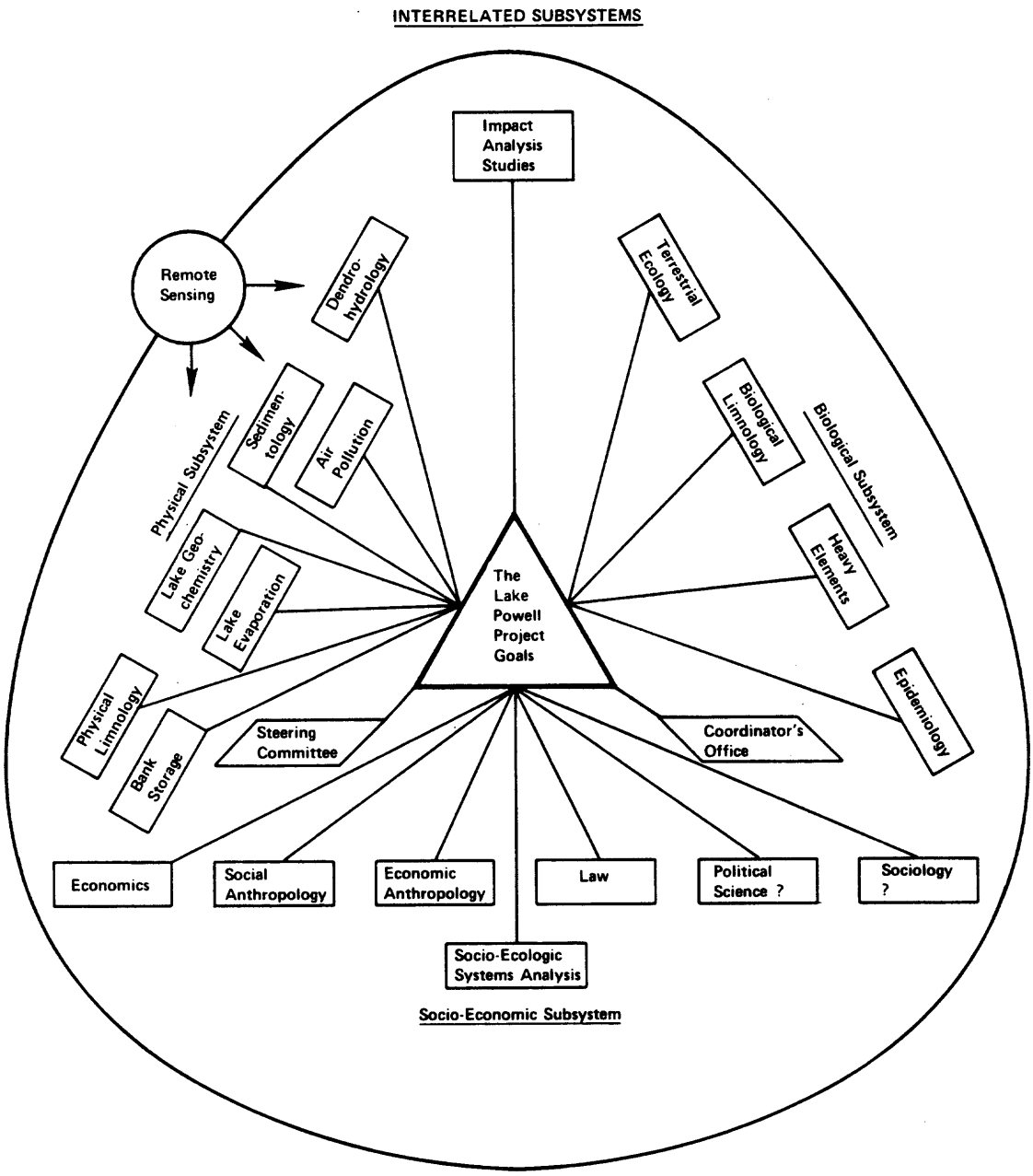


Figure 2

4. The History of the Senior Personnel, with Regard to the Project

o Orson L. Anderson, Institute of Geophysics, UCLA

He submitted an unsuccessful proposal to the Ford Foundation (proposal for a desert ecology station) in 1968. He helped Dr. Vincent Schaefer organize the first Lake Powell workshop in July 1969, which was attended by 20 people, including Drake. He organized the second Lake Powell workshop in 1970 which Drake, Potter, Jacoby, and Aitken attended. He helped write the proposal which was funded by RANN in 1971. He has acted as Coordinator for overall responsibility for the Project since June 15, 1971. He organized the first Steering Committee in June 1971.

o Charles L. Drake, Department of Geology, Dartmouth

He helped Anderson with advice on the Ford Foundation proposal in 1968. He attended the Lake Powell workshops in 1969 and 1970 on Lake Powell, and introduced Aitken to Anderson in the spring of 1970. He organized the Dartmouth team (N. Johnson and R. Reynolds) for their component of the project proposal which was funded in 1971. He has led the research on sedimentation since June 15, 1971. He joined the Steering Committee in June 1971.

o Gordon C. Jacoby, Institute of Geophysics, UCLA

He helped Anderson prepare the proposal for IRRPOS, which was turned down in early 1970. He worked on Lake Powell all during the summer of 1970, gathering preliminary limnological data, which provided the basic background for the Dartmouth College interest. He attended the workshop on Lake Powell for the summer of 1970. He did most of the preparation of the UCLA component of the proposal which was funded in 1971. He has done all the hydrology work since June 1971.

o Donald W. Aitken, Director, John Muir Institute

He attended the Lake Powell workshop in 1970 on Lake Powell, and introduced Loren Potter to Drake and Anderson at that time. He organized the JMI team (M. Williams, Co-Principal Investigator; S. Ben-David, Consultant; F. L. Brown, Consultant) for the JMI component of the proposal, which was funded in 1971. He wrote general introductory statements for the same proposal. He has led the research for JMI since June 15, 1971, and acted as Co-Coordinator from June 1971 to October 1971. He joined the Steering Committee in June 1971. In November 1971, he organized the Albuquerque meeting, when many of the policy decisions concerning the subprojects were made which affected this proposal.

- Loren Potter, Department of Biology, University of New Mexico

He attended the second Lake Powell workshop on Lake Powell in 1970. He organized the UNM team, which included David Kidd, for the UNM component of the project proposal which was funded in 1971. He has led the work on shoreline ecology since June 1971, and joined the Steering Committee at that time.

- David E. Kidd, Department of Biology, University of New Mexico

He helped write the UNM component of the proposal which was funded in 1971, and has led the research on biological limnology since June 1971.

- Noye M. Johnson, Department of Geology, Dartmouth

He helped write the Dartmouth College component of the proposal which was funded in 1971. He has led the research on physical limnology since June 1971.

- Robert Reynolds, Department of Geology, Dartmouth

He helped write the Dartmouth College component of the proposal which was funded in 1971. He has led the research on lake geochemistry since June 1971.

- Shaul Ben-David, Research Associate, John Muir Institute (and Economics Department, University of New Mexico)

He joined the JMI component of the proposal which was funded in 1971, as a consultant in economics. He wrote the outline for the general portions of the present proposal. His work has laid the basis for the economics and systems analysis subprojects. He joined the Steering Committee in January 1972.

- F. Lee Brown, Research Associate, John Muir Institute (and Economics Department, University of New Mexico)

He joined the JMI component of the proposal which was funded in 1971, as a consultant in economics. He wrote the economics subproject in the present proposal.

- Mike Williams, Museum of Northern Arizona (and John Muir Institute)

He joined the JMI component of the proposal which was funded in 1971, as a co-investigator. He planned to write a proposal involving Eric Walther as co-investigator early in

the fall of 1971. The proposal was to have two components. Subsequent to the Albuquerque meeting, the two components were in fact split into two proposals, with Eric Walther as one Senior Investigator and Mike Williams as the second Senior Investigator. One proposal, dealing with plume analysis, was judged by the Steering Committee in Denver in such a way that it is not being submitted with the present proposal. Just after the Denver meeting, it was decided that Mike Williams would join Eric Walther's proposal as a consultant to the Museum of Northern Arizona

- Priscilla P. Dudley, Department of Geology and Geophysics, Boston College

She joined the project as the Coordinator's Assistant in February 1971, and has been supported out of the UCLA budget for the Coordinator's office. She was promoted to Executive Secretary in August 1971. She administers the Coordinators' budgets and runs the Flagstaff summer office.

- Steven J. Kunitz, Department of Preventive Medicine and Community Health, University of Rochester

He attended the 1971 workshop on Lake Powell, although unfunded by the project. He was recruited by Anderson in July 1971, and accepted an appointment to the Steering Committee, which met in July 1971. He recruited Levy as the social science coordinator. He helped Levy in the organization of the social science components, and helped in the organization of the subprojects at the Albuquerque meeting in November 1971. He wrote the epidemiology proposal.

- Jerrold E. Levy, Department of Anthropology, University of Arizona

He was recruited by Kunitz in October 1971, and joined the project as Co-Coordinator, with responsibility for organizing the social science components. His efforts enabled the project to recruit four social science representatives by the time of the Denver meeting: Weatherford and Price for law, Robbins and Wagner for anthropology. He joined the Steering Committee in October 1971.

- Eric Walther, Museum of Northern Arizona

He was recruited by Aitken and Williams to be one of the three co-investigators on a JMI project which was to be submitted at the Denver meeting. However, at the previous meeting in Albuquerque (November 1971) it was decided to split the proposal into two subprojects, one of which would be run by Mike Williams with Walther as the second investigator. Subsequent to the Albuquerque meeting, Walther and Williams

submitted separate proposals, under JMI sponsorship. At the Denver meeting, Walther's proposal on background air quality was accepted by the Steering Committee, as a proposal under the Museum of Northern Arizona. Williams joined this proposal as a consultant, reporting to Walther.

- Gary Weatherford, Ferris, Weatherford and Brennan, San Diego (and UCLA)

He was recruited by Levy to submit a law proposal, along with Monroe Price, to the Denver meeting. He was elected to the Steering Committee on January 19, 1972.

- Roland Wagner, University of Santa Clara

He was recruited by Levy to help write the anthropology proposal at Denver.

- Lynn Robbins, Western Washington State College

He was recruited by Levy to help write the anthropology proposal at Denver.

- Monroe Price, Law School, UCLA

He was recruited by Levy, and will help Weatherford run the subproject on law and political science.

- Dean Mann, Department of Political Science, University of California, Santa Barbara (and UCLA)

He was recruited by Weatherford and will help him and Price run the law and political science subproject.

5. History of the Coordinator's Office

The purpose of the Coordinator's office is to run the administrative affairs of the Lake Powell Project, and to execute the policy decisions of the Steering Committee. Further details of management are found in the management section of this proposal.

It became clear early in the year when the first signs of Project acceptance were detectable, that one of the first problems was to acquire a base camp commonly used by all four funded institutions, but not located at any one of those institutions. This need was particularly acute with Dartmouth and UCLA being on opposite sides of the country, each with its own extensive and different needs for field work and field equipment. An appeal was made to Dr. E. Danson, Director of the Museum of Northern Arizona, in Flagstaff, to provide housing for the Project. Although no money was available for this purpose (since the Project was not funded until June 15) Dr. Danson and his staff found some very nice quarters which were formerly used for storage. This space was refurbished by the Museum, and furniture was provided by UCLA and the Museum, so that by July 1, when Project personnel gathered for the first workshop, field support facilities and meeting rooms were available. The entire Project is indebted to the Museum of Northern Arizona for its help in this regard.

It also became clear early in the year that the administrative burden required for the support of the field parties and for management of the workshop, necessitated the full attention of one person, who would be based full-time in the summer in the Project's Flagstaff office. Assistant Professor Priscilla Dudley, of Boston College, was recruited to head this function, and was given the title of Coordinator's Assistant. Later in the summer, this title was changed to that of Executive Secretary. Dr. Dudley was empowered to disperse the monies for field work out of the budgets of both Dartmouth and UCLA, as well as the budget for the Coordinator's office.

The first officially funded workshop of the Project was held on Lake Powell in the vicinity of Hall's Crossing, on July 4, 5, and 6, 1971. The organization of this workshop was the primary task of the Coordinator's office in the early summer. Planes were provided by JMI and Dartmouth; boats by UNM and the Coordinator's office. The meeting was too short to examine all the interfaces, but nevertheless a great many problems were resolved, affecting the interplay of the programs within natural sciences, and with regard to remote sensing. The meeting adjourned at the Lake without much progress being made regarding the role of the social sciences in the Project. The meeting reconvened at the Museum of Northern Arizona, and there was a seminar from all participants.

The Project had two coordinators from the beginning: Dr. Orson L. Anderson and Dr. Donald W. Aitken. Dr. Anderson was designated as the scientist with overall responsibility to the National Science Foundation in the proposal which was funded in 1971, but the detailed responsibilities were split between the two coordinators. After the July 1971 workshop, the problem of recruiting anthropologists occupied the attention of Coordinator Anderson.

About that time, Professor Jerrold E. Levy, of the Anthropology Department of the University of Arizona (then of Portland State University) became very interested in joining the Project. Dr. Aitken bowed out as Co-Coordinator, due to the press of his duties as Chairman of a department at the California State University at San Jose. Dr. Levy was taken into the Project as Co-Coordinator by vote of the Steering Committee, and, between themselves, the Coordinators' duties were redefined between Anderson and Levy.

In the autumn, the chief problems occupying Coordinator Anderson concerned the establishment of good working relations between the Bureau of Reclamation and the Lake Powell Project.

Coordinator Levy spent the autumn months of 1971 recruiting senior personnel in anthropology, law, and political science. In this endeavor he was greatly assisted by the efforts of Dr. Steven J. Kunitz, who joined the Project, although unfunded, on the Steering Committee at the same time as did Coordinator Levy.

6. The Evolution of Relationships with Tribes and Agencies

From the first days of the Project, it was recognized that the relationships between the Navajo Tribe and the Lake Powell Project investigators required careful attention. The Project proposed to have one tribal permit for all Project activities. The initiative to obtain a tribal permit was undertaken jointly by Coordinator Levy and Kunitz, by sending all published reports to the Office of the Chairman of the Tribe.

Chairman McDonald has reviewed the first year progress reports and a summary of the proposed activities for the next 2 years, and has indicated his approval of the Project activities, through intermediaries. The policy of our activities with regard to the Tribe as emphasized by Coordinator Levy, is that all published reports and proposed activities are openly discussed with the Tribe. No new activities which affect the Tribe will be initiated by any component of the Project without having obtained prior permission from the Tribe. The Tribe is considered as one of the several important user groups, and will receive the information from the Project at the same time as other user groups such as the National Park Service and the Bureau of Reclamation.

The relationships between the Project activities and the Bureau of Reclamation were regarded as important from the very beginning. In order to obtain advice on this problem, as well as others, Anderson asked Dr. Vincent Schaefer to serve as consultant. Schaefer advised that the Coordinators should have a series of conferences with Mr. Dave Crandall, Director of Region 4 of the Bureau of Reclamation, at Salt Lake City. Since July 1971, there have been five conferences in Crandall's office involving specialists of the Project in hydrology, economics, and limnology. As a result of these conferences, the relationships between the Bureau of Reclamation and the Project personnel are cordial. In fact, it is planned to undertake joint programs with scientists from the Bureau of Reclamation and the Project in lake geochemistry, sedimentation, and hydrology.

The policy of our activities with regard to the Bureau of Reclamation, as emphasized by Coordinator Anderson, is that all activities of Project personnel which might impinge upon the working relations between the various projects and the Bureau of Reclamation, must be cleared through Coordinator Anderson. This will be done by the monitoring of activities in sensitive areas.

A particularly sensitive area, which is under scrutiny, concerns activities of Project personnel who are also members of the John Muir Institute, since Friends of the Earth is engaged in lawsuits with the Secretary of the Interior. The JMI

is planning to disassociate itself from FOE, so the legal problem is diminishing. The reservations that the Bureau of Reclamation might have about working with Project personnel who are also on the JMI staff should be satisfied by our policy that there is rigid control of what emanates from the Lake Powell Project in the nature of progress reports and publicity releases. While every scientist has the rights of a citizen, no one has the right to make statements on behalf of the Lake Powell Project unless such statements are cleared by Coordinator Anderson. Furthermore, no one group within the Project automatically gets the data of another group except through an agreed upon plan. The impact statements of the whole Project have to be written by the Senior Investigators as a whole.

The relationships between the Project activities and the National Park Service are important since much of the research in the natural science subprojects is connected with activities conducted by boats upon the Lake. Coordinator Anderson, Drake Reynolds, Johnson, Potter, Kidd, and Jacoby are in contact, in varying degrees, with Superintendent Johnson of the Glen Canyon National Recreation Area.

In December 1971, Anderson and Kunitz presented a briefing of the Lake Powell Project to representatives of the Four Corners Commission at the National Science Foundation headquarters in Washington, D.C. Those attending were the following:

Larry W. Tombaugh
Program Manager, Regional Environmental Systems Program
National Science Foundation

Milton F. Searl
Senior Research Associate--Energy and Minerals
Resources for the Future

Frank T. Carlson
Staff Assistant, Office of Regional Planning
Department of the Interior

Robert L. McPhail
Staff Assistant
Assistant Secretary for Water and Power Resources
Department of the Interior

Richard L. Lehman
NOAA, Office of Ecology and Environmental Conservation
Department of Commerce

John M. Neuhold
Program Director, Ecosystem Analysis
National Science Foundation

Priscilla P. Dudley
Executive Secretary
Lake Powell Project

Joan M. Jordan
Biological and Medical Sciences
General Ecology Program
National Science Foundation

Martin Prochnik
Deputy Science Advisor
Department of the Interior

Carlos Stern
Environmental Protection Agency
Office of Research

Orson L. Anderson
Coordinator
Lake Powell Project

Steven J. Kunitz
Epidemiologist
Lake Powell Project

B. RESEARCH PLAN: SUBPROJECTS AND THEIR TASKS

1. A Summary of the Subprojects

By the time of the Denver meeting in January 1972, the recruiting of new personnel, which was the major responsibility of the Coordinators, was finished in the sense that a balanced team of natural scientists and social scientists assembled in Denver for the writing of this proposal. The problem of how the proposals of the subprojects submitted by the investigators were to be welded into a common proposal was assumed by the Steering Committee.

The subprojects described on the following pages survived the discussions of the Steering Committee in Denver. In terms of budget and the tasks they address, they represent greatly modified versions of the proposals which were submitted by the investigators.

Subproject No.	Title	Tasks	Institutions*	Senior Investigator
1	Biological Limnology	2a,3a	UNM	Kidd
	To develop indices of eutrophication, measures of primary productivity, and to understand impact of man on reservoir aquatic ecology.			
2	Shoreline Ecology	2a,2b, 3a	UNM	Potter
	To examine the ecological changes related to rising water level in terms of nutrient and organic matter enrichment as a base for establishing indices for carrying capacity and public use.			
3	Heavy Metals	2a,2c	UNM	Potter
	To examine the concentrations of metallic cations in the Lake Powell ecosystem as they occur laterally across the basin and vertically through trophic food chains, as one aspect of man's impact upon quality of the environment.			
4	Streamflow Trends	1a	UCLA	Jacoby
	To utilize dendrochronologic techniques to develop past runoff characteristics in order to better understand space and time variations in runoff and available surface water.			

5	Lake Evaporation	1b,2a	UCLA	Jacoby

To develop data stations to record information to calculate evaporation losses via mass-transfer and energy-budget methods in cooperation with on-going Bureau of Reclamation programs to determine evaporative losses.

6	Bank Storage	1b,2a	UCLA	Anderson

To more accurately determine the quantity and location of the infiltration of water into bank storage and to assess its availability to potential users.

7	Physical Limnology	2a	Dartmouth	Johnson

To examine factors related to meromixis in Lake Powell, to provide baseline data on circulation and currents within the Lake as its approaches full volume.

8	Lake Geochemistry	1b,2a	Dartmouth	Reynolds

To examine time-dependent distribution of chemical elements in the Lake to quantify ions added to the Lake by solution and/or chemical precipitation.

9	Sedimentation	2a,2d	Dartmouth	Drake

To determine sedimentation rate, distribution, and origin and methods of deposition as they may affect life of the reservoir and its usefulness.

10	Background Air Quality	3a,3c, 4c	NASSA (MNA)	Walther & Williams

To analyze the state of the atmosphere in Lake Powell region without the influence of man,to identify and define air quality parameters not presently being measured, to facilitate measurements of change.

11	Impact Analysis	4a,5c	JMI	Aitken

To examine various environmental impact statements to develop a framework for utilization in policy definition and decisionmaking regarding utilization of the Upper Colorado River Basin.

12	Systems Analysis	6	JMI	Ben-David

To develop a model expressing relationships of various subprojects--as it may be useful to regional development and resource management policy-making.

13	Economics	3a,3c	JMI	Brown

To investigate specific functional dependencies of economic variables upon activities related to recreation, power, and irrigation in the Lake Powell area.

14	Epidemiology	4a,4c	Univ. of Rochester	Kunitz

To develop baseline data regarding relations between diseases and environmental factors to allow for making predictions regarding impact of Lake Powell on resident populations.

			U. Santa Clara	Wagner
		3b,4a,	U. Arizona	Levy
15	Anthropology	4b,5b	W. Wash. St.	Robbins

To study the social and economic impact of the Lake Powell region and its attendant power, mining, and tourism on the Navajo and his decisionmaking related to legal and political issues.

			UCLA	Price
			UCLA	Weatherford
16	Law and Political Science	5a,5b	UCSB	Mann

To examine historically the legal decisions and institutions related to upper basin water development and determination of the extent to which environmental protection and native interests have been recognized or denied.

The chart on page 31, Figure 3, illustrates the research relationships among the subprojects. Four basic components have been identified: (1) people, (2) atmosphere, (3) Lake Powell, and (4) watershed areas. Directional arrows indicate the effect of one system on another. Within component systems there are subsystems, and these interactions have also been identified. A number adjacent to an arrow indicates that the subproject identified by the number will be concerned with the interaction between these systems.

* UNM=University of New Mexico; UCLA=University of California, Los Angeles; UCSB=University of California, Santa Barbara; NASSA=Northern Arizona Society for Science and Art, Inc.; JMI=John Muir Institute; MNA=Museum of Northern Arizona.

MODEL OF THE RESEARCH INTERACTIONS

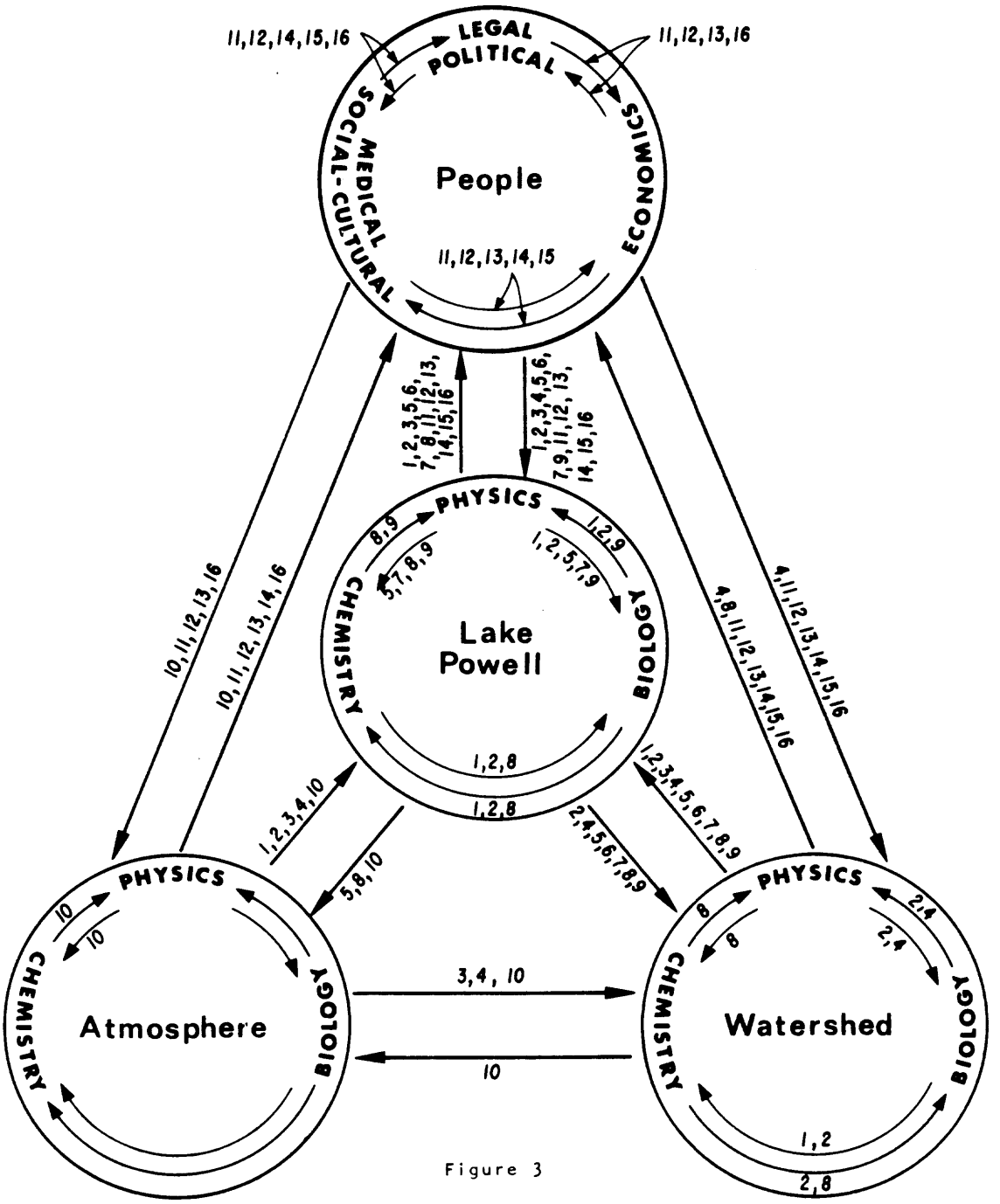


Figure 3

This chart can be considered to be an expanded version of the systems analysis model (Figure 1) on page 9, and is based upon separation by discipline rather than separation by systems analysis components. It is presented here to illustrate the many interactions which must be considered in the systems models. The interactions shown in Figure 3 will not correspond exactly to the interactions shown in Figure 1, because these figures are designed for different purposes.

2. Extent of the Research Area -- "The Lake Powell Region"

Project personnel are often asked, what is meant by the Lake Powell region? The region is defined in terms of its relevancy to the position of the Lake, the decisions affecting the construction of the Lake, and the relation of poeple to the Lake. As a consequence, the Lake Powell region will be different for each subproject. For limnology, geochemistry, and sedimentation, it will be the Lake itself. For the various hydrology subprojects, it will be the shores of the Lake, the air above it, and the headwaters of the Lake hundreds of miles away. For the economists, the region will be extensive. For the anthropologists, it will be the Indian tribes whose reservations are adjacent to the Lake and its main tributaries. For those interested in air quality, it will be the downwind regions of the power plants built in conjunction with the Upper Colorado River system. For those interested in law and political science, the region will extend to state capitols and Washington, D.C.

3. General Plan for the Research

In the arid Southwest, the availability of water for itself and for uses related to its presence affects development more than any other single factor.

The problem for the nation is how to develop the water resources in a manner compatible with both environmental and social factors, and how to understand and deal with the effects and ramifications of this development. The consequences of changes in a natural system are difficult to predict, especially in arid regions such as the Southwest. The pattern of development of water resources in this region has been one of impoundment. The purposes are varied and include irrigation, regulation, recreation, and power generation (both directly in hydroelectric installations and indirectly in plants powered by fossil fuels or nuclear reactors because of the availability of cooling water). These multiple uses are not always compatible with each other or with the varying needs of society, but the incompatibilities and consequences are often not fully recognized

prior to development planning or policy-making. A principal factor has been the lack of identification of the critical factors which must be considered by policy-makers, planners, and managers in formulating plans for utilizing the water resources now and in the future.

Ideally, what is desired is the ability to predict. Prediction requires understanding of the nature of the critical factors and of their interrelations and relative importance. Modelling of environmental systems is, at best, a difficult problem. It involves interactions among people, the biota, the physics, and the chemistry of the natural systems. The Lake Powell area offers some advantages in this regard because of its low density of population, its relatively undeveloped state, and because of its arid nature which tends to simplify the complex natural interactions. This simplicity is only relative as is illustrated by the previous diagram, which shows the interrelationships amongst the varying scientific and sociological disciplines which must be considered. The major interaction is the impact of human activities on the natural system, and conversely the effect of the natural system, or changes in same, on human activities.

The research program which is required to determine the above interactions is complex and involves many disciplines. The research must, of necessity, be conducted by people who are expert within their disciplines but whose work is directed toward the construction of an environmental system model which can be used to estimate the consequences of particular lines of action. The many research projects which have been included in the overall program were chosen for their relationship to the central problem. Initially, preliminary studies were made to determine the feasibility of a multidisciplined approach to the problems of the Lake Powell region. During 1971-72, reconnaissance studies were made under a National Science Foundation (RANN) grant principally in the area of the natural sciences. The social aspects of the problem were at that time in the planning stage.

Inevitably, the natural sciences focussed their attention on studies in the Lake waters, shoreline, and watershed. The beginning work in the social sciences was at an analogous level, i.e., studies of tourism within the area itself. In the course of the initial year, planning for social science and integrative proposals were developed, along with proposals for enlarged work in the natural sciences.

The original thinking was that the work should be aimed at the goal of creating a model of the Lake and its immediate environs that would allow predictions to be made of the results of alternative strategies concerning management of the Lake. Indeed, a systems approach is of value in this regard because,

in addition to allowing increasingly refined predictions to be made, it encourages asking questions to fill in gaps in the research without which such analyses are impossible.

The virtue of such an approach is also its liability. The creation of a model also creates boundaries beyond which investigators are not encouraged to go. In this case, the danger of relying exclusively on a systems approach is that it will confine the investigation to that level of analysis concerned with the impact area itself. While such a study is clearly of value in allowing a coherent veiw of the results of alternate strategies, it leaves outside the system the analysis of the process by which decisions are made. Such decisions are clearly determined by political, economic, social, and other considerations as well as, or in addition to, those of a purely scientific nature.

The Project has defined its users as the population of the southwestern United States and of part of Mexico and those with responsibilities for resource planning and management in this large area. More specifically, so-called "decisionmakers" in various agencies at all levels of government make up one broad category of user--recognizing that even within this broad category many conflicting as well as cooperating arrangements obtain. Another broad category is "the public"--those upon whose behalf decisions are made.

While it is important for both broad categories of users to be aware of the varying outcomes resulting from different management policies, it is equally important that the public understand the process by which such decisions are made. Limiting ourselves to a systematic study of the impact area, and allowing the resulting model to control the questions we ask, will inevitably lead to the neglect of questions of a broader nature. To this end, two of the subprojects deal almost exclusively with questions of this type ("legal-institutional" and "environmental impact" studies). Other subprojects deal with these questions to some degree, while concentrating more of their attention on studies of the impact area itself. Thus, though policy-making involves "trade-offs" and compromises, and while it is hoped that our study will lead to intelligent policy-making by providing good information on the costs of different compromises, it is also planned that we will be able to provide information by which the public may become better informed of the constraints within which policy is made.

We have pointed out that we have defined two very broad categories of users. Both categories of users reside primarily within the southwestern United States. The findings of the studies should be applicable, however, in a direct way to similar areas and in an indirect way through the methodology developed.

Although not the major goal, the experience gained by this cooperative, interdisciplinary effort will have benefit to those planning future activities of this type with a constituency far beyond the area of the Southwest.

4. Interrelationships

The impact of 20th Century man's activities on the Upper Colorado River Basin is clearly multidimensional. In fact, the recognition of this multidimensional nature and the interrelationships between the different dimensions is the basis for the interdisciplinary approach taken by the Lake Powell Project.

The individual subprojects will determine the levels assumed by the specific elements within the vector of man's impact under alternative policies.

The relationships within each component and the relationships between the components will then be joined to form an integrated system. The major sectors in the model will include recreational activities, power production activities, and other industrial and agricultural activities. The model will allow for alternative levels of water availability, water quality, lake levels, air quality, and other environmental factors.

The model will be employed in simulating the impacts of alternative regional development and resource management policies.

Specific results of successful completion of the entire research project will benefit the sets of users. In addition to the massive compilation of baseline data that will be made public, many components of the model can be used independently by outside agencies. The following are included among these components:

- Steady-state chemical model
- Physical classification
- Water budget
- Background air quality parameters which have not been previously measured and air quality characteristics of power plant emissions
- Establishment of eutrophication indices
- Model of source-sink phenomenon
- Recreational carrying capacity of the shoreline regions as a function of Lake level
- The net effects of air pollution on public health in Anglo and Indian communities

- The effects of recreational, power, and irrigation activities on regional employment and income in the area
- Development of legal procedures and controls for protection of cultural and environmental interests in the area

These above-named components will have impact on specific policy decisions such as (a) evaluation of major water development projects; (b) management decisions relating to existing water resources facilities; and (c) policies governing efficient utilization of water resources.

C. THE USERS

1. Definition of the Users of the "Products"

The "users," professional and institutional, will be first those public and private agencies, institutions, and organizations with water resource and related land-use management jurisdiction in the Lake Powell region, but with the Project's larger aim of generalizing in service of the planning needs of similarly concerned "users" throughout the Upper Colorado River Basin.

In order to identify explicitly the potential users of this work, reference is made to the stated "Goals" of the Lake Powell Project (see Introduction).

These immediately define the following questions, to be addressed by the workers associated with the Lake Powell Project:

- Who can make use of the information resulting from the Lake Powell Project? (This includes information exchange between participating subgroups of the Lake Powell Project, by individual Project subgroups with users external to the Project, and by the Project as a whole with external users.)

- Who can make use of these methodologies to be developed under this Project for the evaluation of large resource-based public and private investments (again, who themselves will make pilot applications of the developed methodology; and those external to the Project who must also apply methodologies for such evaluations).

- Who can make use of the results of the applications of the methodologies (including, but not limited to, the application by the Lake Powell Project participants) in the interest of developing public policy?

Although these questions resulted from a concern for the professional service value of the Lake Powell Project, three additional beneficiaries are defined by the same questions. These are (a) the public, which is entitled to a lay-level explanation of the accumulating information, conclusions, and policy recommendations prepared by the workers of the Lake Powell Project; (b) those funding agencies seeking guidance in the development of the most efficient methods to further multidisciplinary, multiinstitutional research applied to national needs; and (c) basic scientists concerned with related scientific work elsewhere.

All of these various "levels" of users are being included in the explicit planning of the Lake Powell Project. Perhaps of equal potential value, though, is that the systems analysis models and environmental impact analysis studies subprojects of the Lake Powell Project are designed in part to aid collectively in the assembly of the Project data in such a way as to be of maximal accessibility to those "users" whom we may not have succeeded in defining explicitly at this time, or to those new users who may be defined by further changes in public law and policy. This enlargened, but not explicitly defined, value will be further supported by the input to the "integrative" subprojects mentioned above from the legal and political (decisionmaking) research to be conducted as still another subproject of the Lake Powell Project.

Finally, an additional service value of the Lake Powell Project is defined by the procedures being developed for continual information exchange with the users: the interface between agencies sharing common or overlapping responsibilities in the Lake Powell Region may be facilitated by communication with the various Lake Powell Project workers as they seek to integrate their results with the various agencies and with the several subprojects.

2. Meeting the Needs of the Users

a. General

The users are identified as both internal and external to the Lake Powell Project. Along with the explicit identification of these is a definition of the routes for communication in the facilitation of the use of the data and methodology. The latter, however, really defines the methodology of the Project as a whole, and is therefore deferred to the discussion of Project methodology. Similarly, the principal intergroup (i.e., intraproject) communication will be for the purpose of furthering the overall Project aims, and is therefore also included in discussion of Project methodology. It should be clear, however, that it is our plan to understand the internal workings of the group not only for our own purposes but for those interested in funding and carrying out such work in the future and those interested more generally in the sociology of science.

Toward the end of facilitating communication with the public, a "Scientific American" level review of the work in progress is proposed at certain intervals from which even more simplified synopses may be extracted for issuance to the news media. A specific budget item ($2500 per year) has been incorporated into the Coordinator's budget for these purposes.

Meeting the needs of the interested funding agencies will be facilitated by frequent review not just of technical progress but of the evolving methodology. This review will be in the form of progress reports, as well as meetings with presentations to interested agencies and representatives of the sponsoring agency, as discussed under the description of Project management.

The other members of the scientific community will be served generally through the normal publication channels used for the dissemination of technical data. This will include transmission of methodologies and other larger Project activities through such channels as the journal Science.

b. Specific

Those various agencies which would be considered as the "ultimate" users of this work are, as defined by the National Environmental Policy Act of 1969, "all agencies of the Federal Government," as well as those regional and local governing bodies which must also take part in resource-based decisionmaking. The number and diversity of these can be illustrated, for example, by simply listing those that contributed to the authorship of the "Upper Colorado Region Comprehensive Framework Study":

- Bureau of Reclamation
- Water Quality Office
- Bureau of Outdoor Recreation
- Bureau of Sport Fisheries and Wildlife
- Bureau of Mines
- Soil Conservation Service
- Economic Research Service
- Corps of Engineers
- Federal Power Commission
- States of Arizona, Colorado, New Mexico, Utah, Wyoming and California

More generally, one can project a list of the users of the products to be assembled by the Lake Powell Project:

- Department of the Interior (Bureau of Reclamation, National Park Service, Bureau of Indian Affairs, Bureau of Land Management, U.S. Geological Survey)
- Department of Agriculture (Forest Service)
- Environmental Protection Agency
- National Oceanographic and Atmospheric Administration
- Interstate Agencies (e.g., Four Corners Regional Commission)
- State Environmental Agencies
- State Departments of Development (especially as related to tourism)

- U.S. Congress
- State Legislatures
- Upper Colorado River Basin Committee
- State Fish and Game Agencies
- Indian Councils
- Power Companies (especially the Salt River Project)
- Federal Power Commission
- State Public Utilities Commissions
- Environmental Organizations
- Natural and social scientists working in the Four Corners area
- Residents of the Four Corners Region

This still defines a very broad spectrum indeed. Some particular examples will serve to illustrate just what kinds of procedures are being defined--and which kinds have already been started--for serving specific users.

c. Examples of Connections to a Particular User

The Bureau of Reclamation is now attempting to develop a computer model of the Colorado River system, to evaluate (predictively) the effects of local development on the rest of the system. In discussions with representatives of the Salt Lake City office of the Bureau, it was learned that they anticipate the systems analysis model of the Lake Powell Project to provide not only assistance in methodology, but also, as real data are included in the model, to provide specific input to the Colorado River systems model. Indeed, they have informed us (verbally) that our proposed Lake Powell impact evaluation and model will be considerably more detailed than their own models of system elements, thereby helping to identify those most important data inputs to their larger model.

Further, the Bureau of Reclamation is going to be involved in future modeling of the Colorado River system airshed, as certain proposed air-impacting developments are expected to fall under their jurisdiction in the future. They therefore defined the Lake Powell Project water-related model as being of "immediate" value to them while the related work on the air shed(s) in the Lake Powell regin will be of "future" assistance to them.

Work to be conducted by the Lake geochemistry subgroup should aid in the definition of procedures for controlling the quality of water below the dam by programmed withdrawals. Discussions toward this end have already been initiated with representatives from the Bureau of Reclamation and the Utah Department of Fish and Game.

More generally, the hydrology subprojects are expected to lead to contributions that can aid in the management of the Upper Colorado River Basin reservoir system. Discussions to this effect have been held with representatives from the Bureau of Reclamation and the Environmental Protection Agency. A "fringe benefit" to these discussions was in the development of a proposed joint effort between the Lake Powell Project hydrology workers and the Bureau of Reclamation to define the magnitude and disposition of bank storage and a cooperative program aimed at accurately calculating evaporation losses from the reservoir. In addition, the streamflow trends program is expected to furnish data for projections of available surface-water supply.

Workers in the background air quality subproject have already been in contact with representatives from Dames & Moore (particularly in the definition of work which would complement--and supplement--the work under contract with the Salt River Project), the Arizona State Department of Health, the Bureau of Reclamation, and Environmental Protection Agency, the National Park Service, the Bechtel Corporation, and the New Mexico Environmental Improvement Agency. In particular, the EPA and the Bechtel representatives have expressed an interest in the calculations regarding the conversion of oxides to particulates and other visibility effects related to smoke plumes from the various coal-fired electric generation plants in the Four Corners Region, which are to be performed by the Lake Powell Project workers.

The anthropology and epidemiology workers have been in contact with the Navajo Tribe, the Bureau of Indian Affairs, the Indian Health Service, and the State Health Departments of Arizona and New Mexico. The Tribe and the BIA have expressed an interest in defining the skills for jobs which may become available, while all of the groups contacted have indicated an interest in obtaining results of our analyses of data to be gathered from their own medical records and death certificates. This is particularly true for data relevant to respiratory disease and air quality, as well as related to changing disease patterns and how these might influence program planning in the future. All of these concerns will be pursued within the adopted work objectives of the Lake Powell Project.

To give yet another explicit example of the range of the societal utility of several of the Lake Powell subprojects, the National Park Service has expressed an interest in the work of the shoreline ecology subgroup as it relates to increasing population pressure and use in the Lake Powell Recreation Area, and are anxious to obtain data which will help define the carrying capacity of the Lake shoreline for camping and recreational use, as an aid toward the preparation of management guidelines.

Finally, the "integrative" workers (systems analysis models and environmental impact analysis studies) have prepared for the external utility of their work, while also developing a framework for the internal function of their alternative models and analyses, specifically in discussions with representatives from the U.S. Geological Survey and staff members of the President's Council on Environmental Quality.

III. MANAGEMENT

A. THE STEERING COMMITTEE AND THE COORDINATOR'S OFFICE

There are two management functions: policy decisions and executive action. Policy decisions are made by the Steering Committee; executive action is carried on by the Coordinator's Office. The division of responsibility between these two functions is in continuous evolution, as is described in subsections II.B.2 and II.B.3. Essentially, day-to-day problems are solved by actions of the Coordinators until such time as serious issues evolve, when such issues are then placed on the agenda of the Steering Committee. The resolutions of the Steering Committee are subsequently executed by one of the Coordinators, or by the Executive Secretary upon instructions from one of the Coordinators.

The Steering Committee now controls the budgetary level of the Project, all future growth and additions to the Project, and policy-monitoring publications and publicity emanating from the Project.

At the present time, the Steering Committee is comprised of experts in a wide spectrum of professions, including law, medicine, oceanography, biology, geophysics, economics, anthropology, environmental science, and an ex officio geologist. The Steering Committee is chaired alternately by the two Co-Chairmen, who are also the Coordinators of the Project. The budget covering the costs of the Steering Committee meetings is found in the Coordinator's budget of UCLA. Money is allocated for five Steering Committee meeting periods in this proposal: two in 1972 (Flagstaff and Washington, D.C.); three in 1973 (Salt Lake City, Flagstaff, and Albuquerque); and 1 in 1974 (Tucson). The present members of the Steering Committee are shown on page 44.

The Coordinator's Office manages the affairs of the Project. The Coordinators are Orson L. Anderson, Professor of Geophysics at UCLA, and Jerrold E. Levy, Professor of Anthropology at the University of Arizona, and their responsibilities are divided as follows.

The senior position of overall coordination with primary responsibility to the funding institution (RANN of the National Science Foundation) and the primary responsibility for external relations with institutions (with special exceptions) is Orson L. Anderson. The specific external groups involving coordination, for which he is responsible, are listed in the diagram on page 47. Another major responsibility of Anderson

LAKE POWELL PROJECT STEERING COMMITTEE

Aitken, Donald	Ph.D.	Environmental Scientist
	Director John Muir Institute San Jose, California	
Anderson, Orson CO-CHAIRMAN	Ph.D.	Geophysicist
	Institute of Geophysics University of California, Los Angeles	
Ben-David, Shaul	Ph.D.	Economist
	Department of Economics University of New Mexico, Albuquerque	
Drake, Charles	Ph.D.	Oceanographer
	Department of Geology Dartmouth College Hanover, New Hampshire	
Dudley, Priscilla EXECUTIVE SECRETARY (ex officio)	Ph.D.	Geologist
	Department of Geology and Geophysics Boston College Chestnut Hill, Massachusetts	
Kunitz, Steve	M.D., Ph.D.	Physician and Sociologist
	Department of Preventive Medicine and Community Health University of Rochester, New York	
Levy, Jerry CO-CHAIRMAN	Ph.D.	Anthropologist
	Department of Anthropology University of Arizona, Tucson	
Potter, Loren	Ph.D.	Biologist
	Department of Biology University of New Mexico, Albuquerque	
Weatherford, Gary	B.D., LL.B.	Lawyer
	Firm of Ferris, Weatherford & Brennan San Diego, California	

is the coordination of the scientific work of those listed in the natural science category. This consists, to the extent that it does impinge upon major policy issues, of determining the balance of effort between the various natural scientists, the overlap of problems arising from work between natural scientists and outside agencies.

A specific example of the last point is that the relationships between agencies of the Department of the Interior (such as BR, NPS, and USGS) and all Project personnel will be governed by one policy, administered by Coordinator Anderson. Some members of the Project, in exercising their rights as citizens, have joined with other groups (not the Lake Powell Project) which are engaged in lawsuits with the Secretary of the Interior over environmental issues. Coordinator Anderson will require all such persons who are part of the Project to file periodic statements which list their legal activities that might be interpreted by others to impinge upon our working relations with outside agencies, and to explicitly define how their Lake Powell Project activities are separated from their activities as citizens exercising their rights in lawsuits.

Coordinator Levy will coordinate the activities of all Project personnel that affect tribal permits. The Project proposes to have one tribal permit from the Navajo Tribe covering all Project activities. In order that there is some control of Project personnel when they are on or over the reservation, so that they do not exceed the limits granted by the permit, all personnel must inform Coordinator Levy of any activities pertinent to Tribal interests. The Navajo Tribe holds Coordinator Levy responsible for all activities of the Project which are undertaken on or over tribal grounds. Any new activities, not granted by the tribal permit, which are proposed by the Project personnel, must be cleared by Coordinator Levy with the Tribe before they can be undertaken.

Levy is also responsible for external coordination to the Bureau of Indian Affairs and the Public Health Service. One of his major responsibilities concerns the integration of the social science investigations and the monitoring of the relative pirorities of the social science investigators to the Lake Powell Project.

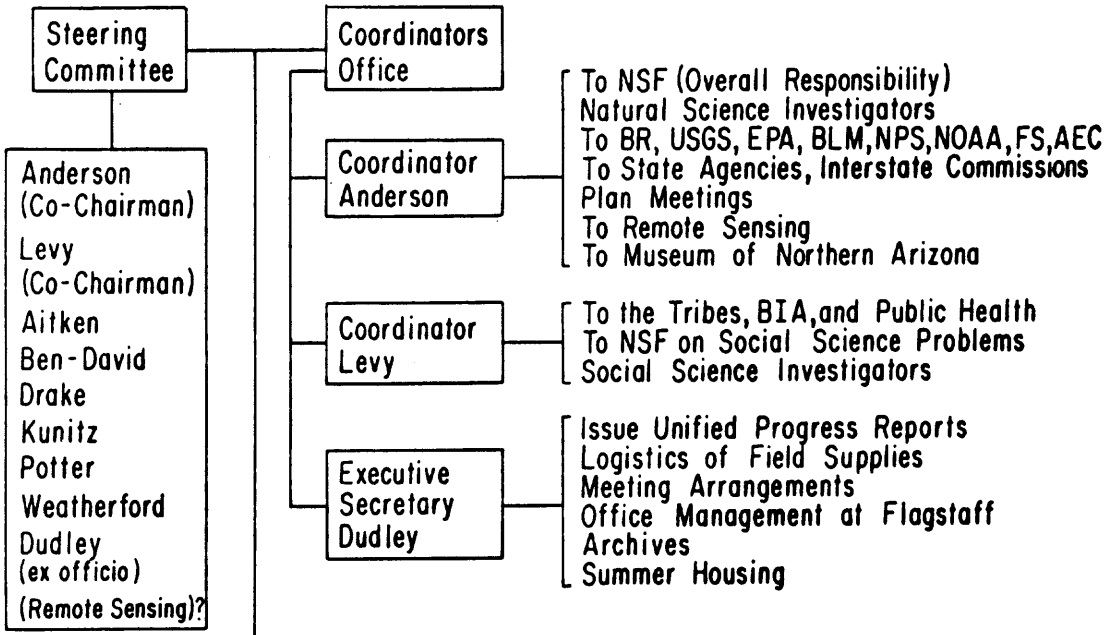
Further division of responsibility between the two Coordinators may be made as new occasions arise.

The Executive Secretary of the Project is Assistant Professor Priscilla Dudley of Boston College. Her general responsibilities and authorities are listed in the table on page 47.

The major responsibility for managing the regional and general meetings are handled jointly by Anderson and Dudley. The money for these meetings is in Anderson's Coordinator's budget.

The coordination and administration are not necessarily conducted from the same location. Each coordinator's home office (Anderson, Los Angeles; Levy, Tucson) is used as a base for coordination activities during the parts of the year that he is not actively engaged in field operations. Much of those activities of the Executive Secretary are carried out from her Boston office (during fall, winter, and spring).

However, in order to facilitate the integration of the field research operations, the Museum of Northern Arizona has been designated as a central field station for the Project. The Coordinator and Principal Investigators will make this their central operations base during the period of the year when they are actively engaged in field work. The field office at the Museum will be open between May and October, with the peak activity between June and September. Coordinator Anderson will have to live on the MNA grounds in a cabin assigned by Director Danson of MNA, from May to October. Dr. Jacoby, the hydrologist, will be working in Flagstaff, so that the field office will be open in the spring and the fall.



Senior Investigators of Subprojects (people doing work) ---------- Consultants (people giving advice)

Social Sciences

Ben-David, S. (E)
Brown, F.L. (E)
Kunitz, S. (M) (S)
Levy, J. (A)
Mann, D. (PS)
Price, M. (L)
Robbins, L. (A)
Wagner, R. (A)
Weatherford, G. (L)

Natural Sciences

Aitken, D. (EN)
Anderson, O.L. (GP)
Drake, C. (O)
Handin, J. (GP)
Jacoby, G. (H)
Johnson, N. (O)
Kidd, D. (B)
Potter, L. (B)
Reynolds, R. (GC)
Stockton, C. (H)
Stokes, M. (H)
Walther, E. (AQ)
Williams, M. (AQ)

Consultants (people giving advice)

Ackermann, W. (H)
Breed, W. (G)
Brown, R. (B)
Danson, E.B. (Gen'l)
Euler, R. (A)
Fritts, H.C. (H)
Gloss, S. (B)
Johnson, L.H. (A)
Jorgenson, J. (A)
Leopold, L.B. (EN)
Kneese, A. (E)
Schaefer, V. (AQ)
Wade, W. (B)
Weisbecker, L.W. (EN)
Winkelstein, W. (M)

Code:

A = Anthropology
AQ = Air Quality
B = Biology
E = Economics
EN = Environmental Science
G = Geology
GC = Geochemistry
GP = Geophysics
H = Hydrology
L = Law
M = Medicine
O = Oceanography
PS = Political Science
S = Sociology

B. THE FUNDING INSTITUTIONS

It is proposed that this Project be funded through the following institutions:

	Subproject	Funding Institutions
1	Biological Limnology (Kidd)	Biology Department University of New Mexico
2	Shoreline Ecology (Potter)	
3	Heavy Metals (Potter)	
4	Streamflow Trends (Jacoby)	Institute of Geophysics UCLA
5	Lake Evaporation (Jacoby)	
6	Bank Storage (Anderson)	
7	Physical Limnology (N. Johnson)	Department of Geology Dartmouth College
8	Lake Geochemistry (Reynolds)	
9	Sedimentation (Drake)	
10	Background Air Quality (Walther)	Museum of Northern Arizona (Northern Arizona Society of Science and Art, Inc.)
11	Impact Analysis Statement (Aitken)	John Muir Institute
12	Systems Analysis (Ben-David)	
13	Economics (Brown)	
14	Epidemiology (Kunitz)	Department of Preventive Medicine and Community Health University of Rochester
15	Anthropology (Levy)	Department of Anthropology Universtiy of Arizona
16	Law and Political Science (Price)	School of Law UCLA
17	Levy's Coordinator's Budget	Department of Anthropology University of Arizona
18	Anderson's Coordinator's Budget	Institute of Geophysics UCLA

The Coordinators' budgets will be handled separately by both the institutions of Anderson and Levy. One contract is sought by UCLA for Anderson's Coordinator's budget, and another contract is sought for subprojects 4, 5, and 6. However, the budget submitted by UA's Department of Anthropology

will include subproject 15, plus Coordinator Levy's budget.

Further details will be found in the attached Appendix.

There are two cases of contractual arrangements. A subcontract in subproject 4, Streamflow Trends, is made to the Laboratory of Tree-Ring Research of the University of Arizona from UCLA, primarily for the salary of Dr. C. Stockton. A subcontract in subproject 10, Background Air Quality, is made to the John Muir Institute, from the Museum of Northern Arizona (NASSA), primarily for the salary of Dr. M. Williams. These contractual arrangements arose as practical management solutions to the decision of the Steering Committee when relative priorities were assigned for the beginning and level of work of each of the subprojects. Essentially, the research covered by these subcontracts is considered by the Steering Committee to be vital for the long-range health of the overall Project, but nevertheless of such a nature that their first phases should be at a controlled rate, with the level of spending less than submitted by their sponsors. In other words, the data generated by these efforts will not be needed until the second year of this contractual period by other researchers (at which time it will be greatly needed), whereas the data of other subprojects will be needed in the first year.

C. SENIOR INVESTIGATORS

The term *senior investigators* is used to designate those investigators who have responsibility for scientific research on subprojects to the Steering Committee and the Coordinators. The term *principal investigators* is used to designate those scientists who have responsibility between the funding institutions and the financial office of the National Science Foundation. In some instances, the Steering Committee and/or the Coordinators have chosen to designate as senior investigators researchers who are legally, insofar as rank within universities is concerned, consultants to the Project. One example is Gary Weatherford, who will spend most of his time for the next few years on the Project, and for this reason has been named a senior investigator. He has also been appointed (and his appointment has been confirmed) to the Steering Committee. On the other hand, his present position in an active law firm makes it so time-consuming to place him on the UCLA faculty in a position commensurate with his responsibility, that he will be named as a consultant to the formal UCLA proposal for law and political science. Another example of a consultant named as a senior investigator for the Project is M. Williams.

The senior investigators who presently comprise the Lake Powell Project were recruited for the Project because they worked in the Four Corners area of the Southwest. They were not recruited because they represented a particular institution, or even a particular department, but rather because they represented proven talent in a discipline or speciality needed for the Project. For this reason, the Lake Powell Project is a rather different type of consortium from those of the past, and is perhaps unique.

The intent of all the senior investigators is to submerge their institutional affiliations, and to magnify the authority of the overall Project. The senior investigators of each subproject submit their budgets and proposals to the appropriate Coordinator, who prepares them for consideration by the Steering Committee. The Coordinators schedule the times of submission and revision, and perform the first step in negotiations between NSF and the senior investigators. The Coordinators visit Washington, D.C., in order to perform this function. From this negotiation, the Coordinators are prepared to recommend priorities, interlocking of the disciplines, and level of budget. However, the budgets and proposals are transmitted to the Steering Committee as received by the senior investigators. The Steering Committee has the responsibility to review, deny, adjust, or confirm the individual budgets. The judgment of the Steering Committee in this decision is guided by the relevance of the subproject to the Project's

problem, goals, and tasks. It is also guided by the timing of results and relevance to other subprojects.

Proposals for major equipment items made by senior investigators, such as boats, trailers, and trucks, are approved or rejected by the Steering Committee, according to an overall plan for common usage for this major equipment. The number of boats, trucks, and trailers proposed by the senior investigators for the next work period is considerably in excess of that allowed by the Steering Committee (which is requested in this proposal).

The Steering Committee insists upon control of this equipment, to the extent that it be used for the good of the overall program. Questions about the ownership, common use, maintenance, and expenses will be answered in the section on Sharing of Equipment in the Lake Powell Project.

When policy matters are brought up, such as budget limitations, in the Steering Committee, the individual subprojects are defended by an individual member of the Steering Committee. This is shown as follows:

Member		Project Number and Title	
Aitken	defends	10	Background Air Quality
		11	Impact Analysis Statement
Anderson	defends	4	Streamflow Trends
		5	Lake Evaporation
		6	Bank Storage
Ben-David	defends	12	Systems Analysis
		13	Economics
Drake	defends	7	Physical Limnology
		8	Lake Geochemistry
		9	Sedimentation
Kunitz	defends	14	Epidemiology
Levy	defends	15	Anthropology
Potter	defends	1	Biological Limnology
		2	Shoreline Ecology
		3	Heavy Metals
Weatherford	defends	16	Law and Political Science

The administration of the policy decisions, as well as the management of on-going affairs,passes through the Coordinators' Office. In administrative matters, the senior investigators look to one of the Coordinators, as shown in the chart on page 47.

PROJECT MEETINGS

In order to facilitate communications between senior estigators, consultants, and outside users, a series of tings will be held periodically throughout each year. These l consist of two general meetings each year, separated by ional meetings. It is planned that all senior investiga- s and most consultants will attend the general meetings. ee regional meetings are scheduled, two in Washington, D.C., one at Albuquerque. The regional meetings are intended gather a few of the senior investigators together at spec- places. Due to the necessity for trips to Washington, D.C. the political and law investigators, two regional meet- s are scheduled in the Washington, D.C., area. At these tings, those investigators in the eastern states will ga- r with investigators in the law and political science sub- ject.

One Washington meeting is scheduled to coincide with the rican Geophysical Union (AGU) meeting, so that the money tickets for four senior people can be saved from the ting budgets (Anderson, Drake, Reynolds, Johnson). It is ortant that this meeting be scheduled to coincide with the meetings, so that a Steering Committee meeting can be held that time. The regional meeting in Albuquerque will be d to discuss the strategy for writing the proposal renewal. uquerque is chosen, to save travel money, since many investi- ors live in or near there.

The general meeting held in Tuscon, January 1974, will for the purpose of budget review prior to proposal submit- . Tuscon is selected because it iscentrally located for many ject personnel.

The general meeting in January 1973 is scheduled to be ld in Salt Lake City, in order to promote relationships be- een the Bureau of Reclamation and Project personnel.

The Coordinator's budget is responsible for the roundtrip rline tickets of most personnel to the Project meetings. ere are some exceptions to this rule. Some investigators have avel to these meetings in their subproject budgets; some are residence at the meeting sites; and some will be in the vicin- y of the meetings on other business. Living expenses for all rsonnel (except some consultants in the Coordinator's budgets) tending Project meetings will be found in the subproject dgets.

A plan reflecting all these considerations, which includes avel expenses to these meetings, plus the costs of meeting commodations (not per diem or travel) is shown in tables on e next two pages. Project personnel may use these tables determine who is to be responsible for their airline ticket the meetings. Executive Secretary Dudley will issue airline

tickets in the amount indicated in the columns. If there is a letter in place of a number, the ticket will not be issued by the Coordinator's office. The total budget for Project meetings in the Coordinator's budget, which includes only airline tickets and accommodations, is $15,310.

Meetings

Personnel	GF and SC Flagstaff 8-9/72	R and SC Wash., D.C. 12/72	G and SC Salt Lake 2/73	R and SC Wash., D.C. 4/73	GF and SC Flagstaff 8-9/73	RF and SC Albuq. 9/73	G and SC Tucson 1/74
ACKERMANN	---	110	B-5	---	---	---	B-5
AITKEN	F	B-11	102	B-11	F	B-11	82
ANDERSON	R	310	102	A	R	110	80
BEN-DAVID	F	234	118	234	F	R	B-12
BROWN	F	---	B-12	234	F	R	66
DANSON	R	---	144	---	R	---	80
DRAKE	F	110	282	A	F	306	304
DUDLEY	R	76	282	76	R	306	304
FRITTS	75	---	B-6	--	75	B-6	R
HANDIN	B-6	---	158	A	B-6	---	B-6
JACOBY	R	---	B-6	B-5	R	B-5	80
JOHNSON	F	---	282	A	F	---	304
KIDD	F	---	118	---	F	---	66
KNEESE	B-12	R	---	R	B-12	234	---
KUNITZ	F	64	278	64	F	230	284

Meeting Codes:
G=general; R=regional;SC=steering committee; F=field

Allocation Codes:
A=attending other meeting; F=field presence; R=residence; B-9= budgeted in subproject 9; 53=roundtrip airfare in UCLA Coordinator's budget.

Meetings

Personnel	GF and SC Flagstaff 8-9/72	R and SC Wash., D.C. 12/72	G and SC Salt Lake 2/73	R and SC Wash., D.C. 4/73	GF and SC Flagstaff 8-9/73	RF and SC Albuq. 9/73	G and SC Tucson 1/74
LEOPOLD	B-11	R	102	---	B-11	140	122
LEVY	R	268	122	268	R	66	R
MANN	B-16	B-16	B-16	B-16	B-16	110	B-16
POTTER	F	234	118	234	F	R	66
PRICE	B-16	310	102	310	B-16	110	80
REYNOLDS	F	---	282	A	F	---	304
ROBBINS	F	---	---	---	F	---	216
SCHAEFER	F	72	270	---	F	---	284
STOCKTON	B-4	---	B-4	---	B-4	---	R
WAGNER	F	---	114	---	F	---	122
WALTHER	R	---	B-10	---	R	80	B-10
WEATHERFORD	B-16	B-16	102	B-16	B-16	110	80
WILLIAMS	F	---	B-10	---	F	R	66
VARADY	---	---	102	---	---	---	80
Meeting Arrangements (not airfare or perdiem)	300	300	1200	300	300	300	1200
Total Cost to UCLA Coordinator's Budget:	375	2088	4380	1720	375	2102	4270

Meeting Codes: G=general; R=regional;SC=steering committee; F=field

Allocation Codes: A=attending other meeting; F=field presence; R=residence; B-9=budgeted in subproject 9; 53=roundtrip airfare in UCLA Coordinator's budget.

E. PROJECT EQUIPMENT

The policy of the Steering Committee on permanent equipment of an expensive nature, submitted by the senior investigators, is that a plan involving general uses be made and submitted for approval. An ad hoc panel was appointed to study the problem, and their report is the basis of this section.

The project vessel is the single largest budget item in the proposal. Its purchase is required in order to provide (1) a stable platform from which to perform various limnological operations such as turbidity, conductivity, and temperature measurements, and bottom coring, water sampling, and plankton growth studies, and (2) a laboratory in which to conduct analyses of labile constituents whose reliable determinations require immediate analysis. In addition, the vessel will serve as a base of operations and will provide living accommodations for personnel engaged in studies in the Lake. It is not feasible to lease such a vessel because permanent modifications of the interior are required in order to obtain suitable facilities for laboratory work and for the operation of the various limnological sensors and sampling devices used in the studies.

Tables found on the next two pages list the scheduled use of the vessel by the eight investigators whose studies require its availability. There are months when the vessel is not scheduled for heavy use, although it will be in service for at least a portion of every month. The advisability of using this vessel for other personnel at Wahweap Bay will be decided as a policy issue by the Steering Committee. For the time being, the policy is that only those who are required to do their research on the Lake can operate the houseboat.

Two vehicles have been purchased by the Project in the past year. They have not been programmed for shared usage, but are listed nevertheless. The Dodge Dart, purchased by UCLA last year, is for Coordinator Anderson's duties, and is also used for local transportation in Flagstaff for Project personnel when not in use by Anderson. The 3/4-ton Chevrolet pickup truck with camper purchased last year on the UCLA budget is scheduled for continuous use by G. Jacoby, Orson Anderson, and John Handin for the three hydrology subprojects.

No other trucks are recommended for purchase this year as a result of slashes made by the Steering Committee. Instead, money for rental of vehicles or personal cars will be used for transportation.

Project Equipment Used In Common

Ownership	Equipment	Equipment Utilization 1972 M	J	J	A	S	O	N	D	1973 J	F	M	A	M	J	J	A	S	O	N	D	1974 J	F	M	A	M	J
UNM	Project Vessel (houseboat) (User's Name and Initials) L. Potter (LP) R. Reynolds (RR) C. Drake (CD) D. Kidd (DK) N. Johnson (NJ) O. Anderson (OA) G. Jacoby (GJ) J. Handin (JH)		DK LP NJ RR CD	DK OA JH	DK LP NJ	DK RR NJ CD	DK OA GJ JH	DK RR NJ CD	DK GJ	DK	DK RR NJ CD	DK OA GJ JH	DK GJ	DK OA JH	DK NJ RR LP	DK CD	DK LP OA JH	DK RR NJ CD	DK OA GJ JH	DK RR NJ CD	DK	DK	DK GJ	DK OA JH	DK RR NJ CD	DK	DK LP NJ
UCLA	3/4-ton Chevrolet truck with camper (purchased in 1971)		Bk.Stor	Bk.Stor	S.Trend	Evapor.	Bk.Stor	Evapor.	Evapor.	Evapor.	Bk.Stor	Evapor.	Evapor.	Evapor.	Bk.Stor	S.Trend	Evapor.	Bk.Stor	Evapor.	Evapor.	Evapor.	Evapor.	Evapor.	Bk.Stor	Evapor.	Evapor.	Bk.Stor
UCLA	1964 Dodge Dart, Coordinator's car (purchased in 1971) and assigned to Anderson; otherwise used for Project personnel		OA 1/2	OA,primar.	OA,primar.	OA,primar.	OA 1/2		To be used in Flagstaff or Los Angeles, wherever most effective						OA 1/2	OA,primar.	OA,primar.	OA,primar.	OA 1/2	To be used in Flagstaff or Los Angeles, wherever most effective						OA 1/2	OA,primar.
UA	Trailer, used for home and mobile office, anthropology, law, and political science			Random locations in the Navajo Reservation. Occasionally in Flagstaff at Museum of Northern Arizona																							
JMI	Portable calculator	Ord	Del	← Impact Analysis →																							
	Computer terminal installed at Dept. of Economics, UNM	Planned Usage by: systems analysis (12); biological limnology (1 economics (13); shoreline ecology (2); background air quality (10 and heavy metals (3)																									

The housetrailer, proposed as a new budget item, will be used continuously on an alternating basis by the social science coordinator and the principal investigators and graduate students who are involved with the subprojects dealing with law, political science, and anthropology. The availability of the housetrailer and the camper is responsible for significant diminution in field expenses which would otherwise be prohibitive if normal, commercial, living accommodations were utilized by study personnel.

The purchase of a computer terminal for use with the IBM 360/67 is to be installed in the Department of Economics at the University of New Mexico. The terminal is scheduled for the general use of subprojects whose investigators are located at UNM, namely, the biological, systems analysis, and economic investigations. The device is not scheduled rigidly for programmed use. Rather, it is available on a continuous, shared, and informal basis to all qualified investigators.

All capital equipment will revert to the original subproject institution upon termination of the grant unless specific arrangements are made otherwise.

Vehicles (trucks and cars) are Project equipment rather than subproject equipment. As such, all use and operators of this equipment will be approved by the Project Coordinator's Office. The Project vessel is an exception. Permission for its use will be obtained from Dr. D. E. Kidd, at UNM.

In addition to these general items, special laboratory equipment for the various subprojects is needed.

In the three biology subproposals, Nos. 1, 2, and 3, there are a number of items involving laboratory analysis work. In the three Dartmouth proposals, Nos. 7, 8, and 9, there are a number of pieces of equipment for laboratory analysis and field measurements. The ad hoc committee reported that in no case was there duplication, and in no case could there be common usage. A similar report was made for the UCLA hydrology equipment budget, Nos. 4, 5, and 6, and the MNA air quality budget, No. 10.

F. TIME SCHEDULES

The Coordinators asked each senior investigator to submit a schedule of the time proposed to be spent on the Lake Powell Project for the next 2 years, using fraction effort and fraction paid as guides for a month-by-month estimate. These estimates are found on the tables on the next four pages. These tables will be used primarily as guides for the senior investigators to find each other for cooperative programs, and for the Coordinators to locate various personnel for special purposes.

It was the intention of the Coordinators to use these tables to design a schedule for achieving major accomplishment milestones in achieving research objectives. This schedule is impossible to grasp at this writing because of the uncertainty in the nature of the interlocking of the social science and natural science components. After many discussions at the Denver meeting in January 1972, it became apparent that the goals of one subproject depend upon the results of other subprojects in a complicated way. The flow of information, data, and results from one subproject to another (see page 31) is involved, and the description of the system is the responsibility of the systems analysis component (subproject 13) under S. Ben-David. It is sufficient to state that this problem will be vigorously undertaken simultaneously with the other subprojects.

Active Time Schedule

	1972								1973												1974									
Names	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
AITKEN, D.		1/4	1	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1	1		1	1	1	1	1	1/4	1/4	1/4	1/4					
Student					1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1	1	1	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3					
ANDERSON, O. work	3/4	1	1	1	1/4	1/4	1/4	1/4	1/2				1/4	1	1	1	1/4	1/4	1/4	1/4	1/2				1/4					
ANDERSON, O. pay		1	1	1										1	1	1														
BEN-DAVID, S.	1/3	1	1	1/2	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1	1	1/2	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3						
Research Assoc.	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2						
Grad. Student	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2						
BROWN, F. L.	1/3	1	1	1/2	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1	1	1/2	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3						
Grad. Student													1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2					
DRAKE, C. L. work		1/2	1	1/2	1/2		1/4			1/4	1/4			1/2	1/2	1/2	1/4		1/4		1/4	1/4		1/4	1/4					
DRAKE, C. L. pay				1/2	1/2										1/2	1/2														
Student		1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2					
Student		1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2					
DUDLEY, P. work	3/4	1	1	1	1	1	1/4	1/4	1/4	1/4	1/4	1/4	1	1	1	1	1	1/4	1/4	1/4	1/4	1/4	1/4	1/4	3/4					
Flag. Ofc. Staff		1	1	1	1								1	1	1	1							1	1	1					
HANSMAN, G. 100%																														
JACOBY, G. C. 100%																														
Field Tech., 25%																														
Grad. Student		1	1	1	1/2	1/2	1/2	1/2				1/2	1/2	1	1	1	1/2	1/2	1/2	1/2	1/2	1/2								
Student			1	1	1										1	1	1													
JOHNSON, N. work			1	1/2	1/4	1/4	1/2	1/4	1/2	1/2	1/2	1	1	1	1	1	1/4	1/2	1/2	1/2	1/2	1/2	1/2	1/4	1/2					
JOHNSON, N. pay			1	1/2								1/2	1/2	1/2	1	1														
Technician					1/2	1/2	1/2	1/2										1/2	1/2	1/2	1/2									
Student			1	1		1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1	1	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3					

Active Time Schedule

Names	1972 M	J	J	A	S	O	N	D	1973 J	F	M	A	M	J	J	A	S	O	N	D	1974 J	F	M	A	M	J	J	A	S	O
KIDD, D. E. work	1/2	1	1	1	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/2	1	1	1/2	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/2					
KIDD, D. E. pay	1/2	1	1	1/2									1/2	1	1	1/2														
Technician, 100%																														
Grad. Student																														
Grad. Student																														
Student, 50%																														
Student, 50%																														
Student, 40%			1/5	2/10	2/10	2/10	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	2/5	2/5	2/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5		
KUNITZ, S.				1/2	1	1											1	1	1/2											
Student			1	1	1	1/10	1/10	1/10	1/10	1/10	1/10	1/10	1	1	1	1	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5		
LEVY, J. E.				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1											
Student				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Student				1	1	1	1	1	1	1	1	1				1	1	1	1	1	1	1	1					1/2		
Student																1/2	1/2	1/2	1/2		1/4	1/4	1/4					1/2		
Student							1/4	1/4	1/4							1/2	1/2	1/2	1/2									1/2		
POTTER, L. D. work	1/2	1/2	1/2	1/2												1/2	1/2	1/2	1/2											
POTTER, L. D. pay	1/2	1/2	1/2	1/2												1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	
Grad. Student	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	
Grad. Student	1/2	1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2																		
Student, 50%																			1											
Student, 50%													1				1/4	1/4	1/2		1/4	1/4	1/4	1/4	1/4	1/2	1/2			
Student, 50%									1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/2	1	1	1/2											
PRICE, M.			1/2	1	1	1/2													1/4											
Law Student				1/4																										
Grad. Student																														

Active Time Schedule

	1972								1973												1974									
Names	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
REYNOLDS, R. work			1		1/4	1/4	1/2	1/4				1	1	1	1	1	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4					
REYNOLDS, R. pay			1									1/2	1/2	1/2	1	1														
Technician					1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2			1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2					
Grad. Student			1	1		1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1	1	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3					
ROBBINS, L.				1	1	1	1	1					1	1/2	1	1	1/2	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3					
STOCKTON, C. W.			1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2		1	1	1/2	1/2	1/2	1/2	1/2	1/2	1/2	1/2							
Technician				1	1	1	1	1	1	1	1	1	1					1	1											
Student				1	1	1	1	1	1	1	1	1	1																	
WAGNER, R.		1	1	1	1/2	1/2	1/2	1/2	1/2	1/2				1/2	1/2	1/2	1	1	1	1/2	1/2	1/2								
WALTHER, E., 25%																														
Technician																														
WEATHERFORD, G.		1	1	1	1/2			1	1	1	1	1	1/2	1	1	1/2							1/4	1/4						
WILLIAMS, M., 60%																														

G. DISSEMINATION OF DATA AND PUBLICITY

1. Internal

The Coordinator's Office implements the dissemination of information within the Project

2. External

All material being readied for publication or considered for dissemination to user agencies must be submitted to the appropriate Coordinator for review and is released only by the authority of Coordinator Anderson. Such information includes the categories of publications, Project reports, news releases, and data exchange with user groups.

It is the specific task of the Coordinators to release publicity or news release statements on behalf of the Project. Any news release not emanating from the Coordinator's Office will be disclaimed by the Lake Powell Project.

Policy adopted for the dissemination of information to user groups is guided by the principle that the data must have been analyzed and that we are reasonably confident of its interpretation. In addition to this, information pertaining to human populations must be reviewed to preserve confidentiality.

The policies guiding the dissemination of information through workshops, seminars, briefings, and public talks will be decided in the very near future by the Steering Committee. Their decision will be guided by the necessity for representing the Project to the public and to our user groups. The decision will conform to the general policy laid down for the dissemination of information.

It is the intention of the Steering Committee to devise methods of publishing reports of the results of the Project, on a technical level that is easily understood by the lay public. Although the mechanism to do this has not been decided upon, a sum of $5000 for this purpose will be found in Coordinator Anderson's budget.

The final reports of the Project will be disseminated to libraries and to major user groups.

The responsibility of the entire Project is to analyze and present data in an integrated manner which ensures that all results are presented as they related to overall problems. The responsibility of devising the means to analyze and present the data in this manner is the responsibility of the systems analysis component (see chart and the detailed proposal of Dr. Shaul Ben-David, Systems Analysis).

H. REMOTE SENSING

This proposal does not have within it a budget request for remote sensing, because any adequate remote sensing program would require support, not only from NSF, but from other agencies such as NASA, DOD, and USGS. However, it is recognized that remote sensing is extremely important to the research of the Project itself. The Lake Powell Project staff is seeking some person or group to write an adequate proposal to the appropriate agencies for support to the Project. It is the plan of the Steering Committee to recommend to the Project's sponsors at NSF that they should contribute to a remote sensing budget on an interagency basis when a good proposal is submitted which protects the rights of the Project. The most likely sponsors of such a proposal, at this time, are personnel working in and with the Photographic Interpretation Research Division (PIRD), U.S. Army Topographic Command, in those aspects of the scientific endeavors amenable to detailed aerial sensing in support of the Project objectives.

If a suitable remote sensing proposal is funded, and if the Lake Powell Project's sponsors contribute to the funding of this proposal, and if the Lake Powell Project's rights to the basic film and interpretive charts resulting from the flights are protected, then the Steering Committee will consider in what way the principal investigators of the remote sensing project will be incorporated within the management.

I. THE BUDGET SUMMARY

The following table shows the budgets actually submitted in this proposal as compared to the amounts approved by the Steering Committee on January 18 (page 16).

Project Number and Title		January 18		Submitted
1 Biological Limnology		$174,000		$174,637
2 Shoreline Ecology		$ 50,000		$ 50,249
3 Heavy Metals		$ 50,000		$ 50,010
4 Streamflow Trends	$38,000		$39,623	
5 Lake Evaporation	$57,000		$56,180	
6 Bank Storage	$51,000		$50,188	
		$146,000		$145,991
7 Physical Limnology				
8 Lake Geochemistry		$181,500		$181,246
9 Sedimentation				
10 Background Air Quality		$117,000		$111,621
11 Impact Analysis		$ 52,000		$ 46,979
12 Systems Analysis		$ 61,000		$ 71,496
13 Economics		$ 71,000		$ 71,335
14 Epidemiology		$ 27,000		$ 27,596
15 Anthropology		$130,000		$126,128
16 Law & Political Science		$ 70,000		$ 74,995
17 Coordinator (UA)		$ 30,000		$ 29,986
18 Coordinator (UCLA)		$122,300		$122,222
TOTAL		$1,281,800		$1,284,541

Most of the budgets are within a fraction of a percent of the amount assigned by the Steering Committee on January 18,1972. All exceptions have been approved by subsequent votes of the Steering Committee. The budget of the Law and Political Science subproject has been increased by 7%, which was authorized by telephone roll call vote on January 27, 1972. This approval was justified by the need for additional work in political science by Professor Dean Mann. The Impact Analysis budget

was decreased, the Background Air Quality budget was decreased, and the Systems Analysis budget was increased as a result of Steering Committee approval. The action was authorized by telephone vote on and about March 28, 1972. The decision for budget changes was taken in response to general criticism by the reviewers of the subprojects proposed who felt that the budget of the Systems Analysis subproject should be strengthened.

The institutional budgets through which the 16 subprojects are to be funded are as follows (subproject numbers precede titles):

University of New Mexico, Biology Department			$ 274,896
1	Biological Limnology	$ 174,637	
2	Shoreline Ecology	$ 50,249	
3	Heavy Metals	$ 50,010	
Dartmouth, Geology Department			$ 181,296
7	Physical Limnology	$ 61,920	
8	Lake Geochemistry	$ 67,516	
9	Sedimentation	$ 51,860	
UCLA: A, Institute of Geophysics			$ 145,991
4	Streamflow Trends	$ 39,623	
5	Lake Evaporation	$ 56,180	
6	Bank Storage	$ 50,188	
UCLA: B, Institute of Geophysics			$ 122,222
	Coordinator's Budget	$ 122,222	
UCLA: C, School of Law			$ 74,995
16	Law & Political Science	$ 74,995	
University of Arizona			$ 156,114
15	Anthropology	$ 126,128	
	Coordinator's Budget	$ 29,986	
University of Rochester			$ 27,596
14	Epidemiology	$ 27,596	
John Muir Institute			
11	Impact Analysis	$ 46,979	$ 189,810
12	Systems Analysis	$ 71,496	
13	Economics	$ 71,335	
Northern Arizona Society for Science and Art, Inc.			$ 111,621
10	Background Air Quality	$ 111,621	
		TOTAL:	$ 1,284,541

Budget Summary

	C. Salaries, Wages and Benefits		D. Permanent Equipment		E. Expendable Supplies	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
1. Biological Limnology	38,411	45,687	24,235	---	1,300	1,300
2. Shoreline Ecology	11,211	11,491	600	---	1,100	900
3. Heavy Metals	13,711	14,107	900	---	2,100	1,700
4. Streamflow Trends	575	575	---	---	224	174
5. Lake Evaporation	11,677	12,328	3,430	3,000	2,700	1,850
6. Bank Storage	11,796	12,094	425	---	900	850
7. Physical Limnology	11,680	9,980	7,410	---	4,110	1,460
8. Lake Geochemistry	12,452	11,520	3,944	---	2,400	2,400
9. Sedimentation	7,167	7,167	5,415	1,005	2,000	1,740
10. Air Quality & Water Mgmt.	14,000	14,770	11,360	---	1,000	1,000
11. Impact Analysis	7,835	16,507	395	---	---	---
12. Systems Analysis	12,650	21,500	8,838	---	850	850
13. Economics	26,120	22,900	---	---	500	500
14. Epidemiology	5,719	3,507	---	---	1,900	500
15. Anthropology	22,000	11,000	---	---	1,325	825
16. Law/Political Science	6,313	6,313	---	---	3,410	3,410
17. Coordinator (UA)	5,830	11,402	---	---	430	650
18. Coordinator (UCLA)	20,585	17,725	---	---	520	520
	239,732	250,573	66,952	4,005	26,769	20,629
	490,305		70,957		47,398	

Budget Summary

	F. Travel		G. Publications		H. Computer Costs	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
1. Biological Limnology	11,764	12,264	300	300	230	230
2. Shoreline Ecology	7,625	7,550	200	300	---	---
3. Heavy Metals	1,840	1,915	100	200	100	200
4. Streamflow Trends	70	70	---	---	---	---
5. Lake Evaporation	2,339	2,231	300	400	1,386	1,386
6. Bank Storage	4,660	4,652	300	400	198	396
7. Physical Limnology	4,320	4,320	200	200	700	500
8. Lake Geochemistry	4,380	3,960	850	840	2,000	2,000
9. Sedimentation	7,250	7,250	1,100	1,100	100	100
10. Air Quality & Water Mgmt.	2,440	2,390	---	---	---	---
11. Impact Analysis	3,682	6,523	300	300	300	300
12. Systems Analysis	3,525	3,525	300	300	2,580	3,040
13. Economics	2,000	2,000	300	300	230	230
14. Epidemiology	3,000	3,000	---	---	500	500
15. Anthropology	7,480	4,380	---	1,000	---	1,620
16. Law/Political Science	5,787	4,124	---	---	---	---
17. Coordinator (UA)	1,235	2,143	---	---	---	---
18. Coordinator (UCLA)	17,486	15,105	2,500	2,500	---	---
	90,883	87,402	6,750	8,140	8,324	10,502
	178,285		14,890		18,826	

Budget Summary

	I. Other Costs		J. Total Direct Costs		Indire
	Year 1	Year 2	Year 1	Year 2	Year 1
1. Biological Limnology	3,600	1,000	79,840	60,781	15,599
2. Shoreline Ecology	---	---	20,736	20,241	4,58
3. Heavy Metals	1,000	1,000	19,751	19,122	5,49
4. Streamflow Trends	24,174	13,441	25,043	14,260	160
5. Lake Evaporation	3,190	3,071	25,022	24,266	3,35
6. Bank Storage	3,153	3,107	21,432	21,499	3,58
7. Physical Limnology	3,780	3,900	32,200	20,360	4,71
8. Lake Geochemistry	3,880	4,000	29,906	24,720	6,765
9. Sedimentation	2,200	2,000	25,232	20,362	3,13
10. Air Quality & Water Mgmt.	15,385	15,385	44,185	33,545	16,73
11. Impact Analysis	1,871	2,880	14,383	26,510	1,95
12. Systems Analysis	2,500	2,500	31,243	31,715	3,16
13. Economics	2,000	2,000	31,150	27,930	6,5
14. Epidemiology	2,784	2,784	13,903	10,291	2,10
15. Anthropology	40,118	26,839	70,923	45,664	6,26
16. Law/Political Science	24,600	14,600	40,110	28,447	3,2
17. Coordinator (UA)	500	950	7,995	15,145	2,31
18. Coordinator (UCLA)	16,318	10,993	57,409	46,843	9,64
	151,053	110,450	590,463	491,701	99,3
	261,503		1,082,164		2

Budget Summary

	L. Total Costs		Grand Total for 2 Years
	Year 1	Year 2	
1. Biological Limnology	95,439	79,198	174,637
2. Shoreline Ecology	25,318	24,931	50,249
3. Heavy Metals	25,244	24,766	50,010
4. Streamflow Trends	25,203	14,420	39,623
5. Lake Evaporation	28,377	27,803	56,180
6. Bank Storage	25,019	25,169	50,188
7. Physical Limnology	36,915	25,005	61,920
8. Lake Geochemistry	36,671	30,845	67,516
9. Sedimentation	28,365	23,495	51,860
10. Air Quality & Water Mgmt.	60,923	50,698	111,621
11. Impact Analysis	16,342	30,637	46,979
12. Systems Analysis	34,406	37,090	71,496
13. Economics	37,680	33,655	71,335
14. Epidemiology	16,003	11,593	27,596
15. Anthropology	77,192	48,936	126,128
16. Law/Political Science	43,329	31,666	74,995
17. Coordinator (UA)	10,311	19,675	29,986
18. Coordinator (UCLA)	67,051	55,171	122,222
	689,788	594,753	1,284,541

1,284,541

Budget Summary

	Special Categories of Other Costs		Special Categories of Travel
	Consultants (2 Years)	Subcontract (2 Years)	LPP Meetings Air Fares (2 Years)
1. Biological Limnology	4,600	---	---
2. Shoreline Ecology	---	---	---
3. Heavy Metals	2,000	---	---
4. Streamflow Trends	---	37,615	222
5. Lake Evaporation	5,200	---	1,060
6. Bank Storage	5,200	---	802
7. Physical Limnology	---	---	---
8. Lake Geochemistry	---	---	---
9. Sedimentation	2,000	---	---
10. Air Quality & Water Mgmt.	---	30,770	358
11. Impact Analysis	2,000	---	1,344
12. Systems Analysis	5,000	---	465
13. Economics	4,000	---	---
14. Epidemiology	2,000	---	---
15. Anthropology	5,052	44,065	---
16. Law/Political Science	37,000	---	2,106
17. Coordinator (UA)	---	---	---
18. Coordinator (UCLA)	9,900	---	11,410
	83,952	112,450	17,767

Budget Summary

	Special Categories of Travel (2 Years)			
	Boat Travel	Per Diem & Living Expense	Total Air Fares LPP Meetings Other Trips	Car & Truck Travel
1. Biological Limnology	8,928	5,400	600	5,500
2. Shoreline Ecology	10,000	3,575	600	1,000
3. Heavy Metals	200	2,055	400	1,100
4. Streamflow Trends	---	---	140	---
5. Lake Evaporation	---	3,102	1,468	---
6. Bank Storage	---	4,265	2,647	2,400
7. Physical Limnology	400	1,440	5,600	1,200
8. Lake Geochemistry	---	2,040	4,320	1,480
9. Sedimentation	1,200	3,600	6,800	1,600
10. Background Air Quality	---	1,880	530	2,420
11. Impact Analysis	---	5,823	4,382	---
12. Systems Analysis	---	5,330	2,360	1,200
13. Economics	---	2,000	400	1,600
14. Epidemiology	---	2,520	3,480	---
15. Anthropology	---	1,960	2,000	7,900
16. Law/Political Science	---	4,479	3,432	2,000
17. Coordinator (UA)	---	1,790	264	1,324
18. Coordinator (UCLA)	---	6,867	20,662	1,162
	20,728	58,126	60,085	31,886

IV. SUBPROJECT DETAILS

A. SUBPROJECT PROPOSALS

The following pages contain the 16 subprojects of the proposal.

Subproject Number 1

Biological Limnology

CULTURAL EUTROPHICATION: AN EVALUATION OF MAN'S POTENTIAL IMPACT ON THE AQUATIC ECOLOGY OF LAKE POWELL

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

Amount Requested	Proposed Duration	Requested Starting Date
$174,637	2 Years	May 15, 1972

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Endorsements

Principal Investigator	Department Head	Approving Administrative Official
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ABSTRACT

The general purpose of this proposal is to develop indexes of eutrophication for Lake Powell in the Glen Canyon Recreational Region. It is planned to measure primary productivity (carbon-14 "light-dark bottle" method) of phytoplankton; primary productivity of periphyton growing on plexiglass slides suspended in the reservoir using a variation of the carbon-14 method devised by us; determination of phytoplankton and periphyton in order to calculate a diversity index for phytoplankton and ellipsis for the periphyton data generated from a normal bivariate distribution function; determination of phytoplankton and periphyton ash-free dry weight; oxygen and biological oxygen demand; and levels of fecal streptococci and coliform bacterial populations. The data should contribute to our understanding of water quality in the reservoir and allow calculation of baseline indexes that can be used by future investigators to evaluate the eutrophication of this and other reservoirs and more fully understand the impact of man on reservoir aquatic ecology (cultural eutrophication).

OBJECTIVES

The general purpose of this proposal is to develop indexes of eutrophication for the Lake Powell region. We wish to accomplish this goal by measuring primary productivity of phytoplankton and periphyton; determination of the quality an quantity of phytoplankton and periphyton in order to calculate diversity indexes; determination of phytoplankton and periphyton ash-free dry weight; oxygen and biological oxygen demand; and measurement of fecal coliform populations.

RATIONALE

The Water Quality Act of 1967 (PL 89-234) requires states to establish water quality criteria for our interstate waterway systems. These standards must be set high enough to mai tain quality of waters so that aquatic habitats may have valu as a public water supply, propagation of fish and wildlife, recreational purposes, agricultural, industrial, and various legitimate uses. Water quality standards have been based largely on chemical and physical criteria and generally not o biological parameters. These is much difficulty in only usi chemical and physical conditions as criteria of water quali They vary widely, act in broad ranges of concentrations, and represent conditions only at the time of sampling (Wilhm and Dorris, 1968). They are not without utility, but we feel t biological parameters are more sensitive indicators of chan such as man's impact on water quality--and should be used in conjunction with physical and chemical criteria. We have i cluded certain chemical analyses because they themselves ca be used as indicators of change, but they also help understand cyclic changes in the biological parameters.

Within the past few years it has become increasingly e dent that we require indexes of eutrophication that will describe changes in lakes over a period of years. Good in dexes document past history and enable researchers to comp rates of change. Our prime procedural problem today is to indexes that are acceptable to the majority of investigator Failure to achieve agreement on indexes makes it very diff cult to evaluate the role of man in accelerating aging cyc and along lakes (cultural eutrophication).

This need for indexes is particularly relevant to the Western United States where there are numerous man-made impoundments (reservoirs). Relevant because "plunking" a reservoir down into an area has profound effects upon man man has profound effects upon the aquatic system. This

interaction between man and reservoir is typified by making possible electrical power generation both as water power and water for cooling of coal-fired generating plants, mining, use of the reservoir for recreational activities--fishing, boating, water skiing, development of shore areas for camping, picnicking, and use of shore regions by land developers. The good side of this interaction is economic development and more widespread public enjoyment and the bad side is acceleration of eutrophication and/or the pollution of these habitats so that they provide reduced economic benefits and aesthetic values.

Southwestern reservoir lakes have relatively short life spans. For example, the useful life of Lake Mead, the impoundment above Boulder Dam, is estimated to be less than 150 years and Elephant Butte Reservoir, the impoundment of the Rio Grande near Truth of Consequences, New Mexico, is about 80 years (Stevens, 1946). There is no reason to believe that Lake Powell will have useable water life longer than about 150 years. Silt is the primary cause of shortened life span. Elephant Butte is already more than halfway along in its predicted life span and turbidity measurements and Secchi disk readings confirm that the upper reaches of this reservoir are, in fact, a rolling river of mud (Kidd and Johnson, 1970). It seems highly probable that the same conditions will come to exist in Lake Powell.

Because Lake Powell has only been open since 1964, we feel that now is the time to initiate a program of selecting eutrophication indexes that meet Hooper's criteria listed below.

Aquatic indexes of eutrophication will be evaluated at the end of the study for their utility in fulfilling Hooper's (1969) four "criteria of useful indices." These criteria are listed below:

1. "A good index should discriminate between changes associatedwith nutrient level and those associated with other categories of environmental change."

2. "A good index should have considerable sensitivity to levels of enrichment, because we want it to help us anticipate changes that are contrary to man's interest."

3. "A good index should be a biological characteristic widespread among aquatic environments but short-lived and sensitive to changes in enrichment levels, especially levels arising from cultural events."

4. "A good index ... should be suitable for long-term surveillance and monitoring by many generations of scientists."

If we do not establish baseline indicators useful for measuring change at this time we may soon be too late to characterize what represents "natural" conditions for Lake Powell waters.

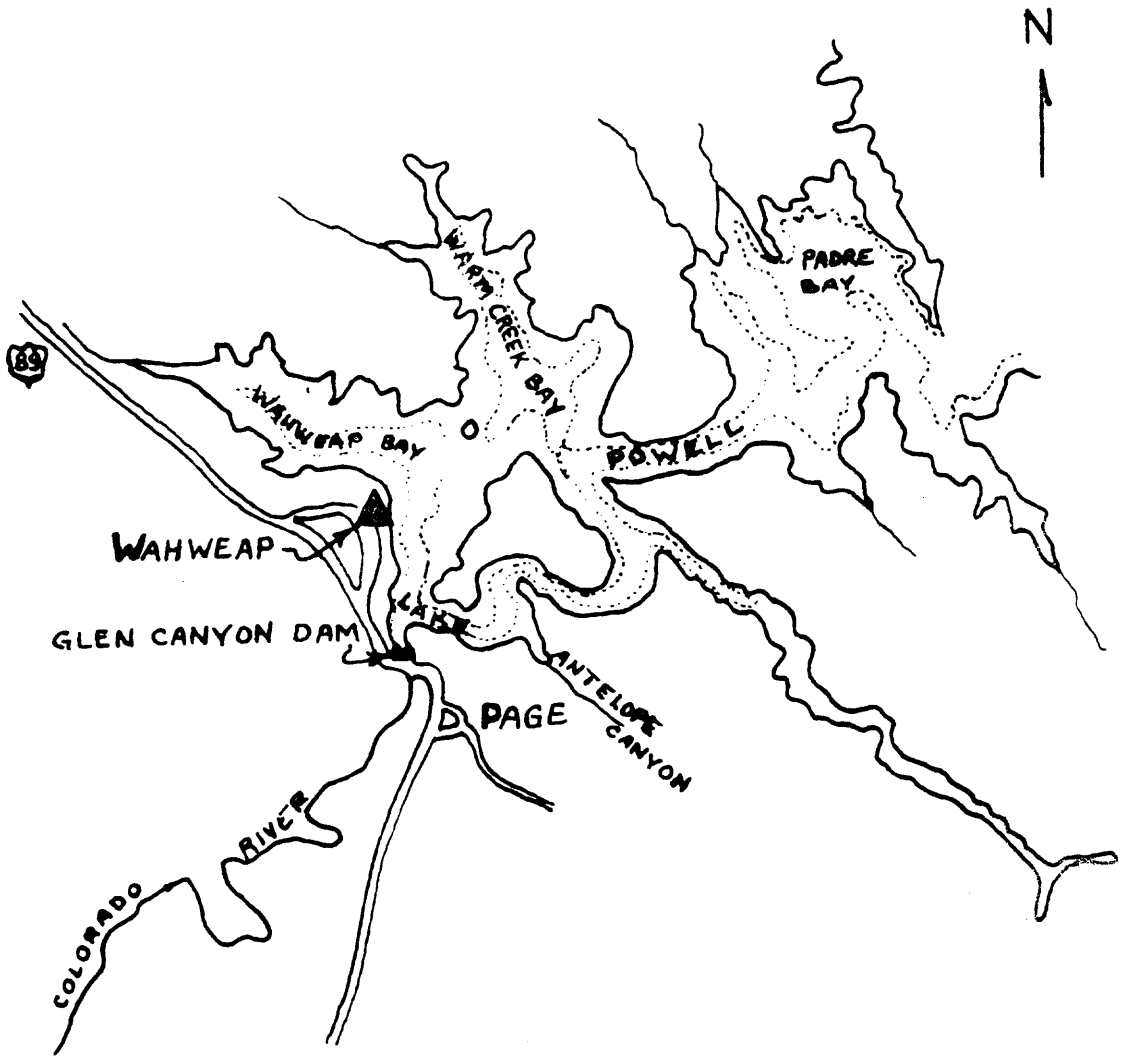
Lake Powell is expected to be subjected to heavy population pressures in years to come. People will be drawn to its overwhelming scenic wonders. The Lake, when filled, should be about 186 miles long, with 1960 miles of canyon-indented shoreline. Recreational potential of this Lake was recognized very early by the government. Congress, in 1956, authorized construction of Glen Canyon Dam. They also authorized the Secretary of the Interior to make the Lake a recreational facility as well as a Colorado River Storage Project to provide for downstream needs. Wahweap (see map) already has National Park Service administrative offices, campground, picnic shelters, launching ramp, swimming beach, marina, restaurant, motel, trailer village, service station, and other tourist-related facilities. Several major marinas and adjacent resort towns are already under development.

A major power plant is now being built adjacent to the Lake which has the potential of altering water conditions in the Lake by direct air pollution. All of these kinds of developments have historically meant changes in water quality through cultural eutrophication (man's impact on water quality).

Lest we think these impacts are not relevant to Lake Powell, we need only to look at what is going on upstream. Investigations of major streams in the Upper Colorado Region indicate that 167 miles have been seriously degraded for aquatic life (Fish and Wildlife, 1971). This is taking place where population levels are sparse. The expected population crunch on Lake Powell will magnify many potential pollution problems. Also upstream degradation can effect changes in water quality at Lake Powell.

We already note heavy boating pressure on Powell, which means discharge of fuels and fuel additives into the water. Marinas are already polluting the water through gas spillages.

Loss of water quality will effect the economic development of the Glen Canyon National Recreational Area. Projections for future recreational days of use for the Lake Powell area are:


N
89
WARM CREEK BAY
PADRE BAY
WAHWEAP BAY
POWELL
WAHWEAP
GLEN CANYON DAM
LAKE
PAGE
ANTELOPE CANYON
COLORADO RIVER

1970	1980	2000	2020
926,000	1,624,800	3,248,300	5,325,000

and the distribution of total use is

Activity	% of Total Use	Activity	% of Total Use
Boating	9.62	Campground	25.99
Fishing	21.48	Back Country	14.15
Water Skiing	3.60	Swimming	10.28
Picnicking	7.55	Sightseeing	7.35

These projections are taken from "San Juan Investigation" (1960).

Hopefully, we may produce a set of criteria that will enable proper monitoring of changes in water quality so that these changes can be detected in time to introduce good management procedures. In this way the above projections may be realized!

Relationship to Other Projects

Since Lake Powell represents a dynamic system which is just beginning its aging process, it can be a very useful model for prediction of useful life as a recreational facility and impact upon indigenous cultures. Knowledge of this kind will be useful for interpreting eutrophication processes in existing and planned reservoirs in this and other countries.

We plan a high degree of interrelationships with the physical and geochemical subprojects of this interdisciplinary proposal. Knowledge of Lake chemical characteristics--particularly the bicarbonate-carbonate buffering system and major ion characteristics will enable us to better understand our primary productivity, biomass, and diversity indexes. The inferences from the Progress Report Dynamic Limnology of Lake Powell (1971) are already useful to us.

There is a natural integration of biological, physical, and geochemical aspects of the reservoir because the information obtained can be used as baseline data against which rates of change in various Lake parameters may be calculated. All of these interactions help understand man's impact on the reservoir.

The subprojects controlled by both Dartmouth and the University of New Mexico plan joint use of a houseboat equipped as a floating laboratory to support field activities of both groups.

Furthermore, we plan to set up our sampling sites at many of the stations already being utilized by the Dartmouth College subprojects.

Coordinating with the hydrology subdivisions of this interdisciplinary proposal will give us an idea of possible influences from the upper Colorado drainage basin on Lake biota and lake chemical components.

As eutrophication proceeds, profound impacts on indigenous cultures occur. A well-managed reservoir can provide an outstanding boost to local economy and greatly affect the native Hopi and Navajo civilizations. These changes affect cultural shifts such as changes in settlement patterns, mores, and tribe structure. Whether these processes of cultural eutrophication provide positive or negative feedback on the Indians is a fundamental question to be answered by the anthropology study. Economic effects, dollar values, and legal problems are other aspects of the interaction between the reservoir and 20th century man in the Glen Canyon Recreationa Region.

Coordination between this project and the UNM subprojects on shoreline ecology and metal ion analysis will be brought about by joint use of laboratory facilities, equipment, and the proposed laboratory boat. The shoreline ecology subproject will provide this project with the information concerning nutrient input into the reservoir. The UNM metal ion analyses relate to eutrophication and man's impact on the Lake.

This subdivision also interacts with the epidemiology and anthropology subprojects. Not only will the results of fecal bacteria measurements, oxygen and biological oxidation demand data, provide baseline criteria of reservoir water quality, but the data also provide background measurements for making epidemiological appraisals of the reservoir through time.

In brief, all proposals relate to important aspects of eutrophication, either through man accelerating natural changes within the Lake or the impact of the Lake changes on the local milieu.

PREVIOUS LAKE POWELL INVESTIGATIONS RELATED TO EUTROPHICATION

The Utah State Division of Fish and Game has been most active in their studies of Lake Powell waters (1965, 1966, 1967, and 1968). These reports deal with the chemical and physical limnology of Lake Powell. This group has also investigated the fish populations and plankton in conjunction with Arizona Department of Game and Fish. None of these studies seeks to set eutrophication parameters in the spirit of Hooper's criteria. No effort is made to set biological parameters for eutrophication or to investigate primary productivity.

As far as is known, there is little or no duplication of the studies presented in this proposal. However, certain patterns related eutrophication are beginning to appear in the data obtained by both the Dartmouth (Progress Report Dynamic Limnology of Lake Powell, 1971) and UNM (Progress Report Primary Productivity, Indexes of Eutrophication Process, and Marginal Vegetation of Lake Powell, 1971).

The "Dynamic Limnology" report asserts that the Lake is "decidedly lotic (river) in character having a mean residence time for the water of only 1 year or so." This finding is important because it explains our phytoplankton counts and taxa information gathered to date (see Exhibit 1). We quickly note the relatively low number of taxa (quality) present at each station depth which is indicative of a lotic (river) environment. There seems to be relative uniformity in counts between the surface and 8 meters. Our data indicate that the euphotic (light) zone extends down to between 8 to 12 meters. Counts are relatively high and appear related to reasonably high rates of carbon fixation during the summer--precise values of carbon fixation have not been computed by us at this writing.

The Dartmouth report poses this "tentative model of the lake chemistry...that calcite is precipitated by photosynthetic withdrawal of CO_2 from surface waters, and that this settles to deeper more acid waters where it is dissolved. During the overturn, a portion of this calcite is precipitated and may accumulate in the bottom muds, thus representing a permanent withdrawal of calcite from the lake." We confirm certain aspects of this model. The pH down to 8 meters during the summer is generally 8.3 or higher and algal counts and rates of carbon fixation appear to be high enough to "precipitate calcite by photosynthetic withdrawal of CO_2 from surface waters."

EXHIBIT 1. ENUMERATION OF TOTAL PHYTOPLANKTON (QUANTITY) AT EACH STATION AND DEPTH THROUGH TIME - COLUMN TWO. THE NUMBER OF TAXA AT EACH STATION AND DEPTH IS INDICATED IN COLUMN ONE OF EACH COLUMN PAIR. COUNTS ARE EXPRESSED AS ORGANISMS PER MILLILITER OF LAKE WATER. DEPTHS ARE EXPRESSED IN METERS.

		1		2		3		4		5	
		Taxa	Nos.	Taxa	Nos.	Taxa	Nos.	Taxa	Nos.	Taxa	Nos.
6/26	s	8	1400	8	2002	10	1190	11	1064	9	700
	2	9	1554	8	2044	10	1764	9	714	6	476
	6	14	2366	13	2800	13	1820	10	1106	10	1078
	8	-	-	-	-	-	-	-	-	-	-
7/3	s	2	140	7	476	8	406	9	588	6	518
	2	8	602	9	672	9	350	10	644	7	420
	6	13	1008	11	574	8	560	7	322	12	448
	8	-	-	-	-	-	-	-	-	-	-
7/10	s	5	180	5	126	5	216	2	36	3	144
	2	7	162	4	144	3	126	2	54	6	252
	6	5	198	4	72	1	18	4	90	4	162
	8	7	162	6	144	3	54	5	144	3	[illegible]
7/17	s	5	1602	7	558	6	270	7	468	3	288
	2	5	936	6	306	6	162	6	594	5	432
	6	5	666	7	270	7	216	3	342	4	288
	8	9	576	6	180	5	252	5	144	3	108
7/24	s	10	342	10	360	7	288	7	306	4	432
	2	8	306	6	216	7	162	5	342	5	918
	6	9	378	6	126	6	288	3	450	3	1062
	8	10	252	4	162	6	504	3	342	7	540
7/31	s	3	108	4	144	4	126	4	360	3	504
	2	5	144	6	234	5	144	8	378	2	324
	6	9	270	5	162	4	144	4	378	4	306
	8	9	414	5	252	5	234	5	630	5	378
8/7	s	7	540	6	378	4	108	4	108	8	198
	2	7	360	4	108	6	270	5	216	7	360
	6	8	666	5	270	5	198	7	288	7	288
	8	8	648	4	216	5	324	9	252	5	126
9/11	s	8	1314	7	1134	6	1080	3	1098	4	2250
	2	7	1656	6	2196	5	1296	4	1584	4	1638
	6	6	558	5	936	4	1278	4	1224	4	1800
	8	6	468	3	270	5	450	5	1044	3	882
10/7	s	6	486	5	396	2	36	2	270	3	396
	2	3	162	3	90	3	846	5	1044	3	342
	6	5	414	4	216	3	774	8	1584	4	252
	8	2	162	2	108	2	684	4	1746	3	576

The euphotic zone in the Lake seems to be homogeneously mixed. Temperature profiles and algal counts made by us confirm this view of the Lake so far.

We do not as yet have a year's data and cannot pose tentative eutrophication indexes for Lake Powell at this time.

A major difficulty which we wish to resolve is that work so far is restricted to about the lower 18 miles of the reservoir. In this proposal we would like to characterize the entire reservoir but this means a major addition to our methodology because the reservoir may be too huge to characterize by present sampling procedures (see Progress Report, 1971).

We therefore feel that slide racks sould be set out at appropriate reservoir stations (see Methods - Periphyton Diversity of this proposal). These can be harvested once a month. At this time we are experimenting with slide racks and have tried a primary productivity experiment using specialized plexiglass chambers of our design. The experiment--see data below--is so successful that we wish to include this as a major portion of this new proposal.

12-4-71

Depth	Organic Matter & Silt Dry Wt.	mg Carbon-12 fixed/ slide/4 hr
1 meter	46.3 mg	33,466.6
1 meter	48.6 mg	
4 meters	24.1 mg	32,525.9
4 meters	23.1 mg	
8 meters	9.7 mg	3,741.4
8 meters	15.1 mg	

Note the large drop in rate of carbon fixation at 8 meters. This same pattern corresponds to the present "light-dark bottles" procedures for measuring rate of carbon-12 fixation. Namely, fixation is low around 8 meters in Lake Powell.

METHODS

The Sampling PLan

The first year of this investigation was restricted to five sampling stations located in Wahweap Bay, the mouth of Navajo Canyon, and the entrance to Warm Creek Bay. All of these stations can be used to characterize the lower portion of the reservoir. In order to characterize the entire reservoir, the following sampling plan is suggested.

Summer Field Work

Collecting stations would be set up at Hite which represents the inlet to Lake Powell (about 150 miles above the dam); at Moki Bar above Bullfrog and Hall's Crossing, and near Iron Top Mesa below Hall's Crossing (both stations approximately 100 miles from the dam); at Sewage Buoy at Rainbow Bridge Marina (about 50 miles from the dam); at the entrance to Warm Creek Bay (about 13 miles from the dam); at the dam (specifically at the boomline above the dam); below and above the main Marina in Wahweap Bay (about 5 and 8 miles from the dam). This bay represents the major portion of Lake most likely to undergo cultural eutrophication because of the population density and high degree of public activity.

Primary productivity studies at each station will be made at five depths: surface, 1, 4, 8, and 12 meters.

Phytoplankton collections will be made at the surface, 1, 4, 8, and 12 meters.

Samples for cation analysis (see subdivision of UNM proposal relating to cations) will be taken at all five depths, placed in plastic bottles and frozen for future determination by atomic absorption at UNM.

Samples for ash-free dry weight will be processed at the Lake and determined at UNM.

Periphyton slides for diversity index determination will be set out for 4 weeks, collected, and processed during the winter at UNM.

Periphyton primary productivity experiments will be run *in situ* at the Lake at time of collection.

Period of Sampling

Summer time period extends from June 5 through August 14. Stations in Wahweap Bay, at the dam, and Warm Creek Bay are to be sampled on Monday of each week; the station at Rainbow Marina on Tuesday, stations in the Hall's Crossing-Bullfrog area on Wednesday, and the station at Hite on Thursday. Thereafter, every fourth week will be spent at Lake Powell.

We plan to utilize a large houseboat equipped with full laboratory facilities as a "mother ship" and a smaller boat for travel to specific stations. This means the houseboat would be moored in the Wahweap Bay area on Monday, then moved progressively up the Lake for use on each sampling day. This sampling activity is coordinated with the Dartmouth limnology-

geochemistry group in that we plan to use many of their sampling sites between the dam (outlet) and Hite (inlet).

Both groups will use the houseboat for laboratory and living facilities. The houseboat will also be shared by the epidemiology subproject.

Determination of Primary Productivity

Primary productivity will be determined using the method originally developed by Steeman Neilson (Nelson, 1966).

Radioactive carbon, as $NaHC^{14}O_3$, is added to each water sample. Water samples are obtained with a plastic Kemmerer water sampler and aliquots of this sample are placed in two transparent bottles ("light bottles") and one opaque bottle ("dark bottle"). The dark bottle provides a correction factor for nonphotosynthetic CO_2 fixation and isotopic exchange of C^{14} which would not reflect primary productivity. These bottles are incubated in situ for 6 hours at the depth of collection. Water samples from each depth at each transect point are analyzed 1 hour after collection for milligrams of C^{12} per M^3 of Lake water according to this relationship:

$$CO_2 mEq/L = (\text{Total mL titrant between pH 8.3 and 4.8}) \times N_{acid} \times 1000 \div \text{mL sample}$$

$$1\ mEq/L = 44\ mg/L\ CO_2 = 12\ mg/L\ C$$

At the conclusion of a 6-hour incubation period, bottles are removed from the Lake, placed in a dark chamber, and then filtered through a 0.45 micron pore size membrane filter. Each filter is washed with a 2% formaldehyde solution. Filters are dried in a desiccator for 24 hours and their radioactivity determined using a Baird-Atomic gas flow counter. From the data for $C^{14}O_2$ assimilation in the dark and light bottles and the CO_2 content of the sample, primary productivity of the sample may be calculated in units of $mg/M^3/hr$ of C^{12}. The equation we use for calculating $mg/M^3/hr$ of C^{12} is

$$C^{12} = \frac{a \times b}{c} \times K \times d \times e$$

where a = cpm on filter above background and dark bottles; d = alkalinity (mg/L); c = dpm in the bottle; b = counter efficiency factor; e = L/hrs; and $K = 1.06 \times 2.52 \times 10^3\ L/M^3$. 1.06 represents a correction factor to compensate for the slower rate of diffusion of C^{14} as compared to C^{12}. 2.52 is a dilution factor (in our case 50 mL is filtered from a bottle containing 125 mL of water plus 1 mL of isotope solution). The factor is 126/50 = 2.52. $10^3/L/M^3$ is plugged

in to convert mg/L to mg/M^3 (mg/L x 1/M^3 = mg/M^3).

Diversity Index

Numerous authors have discussed and proposed diversity indexes (Fisher et al., 1943; Preston, 1948; Gleason, 1922; Peilou, 1966; Wilhm and Dorris, 1966: Brillouin, 1960; Patten, 1962; Patrick and Strawbridge, 1963; Wilhm and Dorris, 1968).

This study will use Patten's (1962) formulas:

$$d = -K\left[\sum_{i=1} n_i \log \frac{n_i}{N}\right]$$

$$r = \frac{d_{max} - d}{d_{max} - d_{min}}$$

Since these formulas are derived from information theory (Brillouin, 1960), Wilhm and Dorris define diversity as the "uncertainty which exists concerning the species of an individual selected at random from the population." The fewer the species and the less equal the distribution of individuals among the species, the lesser the uncertainty, the lower is the diversity in the community. Patten states the advantages of using diversity indexes:

> "Diversity indices permit large amounts of information about numbers and kinds of organisms to be succinctly, if implicitly, summarized. More than this, they allow direct study of communities at the community level."

Phytoplankton Abundance

Phytoplankton for enumeration are concentrated using the iodine settling method. An aliquot of organisms is then placed in a nannoplankton counting chamber for enumeration. Results will be expressed as numbers per millileter of Lake water. Details of this standard counting procedures are outlined in Jackson (1962).

At each sampling date, qualitative collections will be taken for identification of algae in the living conditions.

Phytoplankton Biomass

Phytoplankton biomass will be estimated by multiplying the number of individuals of each species by the average cell volume.

Periphyton Diversity

Plexiglass plates will be suspended in the water at the following depths: 1, 4, 8, and 12 meters. These will be left *in situ* for 4 weeks (our experience shows that good diatom growth is achieved within this time period). The material on the plates is scraped into an appropriate container. Organic matter is oxidized with nitric acid leaving the cleaned diatom frustules. Frustules are washed several times and the diatoms are diluted to a known volume. One cubic centimeter aliquotis placed on a coverslip and the liquid portion is then evaporated. This preparation is mounted on a glass microscope slide in hyrax mounting media. Ellipses will be generated using the log-normal bivariate distribution function.

Periphyton Productivity

Plexiglass slides will be left in the water at the same depths and time period as previously mentioned. Slides will be removed and placed in plexiglass chambers which contain a known volume of filtered Lake water and an increment of carbon-14 isotope of known activity. These will be incubated *in situ* for 4 hours. A "dark chamber"--analogous to a "dark bottle"--will be utilized at each incubation depth. At the end of the incubation period the slides are removed, scraped, and the material filtered and assayed according to procedures mentioned for phytoplankton. This is a new method which we have been developing this year.

Ash-Free Dry Weight

This determination will be made on materials filtered from the Lake water and on materials scraped from plexiglass slides.

Coliform Bacteria

We plan to use a millipore portable water analysis kit for this determination and record count as coliform organisms (colonies) per 10 ml of sample tested. Fecal streptococci populations will also be monitored. All procedures and results are in accordance with standard methods (APHA, 1965).

PRESENTATION OF RESULTS

Primary productivity data from the "light-dark bottle" experiments is expressed as $C^{12}/M^3/hr$. Results expressed in this form can be correlated with other parameters using standard correlation analysis. Initial display of data might be like that for our Elephant Butte Reservoir study (see Exhibit 2). All parameters in the study including carbon-12 fixation rate will then be processed according to a BMD02R Stepwise Regression Program. We have revised this program to make it applicable to our reservoir studies. In this program, the pattern of analysis is descriptive statistics for variables--mean, standard deviation, then a covariance matrix, correlation matrix, F test, and regression coefficient. From this kind of analysis, significant patterns can be detected and their biosignificance, if any , interpreted. This kind of evaluation will be made for each station level through time.

Between station comparison will be made using a Student-Newman-Keuls test. Exhibit 3 provides an example of this test for carbon fixation in Elephant Butte Reservoir.

The final form for expression of primary productivity will be in units of $C^{12}/M^2/day$. Calculations for this are given in IBP Handbook No. 12 (Wollenweider, 1969). In this form the data can be used as baseline indexes which can be contrasted with future measurements of the same parameter.

Results for possible display of phytoplankton quality, phytoplankton quantity, and diversity index are given respectively in Exhibits 4, 5, and 6.

Results from the periphyton investigations will be processed and displayed in much the same manner as the phytoplankton data with the exception of the diversity index.

Our data will be displayed according to Patrick and Strawbridge, 1963 (see Exhibit 7). We feel that in the long run this may be the best way to characterize Lake Powell and enable us to better describe conditions now and set up criteria to evaluate future effects of man's impact on the Lake.

RELEVANT EXPERIENCE OF SENIOR INVESTIGATOR

The Senior Investigator has approximately 12 years' experience in algal taxonomy and general water chemistry. For the past 3 years he has evolved programs for investigating reservoir ecology both at Elephant Butte Reservoir in New Mexico and at Lake Powell. Funding for these activities has come from OWRR and NSF. Experiences have involved

EXHIBIT 2. Carbon-12 fixation in milligrams per liter per hour at five stations located along a gradient extending from the boomline, one hundred feet in front of the dam, to the upper end of Elephant Butte Lake near the inlet.

Date	Gradient One			Gradient Two			Gradient Three			Gradient Four			Gradient Five		
	Surf.	1m	2m	Surf.	1m	2m	Surf.	1m	2m	Surf.	1m	2m	Surf.	1m	2m
1/ 6/70	12.25	17.14	5.88	20.05	32.72	15.16	17.40	22.74	15.20	4.22	11.26	12.22	6.86	10.65	10.63
1/27/70	3.96	4.17	3.61	2.53	3.91	6.75	2.40	4.99	4.25	4.21	11.25	12.21	17.51	29.28	7.36
2/10/70	4.08	4.60	8.34	4.92	6.31	7.13	4.55	4.83	3.10	26.95	51.36	34.64	18.74	22.99	22.27
2/24/70	1.32	17.99	15.01	3.69	6.01	6.99	14.15	20.56	21.51	13.22	46.50	40.05	18.15	16.86	17.01
3/10/70	4.82	6.35	5.65	6.39	6.48	0.00	8.45	17.59	15.11	50.67	60.43	33.71	86.97	92.01	10.82
3/24/70	4.64	4.22	4.46	2.39	3.56	3.69	5.59	9.63	27.08	4.19	7.89	7.62	27.30	43.34	20.23
4/ 7/70	4.25	8.07	9.93	2.04	4.29	3.04	2.50	15.78	8.41	17.15	8.74	21.82	27.91	62.50	48.66
4/21/70	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
5/ 5/70	6.31	6.49	9.24	6.38	11.14	13.48	5.77	18.60	18.16	9.58	18.51	13.92	100.11	57.97	2.22
5/19/70	4.49	13.84	78.87	5.39	7.10	8.95	8.16	6.75	15.77	30.38	26.23	11.42	131.68	10.89	4.54
6/ 2/70	18.82	21.20	23.70	25.45	26.19	22.21	141.77	82.33	13.77	140.00	44.49	5.13	32.97	1.69	0.00
6/16/70	24.64	27.10	26.53	20.86	38.20	25.68	21.34	10.84	5.77	14.69	22.45	2.10	194.10	2.78	0.59
6/23/70	48.74	31.06	21.33	37.09	39.81	53.40	41.72	25.12	4.32	19.28	4.41	0.00	102.38	22.16	0.47
6/30/70	29.50	28.10	23.00	50.35	47.80	36.01	250.59	148.41	21.77	203.09	53.42	5.00	129.77	3.97	3.62
7/ 7/70	53.44	43.71	32.85	66.43	65.51	24.55	96.37	69.96	16.74	240.60	46.74	2.78	13.87	27.03	4.71
7/14/70	46.80	33.73	19.00	44.63	49.84	31.81	76.72	86.58	21.04	266.18	80.93	5.24	158.00	21.45	0.00
7/21/70	41.09	27.79	2.33	55.25	53.43	35.30	125.11	76.98	5.17	139.54	8.87	0.37	144.44	0.32	0.00

STATIONS	SURFACE	1-METER	2-METER
IV-I	X	O	O
V-I	X	O	O
IV-II	X	O	O
III-I	O	X	O
V-II	X	X	O
IV-III	O	X	O
V-III	O	X	O
IV-V	O	O	O
II-I	O	O	O
III-II	O	O	O

EXHIBIT 3. THE SYMBOL X INDICATES THAT THE TWO MEANS BEING COMPARED DIFFER BY AN AMOUNT GREATER THAN WOULD BE EXPECTED ON THE BASIS OF CHANCE ALONE, I.E., THE DIFFERENCE IS SIGNIFICANT OF THE 0.95 LEVEL.

EXHIBIT 4. DISTRIBUTION OF THE TOTAL NUMBER OF ALGAL TAXA (M) COLLECTED ALONG A GRADIENT IN ELEPHANT BUTTE RESERVOIR.

	STATION				
DATE	I	II	III	IV	V
1/6/70	5	3	3	2	3
1/20/70	1	3	2	3	4
2/10/70	3	1	2	8	6
2/24/70	3	5	5	14	6
3/10/70	4	2	3	3	6
3/24/70	4	4	3	2	13
4/7/70	3	2	2	4	7
5/5/70	4	3	1	6	11
5/19/70	8	6	7	6	9
6/2/70	9	6	8	9	8
6/16/70	10	8	8	5	12
6/23/70	5	7	8	8	11
6/30/70	10	10	11	8	7
7/7/70	10	9	15	9	8
7/14/70	11	11	13	10	11
7/21/70	10	7	10	7	10
7/28/70	18	13	12	12	8
8/4/70	10	8	12	9	8
8/11/70	8	6	7	8	7
8/18/70	6	7	9	9	8
8/25/70	7	7	5	9	5
9/8/70	12	8	12	5	6
9/29/70	6	4	4	9	6
10/13/70	3	8	7	13	8
10/27/70	7	6	11	13	8
11/10/70	6	6	5	5	7
11/24/70	4	7	8	6	7
12/8/70	7	8	7	5	4
2/22/70	7	3	8	5	8
1/12/71	13	6	6	3	3

EXHIBIT 5. TOTAL OF MEAN NUMBER OF ALGAE COUNTING UNITS (N) PER MILLILITER OF WATER IN ELEPHANT BUTTE RESERVOIR COLLECTIONS WERE MADE ALONG A GRADIENT FROM THE BOOMLINE TO THE UPPER END OF THE LAKE AT THE INLET.

	STATION				
DATE	I	II	III	IV	V
1/6/70	1679	2799	3547	8984	2053
1/20/70	93	420	1026	1961	
2/10/70	1004	653	1097	2966	1797
2/24/70	1190	816	2566	2472	1120
3/10/70	863	1330	1959	2520	2986
3/24/70	302	442	2059	1307	2518
4/7/70	1119	840	2030	2846	3733
5/5/70	583	489	630	910	1680
5/19/70	371	255	325	953	2404
6/2/70	675	698	2589	3477	279
6/16/70	886	677	839	372	1398
6/23/70	561	724	582	559	2099
6/30/70	886	1190	3452	3872	5273
7/7/70	3149	2309	2586	4270	16520
7/14/70	3521	3407	6507	6602	5319
7/21/70	1726	1143	4266	3009	10336
7/28/70	4104	3687	5717	3266	21747
8/4/70	1866	2170	3358	3289	12739
8/11/70	1539	3290	9052	4440	6743
8/18/70	1492	1936	4363	5390	16682
8/25/70	2659	1796	1934	11714	14909
9/8/70	4271	2426	2309	2870	8400
9/29/70	652	840	794	791	840
10/13/70	2287	4712	2729	10078	26040
10/27/70	2451	2966	2612	11060	-
11/10/70	3196	3850	4035	4013	4059
11/24/70	2940	2308	2821	2495	2169
12/8/70	3664	4292	3966	4083	2169
12/22/70	7139	6346	7255	8072	9541
1/12/71	2216	3475	10779	19016	15353

EXHIBIT 6. AVERAGE DIVERSITY AND REDUNDANCY OF PHYTOPLANKTON ALONG A GRADIENT AT EACH SAMPLING DATE FOR ELEPHANT BUTTE RESERVOIR.

	STATION									
	I		II		III		IV		V	
DATE	D	R	D	R	D	R	D	R	D	R
1/6/70	699	.83	385	.92	560	.90	424	.95	364	.89
1/20/70	0	.99	569	.14	450	.56	638	.80		
2/10/70	635	.60	0	.99	376	.66	1659	.82	1935	.59
2/24/70	546	.72	968	.50	1753	.71	5310	.44	2004	.30
3/10/70	650	.63	486	.64	719	.77	1383	.66	3199	.59
3/24/70	474	.19	570	.35	1942	.41	980	.24	4893	.46
4/7/70	1176	.34	823	.01	1974	.02	2909	.49	6238	.41
5/5/70	508	.57	266	.67	0	.99	1170	.51	3313	.41
5/19/70	818	.27	520	.18	733	.20	1377	.44	6398	.16
6/2/70	1530	.28	1344	.26	5612	.27	7722	.30	795	.01
6/16/70	2273	.22	1554	.17	1905	.24	819	.05	3965	.20
6/23/70	1132	.13	1776	.13	1321	.23	1425	.14	5382	.26
6/30/70	1717	.40	2746	.31	6986	.42	4766	.59	5094	.66
7/7/70	5351	.49	3620	.51	6046	.41	5442	.58	15027	.70
7/14/70	6215	.49	7085	.40	9927	.59	5092	.77	5953	.68
7/21/70	3311	.42	2174	.33	7076	.50	4244	.50	14048	.59
7/28/70	10232	.40	7499	.45	11383	.45	7944	.32	20371	.69
8/4/70	4682	.24	3812	.42	5739	.53	6771	.35	13395	.65
8/11/70	2584	.45	4250	.50	15664	.38	6896	.48	8990	.53
8/18/70	2430	.37	3214	.41	8685	.37	7327	.57	14149	.72
8/25/70	5418	.27	3544	.29	4003	.13	14243	.62	13380	.61
9/18/70	10594	.31	6106	.16	5224	.37	2697	.60		.42
9/29/70	871	.49	1329	.21	1345	.14	1972	.21	1841	.15
10/13/70	2361	.35	6578	.54	4562	.41	16950	.55	20516	.74
10/27/70	4370	.37	3708	.52	4711	.48	15619	.62	-	-
11/10/70	2415	.71	2864	.72	1249	.87	1713	.82	5610	.51
11/24/70	1286	.79	1743	.73	1620	.81	1320	.80	2046	.67
12/8/70	2224	.79	3129	.76	2259	.80	983	.90	550	.88
12/22/70	1867	.91	919	.91	2095	.91	910	.95	1631	.95
1/12/71	3962	.52	1412	.85	1584	.95	512	.98	498	.98

Exhibit 7

APPENDIX—CONFIDENCE INTERVALS AS INDICATED BY ELLIPTICAL CURVES

Using data as shown in Table IV, an ellipse is calculated indicating the confidence interval for brackish water. The first step is to have the appropriate N_0 and σ^2 values from all the individual samples that are to be used in the standard.

These values of σ^2 and N_0 are based on information obtained from analyses of the first 10 intervals which cover the main body of the curve. Using the information from all intervals may change the value of σ^2 by 20 percent and of N_0 by 10 percent. Using the shorter method does not change the relative values of the curves to each other.

TABLE IV.—Data From Brackish Water Diatomoter Studies

River	Station	Date	Number of Species in Mode (N_0)	Number of Species in Theoretical Universe (N)	Number of Observed Species (O_N)	Interval Location of Mode (A)	Variance (σ^2)
York	1B	11–56	19.8	133	95	1.5	7.2
	2A		20.1	138	106	2.0	7.5
	3B		22.0	168	119	1.7	9.2
	2A	2–57	23.5	170	117	1.4	8.4
	3A		16.5	139	95	1.6	11.3
	2A	5–57	16.4	147	94	1.3	12.8
	3B		21.4	183	118	1.3	11.7
	2A	7–57	14.9	120	86	1.8	10.4
	3B		18.2	155	111	2.0	11.6
	2A	11–57	22.3	149	114	1.9	7.1
	3A		19.1	123	105	2.5	7.1
	2A	6–58	24.1	202	124	1.0	11.2
	3A		23.6	177	125	1.6	9.0
	2B	9–58	13.3	120	81	1.7	13.0
	3A		18.2	163	103	1.3	12.8
	2A	11–58	17.0	143	89	1.1	11.2
	3B		20.5	161	112	1.6	9.9
	2B	2–59	20.6	172	106	1.0	11.1
	3B		22.8	174	118	1.4	9.2
	2A	5–59	22.2	174	115	1.3	9.8
	3B		23.9	201	123	1.0	11.3
Nabs Creek	25	10–53	17.9	143	108	2.3	10.1
Middle	2		19.9	132	118	3.4	7.0
Mustang Bayou	6	8–54	21.1	165	121	1.9	9.8
Chocolate Bay	5	7–54	18.8	168	116	1.8	12.8

The arithmetic mean and standard deviation for both the height of mode and the measure of dispersion are then computed:

$$\bar{N}_0 = \frac{\Sigma N_0}{n} = \frac{498.1}{25} = 19.9 \qquad \bar{\sigma}^2 = \frac{\Sigma \sigma^2}{n} = \frac{252.2}{25} = 10.1$$

$$S_{N_0} = \sqrt{\frac{\Sigma (N_0)^2 - \frac{(\Sigma N_0)^2}{n}}{n-1}} = \sqrt{\frac{10125.3 - \frac{(498.1)^2}{25}}{24}} = 2.39$$

$$S_{\sigma^2} = \sqrt{\frac{\Sigma (\sigma^2)^2 - \frac{(\Sigma \sigma^2)^2}{n}}{n-1}} = \sqrt{\frac{2640.45 - \frac{(252.5)^2}{25}}{24}} = 1.93$$

Exhibit 7 (cont'd.)

The produce moment correlation coefficient is computed as:

$$r = \frac{S_{N_0\sigma^2}}{S_{N_0}S_{\sigma^2}} = \frac{[\Sigma(N_0\sigma^2) - \Sigma N_0(\sigma^2)]/n - 1}{S_{N_0}S_{\sigma^2}}$$

$$= \frac{[4974.97 - 498.1(10.10)]/24}{(2.89)(1.93)} = -.417$$

where:

n = number of individual samples.

λ^2 is obtained as follows. If an ellipse is to be contoured having a probability of 0.05 at all points then λ^2 is equal to the *chi* square value having two degrees of freedom and a probability of 0.05. Consulting a probability table, this value is found to be 5.991. For a value of $p = 0.01$ the probability value is 7.824. Now all values necessary to form the ellipse are known, and the following simplification is made.

Let:

$$y = \left(\frac{N_0 - \bar{N}_0}{S_{N_0}}\right) \quad \text{and} \quad x = \left(\frac{\sigma^2 - \bar{\sigma}^2}{S_{\sigma^2}}\right) \qquad (4)$$

then by substitution equation (3) becomes:

$$y^2 + .84xy + x^2 = 4.9342 \qquad (5)$$

This is the equation for the ellipse having a probability of 0.05. Since x and y in effect are standard scores and such scores normally take on values between zero and three, by arbitrarily assigning values of x in this range, y values satisfying the equation are found.

Thus, when $x = 0$ the equation becomes:

$$y^2 + .84xy + x^2 = 4.9342$$

$$y^2 + .84(0)y + (0)^2 = 4.9342$$

$$y^2 = 4.9342$$

$$y = \pm 2.22 \qquad (6)$$

when $x = 0.5$:

$$y^2 + .84(.5)y + (.5)^2 = 4.9342$$

$$y^2 + .42y - 4.6842 = 0 \qquad (7)$$

This last equation is a quadratic of the general form:

$$ay^2 + by + c = 0$$

and its roots are found as,

$$y = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

thus in the solution of the equation:

$$y = \frac{-.42 \pm \sqrt{(.42)^2 - 4(1)(-4.684)}}{2(1)} \qquad (8)$$

In a similar fashion, all the values for $p = 0.05$ have been found. These standard scores can be converted to actual scores using the appropriate means and standard deviations, then rounded to one decimal, and plotted to form a contour ellipse.

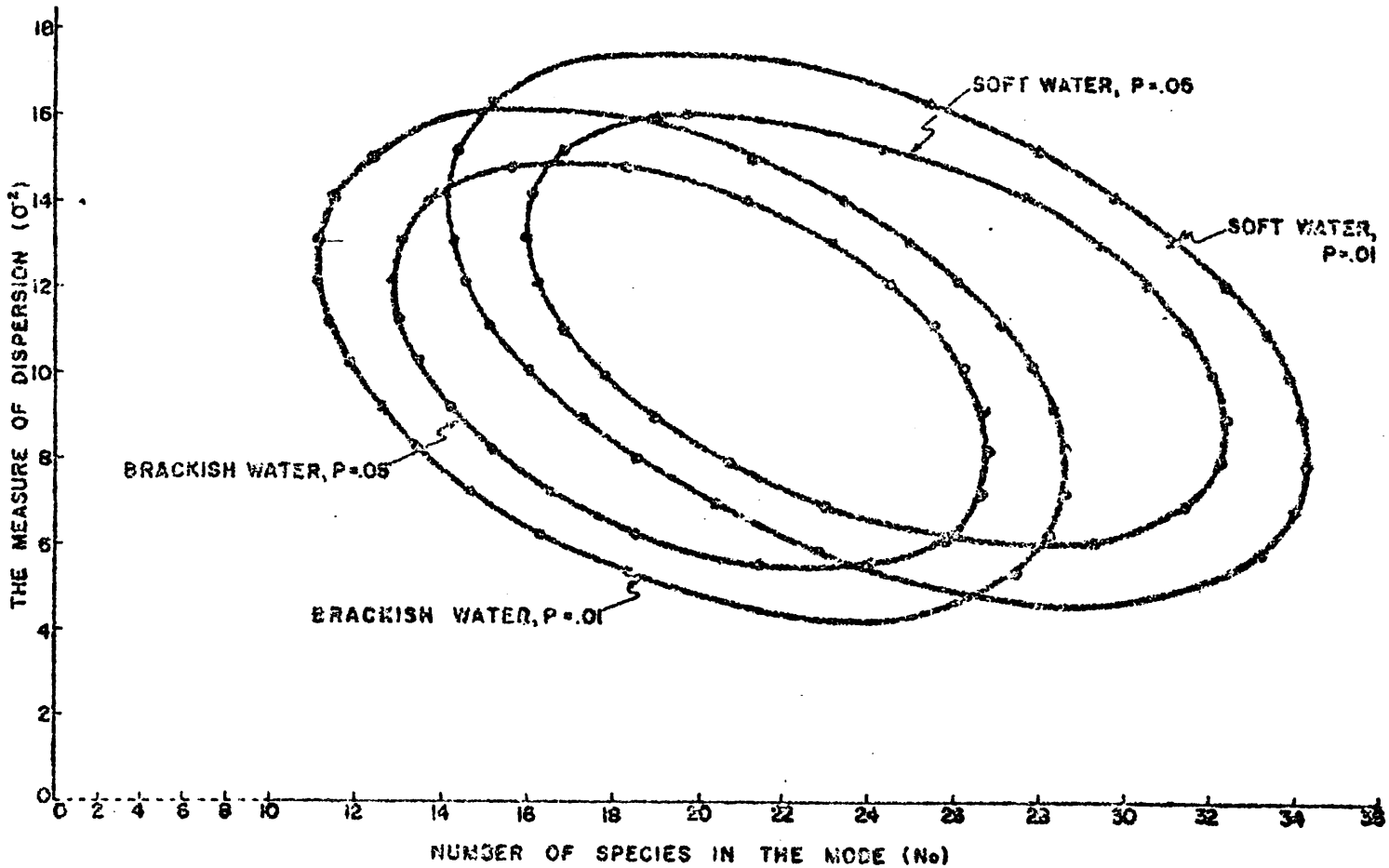


FIGURE 1.—Confidence intervals as shown by elliptical curves.

Exhibit 7 (cont'd.)

In a similar way, the ellipse for soft water is constructed from the Savannah River data. The result of these plots can be seen in Figure 1. It should be noted that much of the data for the brackish water ellipse is taken from the York River and for soft water from the Savannah River, the reason being that most of the studies that have been made are from polluted waters. With more studies in natural areas this heavy weighting can be eliminated. However, if such confidence limits are to be developed for variation in natural areas, the data at hand had to be used.

It is interesting to note that the ellipse for both soft and brackish water show a strong negative correlation between the height of the mode and σ^2. The possible theoretical interpretations of this correlation have been discussed by the authors in a work now in press.

measurement of primary productivity using the carbon-14 method, nutrient analysis, and calculation of algal diversity indexes. Much experience has been gained in the development of computer programs for interpreting reservoir data.

EQUIPMENT AND SPACE AVAILABLE

There is available general limnological equipment, such as Kemmerer bottles, dredges, submarine photometer, phase microscope, algae culture cabinets, refrigerators and freezers, desk calculators, pH meters, Bausch and Lomb Spectronic 600, perchlorate hood, Perkin-Elmer 306 Atomic Absorption Spectrophotometer with carbon rod attachment and mercury analyzer, general laboratory apparatus and glassware, and IBM computer key card punching machine.

Complete computer facilities are available at the UNM Research Center.

Three ecology laboratories are available at UNM for various aspects of this proposal.

PERSONNEL NEEDED

1. Principal Investigator (25% first year; 66% second year). Direction of all phases of subdivision one including field work; participation with L. D. Potter in directing subdivision three of the UNM proposal including field work. All data processing.

2. Research Associate--Postdoctoral (100% first year; 100% second year). Direction of periphyton counting, biomass, and primary productivity; participation in field work, summer and winter.

3. One graduate student. Full-time summer at Lake Powell for primary productivity studies and bacterial work half-time in winter.

4. One graduate student. Full-time summer at Lake Powell and half-time winter at UNM for phytoplankton counting.

5. Three undergraduate technicians (50% first year; 50% second year). General chores and periphyton counting.

6. Consultant, biometrician.

7. Visiting Professor (25% first year). At Lake Powell and UNM. Dr. Robert Brown of Miami Dade Junior College, Florida, from May 15 to August 1, 1972.

8. Visiting Professor (25% first year). At Lake Powell. All phases of algal taxonomy. Dr. Bill Wade of Michigan State University.

9. Secretary (50% first year; 50% second year).

10. Computer programmer.

EQUIPMENT NEEDED

Nauta-Line, 34-foot, plus options ($18,572) provides stable platform and flat deck areas for the actual phases of water collecting. It is capable of reaching the most remote areas of the reservoir for collection of sediments and other samples for cation analysis. Last summer's work on Lake Powell showed the futility of trying to work out of a conventional boat. Three people will be needed for each day's sampling run, and they must be out of each other's way. This is the main reason for this size boat.

The boat will also serve as a floating laboratory and serve the Dartmouth College subprojects and also the other two UNM subprojects. In addition, the boat will be used for gathering and processing samples for bacteriological analysis. In this latter capacity, the boat will also be used in conjunction with the epidemiology subproject.

LITERATURE CITED

APHA. 1965. Standard methods for the examination of water and wastewater. American Public Health Association, Inc., New York, N. Y.

Brillouin, L. 1960. Science and information theory. 2nd ed., Academic Press, Inc., New York.

Fish and Wildlife. 1971. Upper Colorado Region. Appendix XIII.

Fisher, R. A., A. S. Corbet, and C. B. Williams. 1943. The relation between the number of species and the number of individuals in a random sample of the animal population. J. Animal Ecol. 12:42-58.

Gleason, H. A. 1922. On the relation between species and area. Ecology 3:158-162.

Hooper, F. A. 1969. Eutrophication indices and their relation to other indices of ecosystem change. In Eutrophication: Causes, Consequences, Correctives. Proceedings of a Symposium, National Academy of Sciences, Washington, D. C.

Jackson, H. W., and L. Williams. 1962. Calibration and use of certain plankton counting equipment. Transactions of the American Microscopical Society 81(1):96-103.

Kidd, D. E., and G. V. Johnson. 1970. Unpublished data.

Nelson, C. W. 1966. Laboratory exercise in the carbon-14 method of estimating primary productivity. Mimeographed.

Patrick, R., and D. Strawbridge. 1963. Methods of studying diatom populations. J. Water Pollution Control Federation 35(2):151-161.

Patten, B. C. 1962. Species diversity in net phytoplankton of Raritan Bay. J. Mar. Research 20(1):57-75.

Peilou, E. C. 1966. The measurement of diversity in different types of biological collections. J. Theoretical Biol. 13:131-144.

Phelps, J. E. 1965. Glen Canyon Reservoir Post-Impoundment Investigation. Progress Report No. 3, Utah State Dept. of Game and Fish. 56 p.

_____. 1966. Glen Canyon Reservoir Post-Impoundment Investigation. Progress Report No. 4, Utah State Dept. of Game and Fish. 124 p.

_____. 1967. Glen Canyon Reservoir Post-Impoundment Investigation. Progress Report No. 5, Utah State Dept. of Game and Fish. 124 p.

_____. 1968. Glen Canyon Reservoir Post-Impoundment Investigation. Progress Report No. 6, Utah State Dept. of Game and Fish. 16 p.

Preston, F. W. 1948. The commonness, and rarity, of species. Ecology 29:254-283.

Progress Report. 1971. Dynamic limnology of Lake Powell. The Dartmouth College part of a combined project entitled The Impact of 20th Century Man's Activities on the Upper Colorado River Basin.

Progress Report. 1971. Primary productivity, indexes of eutrophication processes, and marginal vegetation of Lake Powell. The University of New Mexico part of a combined project entitled The Impact of 20th Century Man's Activities on the Upper Colorado River Basin.

Stevens, J. C. 1946. Future of Lake Mead and Elephant Butte Reservoir. Trans. Amer. Soc. Civil Engr. 111:1231.

USDI. 1969. San Juan Investigation - Utah and Colorado. Bureau of Reclamation, Floyd E. Dominy, Commissioner, Salt Lake City, Utah.

Vollenweider, R. A. 1969. A manual on methods for measuring primary production in aquatic environments. IBP Handbook No. 12.

Wilhm, J. L., and T. C. Dorris. 1966. Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluents. Am. Midland Naturalist 76:427-449.

Wilhm, J. L., and T. C. Dorris. 1968. Biological parameters for water quality criteria. Bioscience 18(6):477-481.

Subproject Number 2

Shoreline Ecology

SHORELINE ECOLOGY OF LAKE POWELL: VEGETATIONAL CHANGES AND MAN'S USE

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

Amount Requested	Proposed Duration	Requested Starting Date
$50,249	2 Years	May 15, 1972

Principal Investigator: Loren D. Potter
SS: 501-09-3597
Telephone: (505) 277-2614

Biology Department
University of New Mexico
Albuquerque, New Mexico, 87106

Endorsements

Principal Investigator	Department Head	Approving Administrative Official
Loren D. Potter	Loren D. Potter	Edmund B. Kasner
Prof. & Chm., Biology	Prof. & Chm., Biology	Director, Research UNM
Feb. 8, 1972	Feb. 8, 1972	Feb. 8, 1972

ABSTRACT

A major benefit to be derived from Lake Powell is the recreational use, as indicated by its designation as the Glen Canyon Recreational Area under the National Park Service. The ecological changes of both the Lake and the shoreline must be studied as part of the reservoir ecosystem.

It is proposed to continue the transect studies of the effect of rising water level on the terrestrial vegetation as an index to the vegetational development upon stabilization. Decompositional studies of flooded vegetation are proposed as related to nutrient and organic matter enrichment of the Lake and the problem of unsightliness of the "bathtub ring" with each draw-down cycle. Mapping of the shoreline surface material, physiography, and vegetation to establish indexes for carrying capacity for public use will be continued.

OBJECTIVES

The objectives of this project are to index the effect of the Lake with its fluctuating levels and ground water on the marginal vegetation and as an indication of shoreline stabilization when the final reservoir level is reached; to study some of the roles of the shoreline and its vegetation on the nutrient and organic matter enrichment of the Lake; to map the surface materials and vegetation of the shoreline area; and to formulate indexes of the carrying capacity of various shoreline types, and of the entire Lake shore, for recreational use. These indexes should be useful in future public use management planning.

RATIONALE

The shoreline and marginal area for a reservoir in a desert area of sedimentary rock must respond to the presence of water, and contribute to the enrichment of the Lake, in quite a different manner than in regions of greater precipitation; higher primary productivity; and forest, grassland, or agricultural soils. Sequential studies are needed to measure changes in species composition and productivity of the terrestrial desert vegetation as the water level increases and becomes stabilized. Likewise, measurements are needed of the addition of nutrients from the flooded surface materials and both nutrients and organic matter from the surrounding vegetation.

With each increase in water level, there is undercutting and sloughing off of tons of material. Poorly consolidated talus slopes and alluvial fans on what were once high benches are quickly washed into the Lake. Sand dune areas many feet in depth, slump into the water. Even the Navajo sandstone, because of its porous nature, is becoming saturated with water and great new cracks, measured to be up to 23 inches, have opened up on vertical cliff walls several hundred feet high which will result in tons of blocky sandstone falling into the reservoir.

Population pressure around the shoreline is rapidly increasing. Wahweap already has National Park Service administrative offices, campground, picnic shelters, launching ramp, swimming beach, marina, restaurant, motel, trailer village, service station, and other tourist-related facilities. In addition to Wahweap, several major marinas and adjacent resort towns are already under development at Rainbow Bridge, Hall's Crossing, Bullfrog, and Hite. Future facilities are planned at Warm Creek Basin, Padre Point, Gunsight Bench, Hole-in-the-Rock, Oil Seep Bar, and Castle Butte. While these developments and the heavy public use produce direct eutrophication

effects on the Lake itself, there is a real demand placed on the shoreline areas where it is possible to use them as campsites. Although the Lake level has been rising each year, making new shoreline sites available, even now there are many areas where suitable or "unspoiled" campsites are at a premium. As the waterline becomes more stabilized, some kind of management of public use to maintain any semblence of natural conditions will be necessary in addition to the concentration of facilities at marinas or resort towns.

METHODS

Terrestrial Transects

Several detailed biological studies of Glen Canyon were made prior to its flooding (e.g., Woodbury, A.M., 1959) which will be valuable in making comparisons of the developing shoreline vegetation. Other studies of interest include Gaines' (1960) catalogue of Glen Canyon plants and Martin's (1965) pollen analysis in Glen Canyon.

In the summer of 1971, ten permanent belt transects were established at representative shoreline types extending from the waterline at approximately 3620 feet to about the 3700-foot level. These transects worked in July, showed little or no growth due to the unusually severe drought conditions of 1971. The belt transects were divided into 50-foot units and varied from 200 to 600 feet long. Species composition, foliage cover, and frequency were determined. Each transect should be reexamined yearly to measure changes in species composition and growth as indicated by foliage cover due to changes in available water as influenced by the Lake level and differing capillary rise in various soils.

Decomposition of Submerged Vegetation

Preliminary observations in the summer of 1971 indicated that desert vegetation when submerged by rising water level soon becomes covered with the coating of silt and microorganisms. In addition to establishing the transects above the shoreline for future study, an attempt was made to determine the fate of vegetation when submerged. Many desert species, e.g, Ephedra, stay green for several months in shallow water. Most grass species soon die and start to deteriorate. The sudden conversion of Great Basin desert vegetation to "submerged aquatics" is a new field in physiological plant ecology. Without diving equipment it was not possible to do any extensive analysis at depths below the current year's submergence. With scuba diving equipment , it is proposed to determine rates of decomposition along submerged transects at

sites with a sloping bottom. With available continuous records of water level from the Bureau of Reclamation, it will be possible to reconstruct the time of submergence, sequence of depths, and any period of emergence. Plastic bags can be slipped over individual submerged plants which can then be cut off. The surface attached macro- and micro-organisms can be agitated and washed off the plant and examined for species composition and macronutrients, especially nitrates and phosphates. Comparisons can be made with similar shoreline plants as to relative loss of volume, green weight, and dry weight.

In the manner of studying rate of litter decomposition as described by Bocock (1964) and recently used, for example, by Bleak (1970) and by Van Cleve (1971) under snow, it is proposed to study the rate of decomposition and leaching of nutrients from desert vegetation when submerged under "natural" conditions of a desert reservoir. Plants of three representative species of different growth forms will be cut off at the ground level, green weights determined, enclosed in nylon or dacron mesh bags and immersed and anchored to the bottom in several feet of water at the time of the year when the reservoir is at its low-level stage. Determinations for comparable plants will be made on green weight, oven-dry weight, caloric content per gram of oven-dry weight, and nitrate and phosphate content. At periodic intervals, e.g., 1 month, 2 months, 4 months, 6 months, 9 months, and 1 year, triplicate samples will be removed. The plants will be gently washed and the fine material removed and examined. The undecomposed plant will be oven-dried and examined as indicated above for the control plants.

Sparse as the surrounding vegetation may appear, it and the flooded alcove and riparian vegetation are an important source of organic matter and intrabiotic nutrients being added to the Lake. Details of the rate of decomposition and nutrient leaching will greatly add to the knowledge of reservoir energy flow and nutrient cycling in the ecosystem.

Even after the maximum water level is determined, there will be yearly periods of "draw-down" exposing a zone of shoreline with its vegetation which has been submerged. The degree of decomposition and the physical state of this organic material also will be an important aesthetic consideration in the use of the Lake as a recreational area.

Shoreline Mapping

During July 1971, the shoreline of Lake Powell from Wahweap Bay to Seven-Mile Canyon, approximately 22 miles upstream

from Hall's Crossing was mapped. The shoreline of the Lake and all the tributaries, except the San Juan, were included, a total distance of about 600 miles. Surface materials and physiographic characteristics within the zone of 3620 to 3700 feet were mapped. Superimposed on a geological classification of the bedrock on U.S. Geological Topographic Quadrangle maps at 1:62,500 scale were delineated the following types:

1a Cliff wall, where degree of slope was too great for shoreline use, such as landing a boat

1b Domed terraces, where sandstone formations were eroded in rounded contour, usually with pocket depressions often containing a thin accumulation of sand

1c Shelfy terraces, where topography was irregular, with extended shelves resulting from erosion of thin-bedded sandstone formations, such as Carmel

2 Talus slopes, common along cliff walls and alcoves

3 Sand dunes of varying thickness and overlying a variety of materials

4 Alluvium, usually confined at the present to valley floors near the heads of canyons now being flooded

5 Landslides, mixtures of coarse rubble and blocky material, most common where sandstone formations overlie Chinle shale

It is expected that mosaics and stereo pairs of 9" by 9" black and white photocoverage will soon be available. It is planned to recheck the field mapping on photo overlays and to add a system of indexing the carrying capacity of each area in regard to human use, particularly in regard to potential campsites. There are a number of specific criteria determining a good campsite and its "carrying capacity." These include proper shoreline for landing or tying up a boat which might vary from a sloping sandy shoreline, gently sloping smooth rock, or a protective steeper-walled alcove; a relatively level spot of slick rock or sand for a campsite; and the availability of the local areas of weathered soil which are used for human sanitation purposes. Except for extensive sand dune areas, such sites are usually highly localized to small pockets of weathered sand which soon become offensively littered. As the population pressure and overnight camping increase, it is likely that some regulation of campsite use and distribution will become necessary to protect the very scenic features which the public came to enjoy. Mr. C. E. Johnson, Superintendent, Glen Canyon

Recreational Area, concurs and is anxious to have some factual guidance available for management use to handle the public pressure which is currently predicted.

The development of indexes for shoreline use for each of the major tributaries and bays should become an important management aid and may be used in the manner of present-day regulation of terrestrial campsites. They can be used as part of the overall approach to evaluation and management relating to environmental impact and the use of campsites, e.g., Leopold et al. (1971) and Lime (1971).

During the summer of 1972, it will be necessary to complete the mapping of the balance of the northern part of the Lake above Hall's Crossing, its tributaries, and the San Juan River.

After completion of the mapping from the stereo pairs of aerial photos, it is hoped that data may be transferred to topographic maps now available for the entire shoreline at a scale of about 1 inch to 400 feet with contour intervals of 10 feet from the former riverbed to 3750 feet. It is estimated that the mapping from air photos and the transfer will take 1.5 to 2.0 months full-time work. The final product should be a combined map showing features of vegetation, surface material and physiography, and indexes of recreational land use.

FACILITIES

A 21-foot leased boat was used for the 1971-72 field research and will continue to be available for this project. In addition, with the expanded program in biological limnology of the Lake, it will be absolutely essential to have the requested laboratory-equipped houseboat. Previous and current efforts to obtain laboratory space from the National Park Service Headquarters have been unsuccessful. In 1971 space was rented from the Museum of Northern Arizona, Flagstaff, but much of the proposed laboratory work will require on-the-site analysis which can only be done by a "floating lab" arrangement. It should be pointed out that the area of investigation is not serviced by roads, except in a few places, and these are connected by very long circuitous routes, making overland travel impossible and the establishment of a single base laboratory on the shore very difficult and costly. Three plant ecology research laboratories at UNM will be available for chemical analyses. Instrumentation includes a Perkin-Elmer 306 atomic absorption unit with graphite rod attachment for rapid analysis of low-concentration elements. Interpretive facilities for aerial photography and remote sensing at the National Park Service-University of New Mexico Archeological Center on campus will be available.

LITERATURE CITED

Bleak, A. T. 1970. Disappearance of plant material under a winter snow cover. Ecology 51:915-917.

Bocock, K. L. 1964. Changes in the amounts of dry matter, nitrogen, carbon, and energy in decomposing woodland leaf litter in relation to the activities of the soil fauna. J. Ecol. 43:273.

Gaines, X. M. 1960. An annotated catalogue of Glen Canyon plants. Mus. of Northern Ariz. Tech. Series No. 4. 18 p.

Leopold, L. B., et al. 1971. A procedure for evaluating environmental impact. USGS Circ. 645. 13 p.

Lime, D. W. 1971. Factors influencing campground use in the Superior National Forest of Minnesota. USDA Forest Serv. Res. Paper NC-60. 18 p.

Martin, P. S. 1965. Pollen analysis in Glen Canyon. Contrib. No. 101. Program in Geochronology, Univ. of Ariz., Tucson. 20 p.

Van Cleve, K. 1971. Energy- and weight-loss functions for decomposing foliage in birch and aspen forests in interior Alaska. Ecology 52:720-723.

Woodbury, A. M., et al. 1959. Ecological studies of flora and fauna in Glen Canyon. Anthropological Paper No. 40. (Glen Canyon Series No. 7). Univ. of Utah. 226 p.

Subproject Number 3

Heavy Metals

ANALYSIS OF METALLIC CATIONS IN THE LAKE POWELL ECOSYSTEM

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

Amount Requested	Proposed Duration	Requested Starting Date
$50,010	2 Years	May 15, 1972

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ABSTRACT

While there has been a great emphasis on the dangers of mercury in the environment, other heavy metal cations such as beryllium, cadmium, lead, arsenic, chromium, silver, and selenium are possibly more dangerous but have unknown tolerance limits. As boating use increases, input of lead and nickel directly into the Lake by gas spillages can be expected to increase. Although industrial development is not yet great in the Upper Colorado River Basin, the release of heavy metals from the burning of large quantities of coal in power plants in the area is reason for concern. Also, the upper watersheds arise in areas of rich deposits of heavy metal ores.

It is proposed to establish baseline concentrations for Hg, Pb, Cd, Ca, Mg, Zn, Si, Cu, Fe, Ag, Mn, Cr, Mo, Co, Be, and Se as they occur laterally across the Upper Colorado River Basin, and vertically through the trophic food chains from atmospheric absorption by vegetation, water, sediments, aquatic microorganisms, and vertebrates. This study will be coordinated with other agencies concerned with the quality of the environment and several subprojects of this combined proposal.

INTRODUCTION

One of the early nationwide reconnaissance of minor elements was made by the U.S. Geological Survey in cooperation with the U.S. Bureau of Sport Fisheries and Wildlife in October-November of 1970 (Durum, Hem, Heidel, 1971). Water samples were filtered to remove sediment >0.45 microns and acidified to prevent separation of minor elements. This survey included analyses for As, Ca, Cr, Co, Pb, Hg, and Zn. Standard analytical methods of Brown, Skougstad, and Fishman (1970) were used.

The element receiving the most attention recently has been mercury, with concern expressed about its release from industrial processes and its discharge from crushing and burning of fossil fuels, especially coal. It is found in a variety of forms from the simple mercury sulfide in cinnabar, the most common ore mineral, to complex metallo-organic complexes. Some of the concentration is natural, with both igneous and sedimentary rocks averaging about 100 ppb of mercury and seldom exceeding 200 ppb, except for organic-rich shales which may be as high as 10,000 ppb (e.g., Green River shales of the western Colorado Plateau).

Analyses of mercury in sedimentary rocks of the Colorado Plateau and typical of shoreline of Lake Powell have been reported as follows by Cadigan (1970);

Formation	Median	High	Low
Morrison, ss, mudstone	190	>6,000	10
Entrada, ss	170	5,000	30
Carmel, ss, siltstone	100	700	10
Navajo, ss	40	500	<10
Wingate, ss	260	1,900	80
Dolores, ss, siltstone	210	760	80
Chinle, mudstone, ss	260	>6,000	60
Moenkopi, siltstone, ss	110	>10,000	10

Rain washes mercury from the atmosphere where it is normally absorbed in the upper inches of soil. In the Lake Powell region, however, the lack of soil development over most of the area would result in high percentages of runoff into the streams. Particulate matter suspended in water or in bottom sediments may accumulate concentrations of mercury from 5 to 25 times that of the water around it. Alkaline streams apparently show a rapid decrease of mercury concentration due to dilution, vaporization, precipitation, absorption, and chemical reaction. Ponds and lakes are likely mercury traps because of its tendency to sink and to combine with sulfides of anaerobic bottom sediments and with both living and dead organic matter. The entrance of mercury into the

food chain may be enhanced by conversion of inorganic mercury by some anaerobes. Klein and Goldberg (1970) report mercury levels in marine organisms to be several orders of magnitude greater than in surrounding sea water. Examples of biological concentration factors have been reported in algae of 250 to 3000, in ocean fish of 1000 to 10,000, and in some sea life of 100,000. In summarizing mercury in plants, Shacklette (1970) indicates that unless plants actually are rooted in mercury deposits, concentrations rarely exceed 500 ppb. Both plants and animals tend to concentrate mercury in areas of vegetable or animal fats(USGS, 1970).

In a study of nutrient cycling in watersheds of southwestern forest types, Dr. James Gosz, UNM, has also been analysing nutrient concentration of headwater streams. In a continuing study he plans to consider heavy metals of Hg, Pb, Cd, Ni, and Ag as components of the forest ecosystem and first-order streams. The correlation and exchange of research will be valuable.

There is some evidence that the harmful threshold for mercury is at greater concentrations at higher steps in the food chain and that there is a synergistic effect when other heavy elements are present. The flow of mercury through aquatic food chains is well summarized by Greeson (1970).

An additional problem is that of inhibition of photosynthesis. A study by Harris et al. (1970) indicates that concentrations of mercury well below proposed water quality standards may have detrimental effects on the photosynthesis of phytoplankton. He found that mercurials as low as 1 ppb significantly reduce photosynthesis and growth of phytoplankton species. The question then is whether the proposed power plants near Powell will raise the concentration of mercury in Lake Powell waters to the 1 ppb level.

OBJECTIVES

An immediate problem is to establish baselines to enable the evaluation of the effect of the Navajo Power PLant which is being built in the vicinity of the southern end of Lake Powell. This will be a conventional coal-burning plant. It is known that 22 metals (Schroeder, 1971) can be released from the burning of coal and oil. Of these 22, mercury, cadmium, nickel, beryllium, and lead present definite health hazards. While mercury has been in the spotlight, the American Chemical Society and others have warned about other toxic metals possibly more dangerous but currently unknown as to the tolerance limits which can be permitted. From a list of these other metals, beryllium, cadmium, lead, arsenic, chromium, silver, and selenium, the EPA has recently placed beryllium on a list of hazardous pollutants.

There is also input of lead and nickel directly into the Lake from gas spillages and boat motors. Because these cations are already being injected into the Powell habitat and will be injected into the Lake environment at ever-increasing rates, it becomes critically important to establish present levels and to monitor these ions. Areas around marinas are especially suspect to such contamination and it is significant that many fish are caught and eaten from these same sites.

It is planned to establish a network of sampling stations to provide a baseline of present cation concentrations without prejudicial implication of the present and future coal-burning power plants. Within the vast area of the Colorado River watershed are mountainous areas rich in a variety of minerals which have become available to streams through mining and erosion of tailings. Sampling stations for a variety of heavy metal cations will be established at the junction of major tributaries into the upper Colorado River and at several points on Lake Powell. Samples will include water, aquatic organisms, sediments, soil, and representative terrestrial vegetation at each site. The last will serve as an index for continued monitoring of vegetational absorption of atmospheric cations throughout the extent of the Upper Colorado River Basin and in future years. Collections of water samples will be coordinated and checked against those data reported from similar areas in the National Reference List of Water Quality Stations (USGS, 1971), and the Catalog of Information on Water Data--Index to Water Quality Section (USGS, 1970).

In a reconnaissance of selected minor elements in surface waters of the United States in 1970, Durum, Hem, and Heidel (1971) reported on several areas of the Colorado River drainage. Only the Colorado River at Fruita, Colorado, with 20 micrograms/L Zn, the San Juan River near Carracas, Colorado, with 1 microgram/L of Co, and the Green River at Green River, Wyoming, with 20 micrograms/L of Zn had concentrations of minor elements above detection levels (10 micrograms/L for As and Zn, 1 microgram/L for Cd, Cr, Co, Pb, and 0.5 microgram for Hg). An advantage of testing biological materials is the higher concentrations normally resulting from the phenomenon of biological magnification or accumulation, commonly known for selenium accumulators and recently dramatically illustrated for DDT concentrations which accumulate rapidly in steps up the food chain.

Sixteen fish from Lake Powell have been monitored for mercury concentrations by the U.S. Department of the Interior. This is a Federal monitoring program (1970) that indicated an average level of mercury of 0.19 ppm-mg/kg wet weight of whole fish. Kidd and Potter (1971) have reported the following preliminary levels for lead, mercury, and cadmium for materials

from a few areas of Lake Powell. The lead concentratio some materials collected at Lake Powell in 1971 are giv Exhibit 1.

Although the data are sparse at this writing, it m prove of interest to note that one bottom sediment regis 34.33 ppb mercury. This concentration is significant a 0.95 level. The possibility is raised that in those si tions where there are strong anerobic conditions, micro action may be concentrating this metal. We will have to until further data are available from the present progr bottom sampling.

Exhibit 2 indicates mercurial levels in various bl tissues. Higher concentrations of mercury occur in the flesh, heart, and liver. In Exhibit 3 are shown mercur for various tissues in carp. In carp, higher levels are found in the flesh and liver. All mercury concentration in fish are within acceptable levels of safety.

Exhibit 4 includes data for Elephant Butte Reser in New Mexico (Kidd and Garcia, 1971). This is an olde voir and we note higher levels of concentration in vari tissues. Some of the values are above the accepted min level of 0.5 ppm for mercury in flesh.

We have also monitored cadmium levels in Lake Pow (see Exhibit 5). The data for cadmium indicate higher l in sediment materials from the upper end of the San Jua of Lake Powell. There is heavy input of silt materials the San Juan River in this region.

There is still no broad coverage cation analysis p characterizing the entire extent of Lake Powell and its jor input tributaries. There is need for a monitoring f the ecosystem viewpoint with evidence of concentrations representative steps of the trophic levels of the food

METHODS

Cation Analysis

To provide baseline data of cation concentrations the Colorado River and Lake Powell, the following sampl pattern is suggested:

1. Upper Colorado River east of Grand Junction, senting the drainage from north-central Colora

2. Gunnison River at Grand Junction prior to its fluence with the Colorado, representing drai of west-central Colorado.

EXHIBIT 1. LEAD CONCENTRATIONS IN MATERIALS COLLECTED AT LAKE POWELL. (Unpublished data from 1971-72 NSF Lake Powell Project - Kidd and Potter)

Material	ppb	Location	Remarks
Bottom Sediment	$\bar{x}$ 11.48	Swimming area, Wahweap Bay	13 M depth
Bottom Sediment	$\bar{x}$ 24.89	N. end Wahweap Marina	16 M depth
Bottom Sediment	$\bar{x}$ 22.95	Marker 59, mouth of San Juan	105 M depth
Soil	$\bar{x}$ 18.93	Anasazi Indian Ruin in Reflection Canyon	Shoreline material
Soil	$\bar{x}$ 17.74	Head of Alcove Canyon, San Juan	Shoreline material just above waterline
Bottom Sediment	$\bar{x}$ 13.40	S. end Wahweap Marina	25 M depth
Bottom Sediment	$\bar{x}$ 14.28	Rainbow Bridge Marina Bay towards monument	81 M depth
Bottom Sediment	$\bar{x}$ 18.75	N. end of Wahweap Bay	9 M depth
Soil	$\bar{x}$ 14.21	San Juan near Mike's Mesa	red ss. muck shallow water
Bottom Sediment	$\bar{x}$ 34.33	San Juan near Piute Mesa	22 M, septic odor
Bottom Sediment	$\bar{x}$ 19.45	Padre Bay Weather Station	60 M depth

Exhibit 2. Mercurial concentrations in tissues of bluegills collected at mouth of Reflection Canyon, Lake Powell. (Unpublished data from 1971-72 NSF Lake Powell Project - Kidd and Potter.)

Tissue	ppb	Remarks	
Flesh	56.6	Bluegill:	wt. 210 g, l. 19.5 cm
Flesh	102.0	Bluegill:	wt. 202 g, l. 19.5 cm
Flesh	63.1	Bluegill:	wt. 217 g, l. 20.4 cm
Flesh	97.1	Bluegill:	wt. 230 g, l. 20.3 cm
Flesh	83.2	Bluegill:	wt. 182 g, l. 18.4 cm
Flesh	106.0	Bluegill:	wt. 197 g, l. 19.4 cm
Flesh	127.0	Bluegill:	wt. 278 g, l. 21.0 cm
Flesh	92.7	Bluegill:	wt. 178 g, l. 18.5 cm
Heart	143.0	Bluegill:	combined tissues
Heart	158.0	Bluegill	
Heart	87.3	Bluegill:	combined tissues
Liver	96.3	Bluegill	
Liver	92.0	Bluegill	
Liver	62.4	Bluegill	
Liver	95.8	Bluegill	
Stomach	28.0	Bluegill	
Stomach	41.4	Bluegill	
Stomach	27.8	Bluegill	
Stomach	46.5	Bluegill	
Brain	12.5	Bluegill	
Brain	23.1	Bluegill:	combined tissues
Kidney	28.6	Bluegill	
Gonad	23.6	Bluegill	
Fat	27.8	Bluegill	
Bones	5.8	Bluegill	
Bones	24.1	Bluegill	
Bones	18.4	Bluegill	
Bones	<5.0	Bluegill	
Bones	18.0	Bluegill	
Bones	3.5	Bluegill	
Gills	22.3	Bluegill	
Gills	21.9	Bluegill	
Gills	9.2	Bluegill	
Skin	30.8	Bluegill	
Skin	33.3	Bluegill	
Skin	29.0	Bluegill	
Skin	67.9	Bluegill	

EXHIBIT 3. MERCURIAL CONCENTRATIONS IN TISSUES OF CARP COLLECTED FROM LAKE POWELL. (Unpublished data from 1971-72 NSF Lake Powell Project - Kidd and Potter)

Tissue	ppb	Location	Specimen No.
Flesh	229	Padre Bay	#1
Flesh	221	Wahweap Bay	#2
Flesh	288	Wahweap Bay	#4
Heart	100	Padre Bay	#1
Heart	84	Wahweap Bay	#2
Heart	56	Wahweap Bay	#4
Liver	187	Wahweap Bay	#6
Liver	216	Padre Bay	#1
Liver	217	Wahweap Bay	#4
Stomach	57	Padre Bay	#1
Stomach	31	Wahweap Bay	#2
Stomach	44	Wahweap Bay	#4
Brain	36	Padre Bay	#1
Brain	60	Wahweap Bay	#2
Brain	83	Wahweap Bay	#4
Brain	84	Wahweap Bay	#6
Brain	120	Wahweap Bay	#10
Fat	63	Padre Bay	#1
Bone	42	Padre Bay	#1
Bone	16	Wahweap Bay	#2
Bone	31	Wahweap Bay	#4
Bone	32	Wahweap Bay	#6
Bone	23	Wahweap Bay	#10
Skin	20	Padre Bay	#1
Gills	19	Wahweap Bay	#2
Gills	29	Wahweap Bay	#4
Gills	25	Wahweap Bay	#6
Gills	39	Wahweap Bay	#10
Skin	36	Wahweap Bay	#2
Skin	20	Wahweap Bay	#4
Skin	16	Wahweap Bay	#6
Skin	24	Wahweap Bay	#10
(from lateral line, including lateral line tissues.)	60		
Gonads		Wahweap Bay	#2
Vascular	100	Wahweap Bay	#2
Kidney	193	Wahweap Bay	#4
Kidney	95	Wahweap Bay	#6
Kidney	251	Wahweap Bay	#10

EXHIBIT 4. MERCURIAL CONCENTRATIONS IN TISSUES OF SOFTSHELL TURTLE, WHITE BASS, WHITE CRAPPIE, CHANNEL CAT, GIZZARD SHAD, LONG EAR SUNFISH, AND CRAYFISH. DATA FOR ELEPHANT BUTTE RESERVOIR, NEW MEXICO. D. E. KIDD AND J. GARCIA. (Unpublished data.)

Tissue	Mercury ppm	Taxon	Length (cm)	Weight (g)	*Site	Collection Date
Muscle	$\bar{x}$ .272	Trionyx spiniter (soft shell turtle)	18	461.00	A	6/24/71
**Lungs	$\bar{x}$ .195	"		4.30	"	"
**Liver	$\bar{x}$ .763	"		25.40	"	"
Ovary- + eggs	$\bar{x}$ .107	"			"	"
Testes	$\bar{x}$ .055	"			"	"
Pancreas	$\bar{x}$ .986	"			"	"
Stomach	$\bar{x}$ .178	"			"	"
Intestine	$\bar{x}$ .177	"			"	"
Heart	$\bar{x}$ .143	"			"	"
Spleen	$\bar{x}$ .060	"			"	"
Kidney	$\bar{x}$ .433	"			"	"
Muscle	$\bar{x}$ .309	Roccus chrysops (white bass)	30	31.00		8/11/71
Gills	$\bar{x}$ .318	"				"
Heart	.27	"				"
Testis	.11	"				"
Stomach	$\bar{x}$ .292	"				"
Eyes	$\bar{x}$ .998	"				"
Spleen	.765	"				"
Muscle	$\bar{x}$ .061	Pomoxis annularis (white crappie)	18.5	79.00	A	6/24/71
Gills	$\bar{x}$ .032	"			"	"
Liver	.078	"			"	"
Ovary-						

EXHIBIT 4 (cont'd.)

Tissue	Mercury ppm	Taxon	Length (cm)	Weight (g)	*Site	Collection Date
Muscle	$\bar{x}$ .066	Ictalurus punctatus (channel cat)	23	107.55	A	6/30/71
Gills	$\bar{x}$ .008	"			"	"
Liver	.061	"			"	"
Testis	.143	"			"	"
Stomach	$\bar{x}$ .013	"			"	"
Intestine	$\bar{x}$ .012	"			"	"
Swim bladder	.011					
Kidney	.051	"			"	"
Eyes	.049	"			"	"
Muscle	$\bar{x}$ .069	Dorosoma cepedianum (gizzard shad)		51.41	"	6/23/71
Gills	.011	"			"	"
Liver	.067	"			"	"
Testiss	.113	"			"	"
Stomach	.057	"			"	"
Intestine	.049	"			"	"
Muscle	$\bar{x}$ .320	Lepomis megalotis (long ear sunfish)	13	47.10	B	7/28/71
Gills	.118	"			"	"
Liver	.358	"			"	"
Stomach	$\bar{x}$ .205	"			"	"
Intestine	.184	"			"	"
Eyes	.089	"			"	"
Tail muscle	$\bar{x}$ .031	Crayfish		8.60	C	7/2/71
Gills	.008	"			"	"
carapace + appendages	$\bar{x}$ .008	"			"	"
Internal organs	.003	"			"	"

*Site A-Engle Point, B-Near Castle Rock, C-McRae Canyon
**Analysis on combined samples.

EXHIBIT 5. CADMIUM CONCENTRATION IN MATERIALS COLLECTED AT LAKE POWELL. (Unpublished data from 1971-72 NSF Lake Powell Project - Kidd and Potter)

Material	ppb	Location	Remarks
Bottom Sediment	Below detectable limit	Swimming area, Wahweap Bay	13 M depth
Bottom Sediment	$\bar{x}$ 0.21	N. end, Wahweap Marina	16 M depth
Bottom Sediment	Below detectable limit	Marker 59 above mouth of San Juan	105 M depth
Soil	Below detectable limit	Anasazi Indian Ruins in Reflection Canyon	shoreline material
Soil	$\bar{x}$ 0.17	Head of Alcove Canyon San Juan	shoreline material collected just above waterline.
Bottom Sediment	$\bar{x}$ 0.17	S. end Wahweap Marina	25 M depth
Bottom Sediment	$\bar{x}$ 0.18	Rainbow Bridge Marina Bay toward monument	81 M depth
Bottom Sediment	$\bar{x}$ 1.15	N. end of Wahweap Bay	9 M depth
Soil	$\bar{x}$ 2.62	San Juan near Mike's Mesa	red ss. muck collected in shallow water
Bottom Sediment	$\bar{x}$ 5.65	San Juan near Piute Mesa	22 M depth, septic odor
Bottom Sediment	$\bar{x}$ <1.31	Padre Bay Weather Station	60 M depth

3. Dolores River north of Moab, representing drainage of southwestern Colorado.

4. Green River south of Moab, representing drainage of eastern Utah, southwestern Wyoming, and northwestern Colorado.

5. Dirty Devil River north of Hite, draining central Utah.

6. San Juan River at Navajo Reservoir, Mexican Hat, and prior to its confluence with the Colorado River.

7. The eight stations previously indicated in the biological limnology project for regular yearly sampling, namely, Hite, Moki Bar above Hall's Crossing, below Hall's Crossing, Rainbow Bridge Marina, Warm Creek Bay, Glen Canyon Dam, above and below Wahweap Bay Marina.

At each of the 16 stations listed above, collections will be obtained of the water at one or more depths, the bottom sediment, one or more samples of aquatic organisms--plants and fish, soil, and several species of the dominant terrestrial vegetation including one species common to all sites. This species will provide an index of site variation rather than different species response. The biological samples are to represent concentrations in the trophic levles of the food chain. Samples will be frozen or preserved in acidified solution in plastic bottles for cation analysis by atomic absorption at the UNM plant ecology research labs, where the Perkin-Elmer 306 atomic absorption spectrophotometer with graphite rod and mercury attachments will be used. These attachments were purchased and used on the first-year phase of the Lake Powell Project. Samples will be analyzed for Hg, Pb, Cd, Ca, Mg, Zn, Si, Cu, Fe, Ag, Mn, Cr, Mo, Co, Be, and Se; a total of 16 elements.

Bottom sediment samples will be taken at each station using an Ekman dredge or core sampler. Organisms will be removed and preserved for later analysis. Attached algae will be collected at various stations by allowing them to grow on submerged glass slides. These will be harvested and preserved for analysis. Benthic macroinvertebrates will be taken from each station using a Hester and Dendy multiple-plate sampler. The sampler will be attached to a line lowered to the bottom and marked with a fixed buoy. Samples will be harvested, preserved, sorted, and saved for subsequent analysis. Zooplankton samples will be taken at each station with a Wisconsin plankton net and saved for subsequent analysis.

Vertebrate samples, especially fish, will be taken by any feasible means after necessary arrangements with the Department of Game and Fish. Frogs, toads, salamanders, and turtles will also be taken when available.

Stations above Hite and the ones on the San Juan River will be sampled in June and December, at times generally coincident with periods of high and low runoff and Lake level. Sampling at more frequent intervals will be done at the eight stations previously indicated for year-round sampling under the eutrophication subproject.

A concentration factor expressing the quantity of metal compound which moves from soil to animal, water to animal, soil to plant, water to plant, and from diet will be determined. This should indicate path of movement of metal in an aquatic environment. The following calculations will be used for determining concentration factors:

1. Movement of metal from soil (sediment) into animal or plant:

$$\text{Concentration factor} = \frac{\text{Concentration of metal in animal or plant}}{\text{Concentration of metal in water}}$$

2. Movement of metal from water into animal or plant:

$$\text{Concentration factor} = \frac{\text{Concentration of metal in animal or plant}}{\text{Concentration of metal in water}}$$

3. Movement of metal into animal from diet:

$$\text{Concentration factor} = \frac{\text{Concentration of metal in animal}}{\text{Concentration of metal in diet (various sources)}}$$

Thus, there will be established a baseline of heavy metal cations and the role of various trophic levels of the ecosystem which will be invaluable for future comparisons.

LITERATURE CITED

Brown, Eugene, M. W. Skougstad, and M. J. Fishman. 1970. Methods for collection and analysis of water samples for dissolved minerals and gases: U. S. Geol. Survey Techniques Water Resources Inv., Book 5, chap. A1. 160 p.

Cadigan, R. A. 1970. Mercury in sedimentary rocks of the Colorado Plateau region, pp. 17-18, 61. In Mercury in the Environment. USGS Prof. Paper 713.

Durum, W. H., J. D. Hem, and S. G. Heidel. 1971. Reconnaissance of selected minor elements in surface waters of the United States, October 1970. USGS Circ. 643.

Greeson, P. E. 1970. Biological factors in the chemistry of mercury, pp. 37-39, 66. In Mercury in the Environment. USGS Prof. Paper 713.

Harris, R. C., D. B. White, and R. B. MacFarlane. 1970. Mercury compounds reduce photosynthesis by plankton. Science 170:736-737.

Kidd, D. E., and J. Garcia. 1971. Unpublished data for Elephant Butte Reservoir.

Kidd, D. E., and L. D. Potter. 1971. Unpublished data for Lake Powell.

Klein, D. H., and E. D. Goldberg. 1970. Mercury in the environment. Environmental Sciences and Technology 4(9):765-768.

Shacklette, H. T. 1970. Mercury content of plants. In Mercury in the Environment. USGS Prof. Paper 713.

USGS. 1970. Mercury in the environment--a compilation of papers on the abundance, distribution, and testing of mercury in rocks, soils, waters, plants, and the atmosphere. USGS Prof. Paper 713 67 p.

USGS. 1971. National reference list of water quality stations, Water year 1971. USGS Water Resources Division.

USGS. 1971. Catalog of information on water data--index to water quality section. USGS Office of Water Data Coordination.

Subproject Numbers 4, 5, and 6

4: Streamflow Trends, 5: Lake Evaporation, and 6: Bank Storage

4: SECULAR RUNOFF TRENDS IN THE MAJOR SOURCE AREAS OF THE UPPER COLORADO RIVER BASIN

5: EVAPORATION FROM LAKE POWELL

6: BANK STORAGE AT LAKE POWELL

three components of

COLLABORATIVE RESEARCH ON ASSESSMENT OF

MAN'S ACTIVITIES IN THE LAKE POWELL REGION

Amount Requested	Proposed Duration	Requested Starting Date
4 -- $39,623 5 -- $56,180 6 -- $50,188	2 Years	May 15, 1972

Total Amount Requested: $145,991

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Endorsements

Investigators	Institute Head	UCLA Administration
Orson L. Anderson Prof. of Geophysics	Willard F. Libby Director	Robert W. Ryperson Contracts and Grants Officer

Gordon C. Jacoby
Research Geophysicist

PREFACE TO THE UCLA HYDROLOGY PROPOSALS

The principal thrust of the three UCLA hydrology subprojects is to establish what waters are, and will be, available in the Upper Colorado River Basin, especially in the Lake Powell region. This information is essential to the political and institutional entities in the region. Water-resource allocation decisions at the highest levels of government may be vitiated if the quantitative value of the resources are overestimated or if there are nonrecoverable losses.

The legal subproject of the Lake Powell Project is considering the following question with regard to precedent establishing decisions:

> "Whether, and to what extent, scientific data and evidence was presented to and considered by the decision-making body?".

The purpose of the hydrology subprojects is to assure that accurate "scientific data and evidence" are available to federal, state and regional institutions making decisions regarding water-resource allocations.

Components of the hydrology subproject are Bank Storage, Evaporation and Streamflow Trends. These three subprojects furnish the information for a budget of the amounts of water in the region and facilitate prediction of future availability.

Bank Storage may be a negligible quantity, an infiltration loss, or a real storage that is available for future use. In the case of Lake Powell the bank storage is estimated to be very large, its availability is unknown. The disposition of this large amount of water must be established for good reservoir management purposes. If it is a "loss", this fact must be considered in future water-resource allocation decisions. If the bank storage is a readily returable storage, the situation could be very beneficial for the Upper Colorado River Storage Project.

Evaporation is a loss but at present it is not an accurately defined loss. Until the evaporation is accurately known, calculations of loss as a function of depth and surface area cannot be considered precise, This precise

knowledge is necessary for good reservoir management. There should be optimum lake levels where the evaporation losses are best compensated for by power production, recreation, storage and other management considerations. Also, this loss must be subtracted in determining water available for allocation to user institions.

For future allocations and present management it is necessary to know what the long-term trends are in surface-water flow. The questions must be asked, "In the context of recent centuries, are we in a dry or wet period? Are we heading into a dry or wet period?". Water-resource allocation decisions made in a wet period become specious if 10 years later the allocated quantities do not exist. Streamflow records show we are presently in a period drier than 40 years ago but do not show how this dry period fits into a longer context. There is just not enough information available to predict or even justifiably hope for an upturn. Historical records are insufficient to resolve this question. We must interrogate witnesses that have been monitoring the river system for a much longer time than modern man. These witnesses are centuries-old trees to whom water is survival. With the information they provide we can reconstruct the past, place ourselves in the proper perspective and better estimate trends of the future. These estimates of the future are essential for the water-resource management decisions of today.

SECULAR RUNOFF TRENDS IN THE MAJOR SOURCE AREAS OF THE UPPER COLORADO RIVER BASIN

Abstract

During the first year of the Project, streamflow records for the entire Upper Colorado River Basin (UCRB) were examined. These data showed that there were wide variations in runoff from the major source areas of the Colorado River. The high tributary basins are the source areas for most of the runoff that maintains the reservoirs of the Colorado River Storage Project. Largest of the upper basin reservoirs is Lake Powell. The runoff variations (wet and dry years) in the subdivisions of the basin are not always in phase (see Figure 1). Most of these records go back less than 50 years in time. In order to better understand the space and time variations in runoff or available surface water, information is needed extending beyond this 50-year period. Toward this end, tree ring chronologies will be used to reconstruct streamflow patterns for the past two centuries. The tree-ring chronologies will be assembled by the Laboratory of Tree-Ring Research, Tucson. There is a consulting agreement with that Laboratory for this work.

PROPORTIONATE FLOW OF THE

THREE MAJOR RIVERS ENTERING

LAKE POWELL

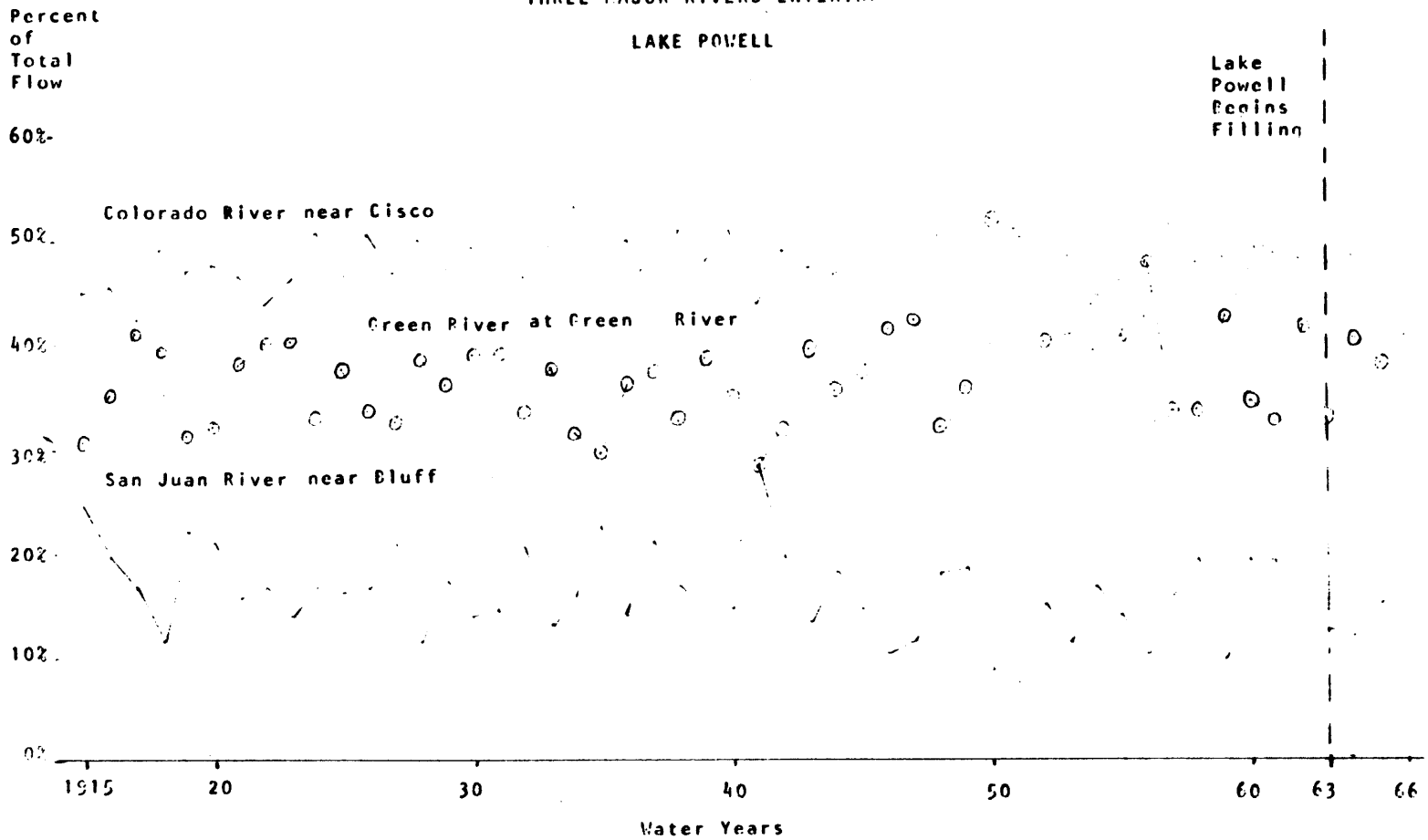


Figure 1

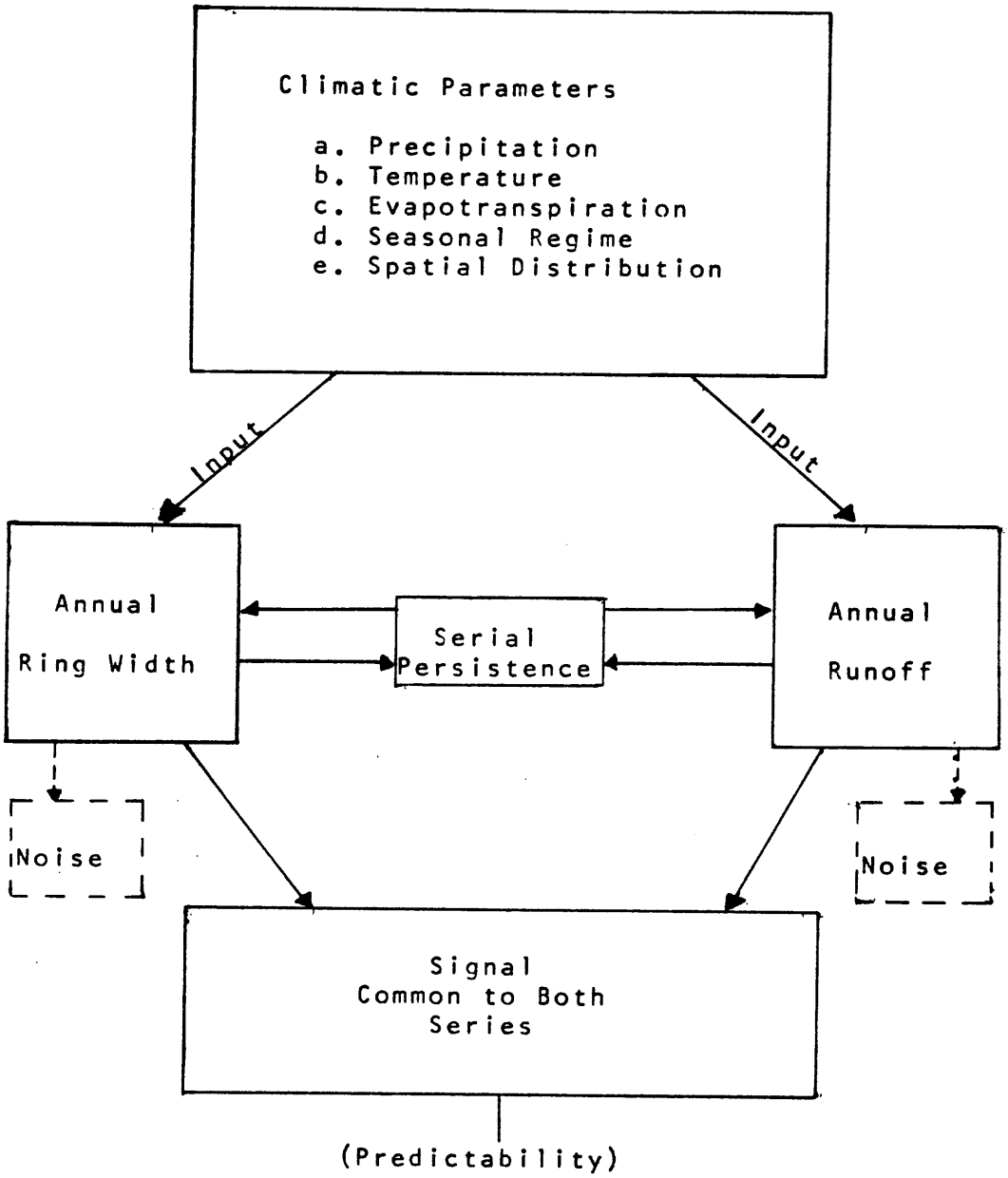
Introduction

During the next 2 years, we wish to concentrate on the problem of obtaining estimates of the runoff of certain subdivisions of the UCRB, going back several hundred years. We believe that the best way to do this is to conduct a detailed study of tree-growth variation as it responds to the climatic variations which also influences runoff (see Figure 2). This growth variation is recorded in the differential width of the trees' annual growth rings.

The upper tributary streamflow records, when used with dendrochronologic records of carefully controlled sites, can be used to create a reconstructed record of the runoff in the past as far back as the age of the trees (Stockton, 1971; Stockton and Fritts, 1971a: Schulman, 1945). A number of tree cores, measured at one site, yield data for that site. In many of the sub-basins several such sites will be used in reconstructing past runoff trends. Such controlled sampling will give a realistic figures for the runoff contribution of a sub-basin into the river network feeding Lake Powell. The trends of all these subbasins over time will show what quantities of water should have been available to Lake Powell, and to the Lee's Ferry station (the division point in the Colorado River Compact).

Also, the divergence between these subbasin runoff contributionsand streamflow records of major lower-basin tributaries may reveal consumptive use patterns and trends. Undoubtedly, uppper basin consumptive use, in addition to climatic variation, directly affects the availability of water to maintain reservoirs like Lake Powell.

The reason that records extending back beyond 50 years are needed is that long-time trends as well as short-time trends influence secular changes. These long-time trends are not discernable in the available streamflow records.



Schematic diagram of relationship between ring-width series and annual runoff series for medium and large watersheds. (After Stockton and Fritts, 1971)

Fig. 2

Background

The records reviewed and plotted in the first year's efforts showed wet and dry periods in the smaller, relatively undisturbed tributaries. Some of these periods were of short duration and did not reveal a long-term trend. Other lower frequency "cycles" may relate to long-term trends but these departures from the means had apparent periodicities that were of the order of or larger than the length of record.

In trying to develop longer term streamflow information, Fiering (1967) and others of the water resources group at Harvard University approached the problem by using synthetic series generated as a function of the statistical parameters of existing gaged records and Markov-chain relationships. However, these series are still based on the sample statistics of the short-term recorded data. And, as shown by Mandelbrot and Wallis (1968), there are long-term nonrandom, low-frequency components that cannot be modeled using the Markovian approach. It is the suggestion of Mandelbrot and Wallis that a "reference horizon" or reference series be analyzed. This series can then be rescaled to produce long-term information about a streamflow series.

It has been shown, as a result of recent research by the Laboratory of Tree-Ring Research at Tucson, that tree-ring series can be used as a reference series to reconstruct streamflow conditions of the past. The results will not only allow evaluation of the nonrandom, low-frequency variances described by Mandelbrot and Wallis, but will also produce improved estimates of the long-term mean and variance.

Thus, there is substantial information of a hydrologic nature in appropriately chosen tree-ring series, and reconstruction of past runoff series is feasible (Stockton, 1971); Stockton and Fritts, 1971a). Mandelbrot and Wallis (1969) have also investigated the use of tree-ring series as a source of paleohydrologic information and have pointed out the excellence of such series in containing long-term climatic information.

A limited number of increment cores were taken in the UCRB in the first year of the Lake Powell Project. These cores were taken in the drainage basins of small tributaries in the major input areas of the UCRB.

Preliminary plotting and comparison of streamflow data and tree-ring data have shown good correlations. The best correlations were between narrow ring widths and low flow years. In other studies the best correlations between runoff for a given year and ring widths of the concurrent year and previous year. This relationship is consistent with the climatic lag or carryover effect in ring-width series as described by Fritts, et al 1971.

PLANNED RESEARCH

The main areas contributing to surface runoff in the UCRB are shown in Figure 3. Reconstructed runoff series will be developed for these areas. The reconstructed runoff series will be developed using existing recently collected chronologies where available and chronologies based on new sites where good chronologies do not exist. The available data sites and proposed new sites are shown in Figure 4. Also indicted on this figure are stream gage sites where there are good records of surface flow available. The ring-width chronologies will be used to extend the streamflow data at these gage sites back through several centuries.

The results will be reconstructed flow records for the main streamflow contributing areas of the UCRB. In the proposed two-year program the reconstruction of the streamflow record will be accomplished. On a time-available basis the UCLA hydrology personnel will try to interpret these records to show the long-term time-space distribution of surface water in the UCRB. Also, comparison between these reconstructed flow records and records from major stream gages in the UCRB may be used to reveal information about consumptive use in the larger basins.

METHODS

For the purposes of this study, the UCRB is divided into subareas with estimated mean flow contributions to the basin outflow as follows:

1. West side of the Wind River Mountains in Wyoming, 9%

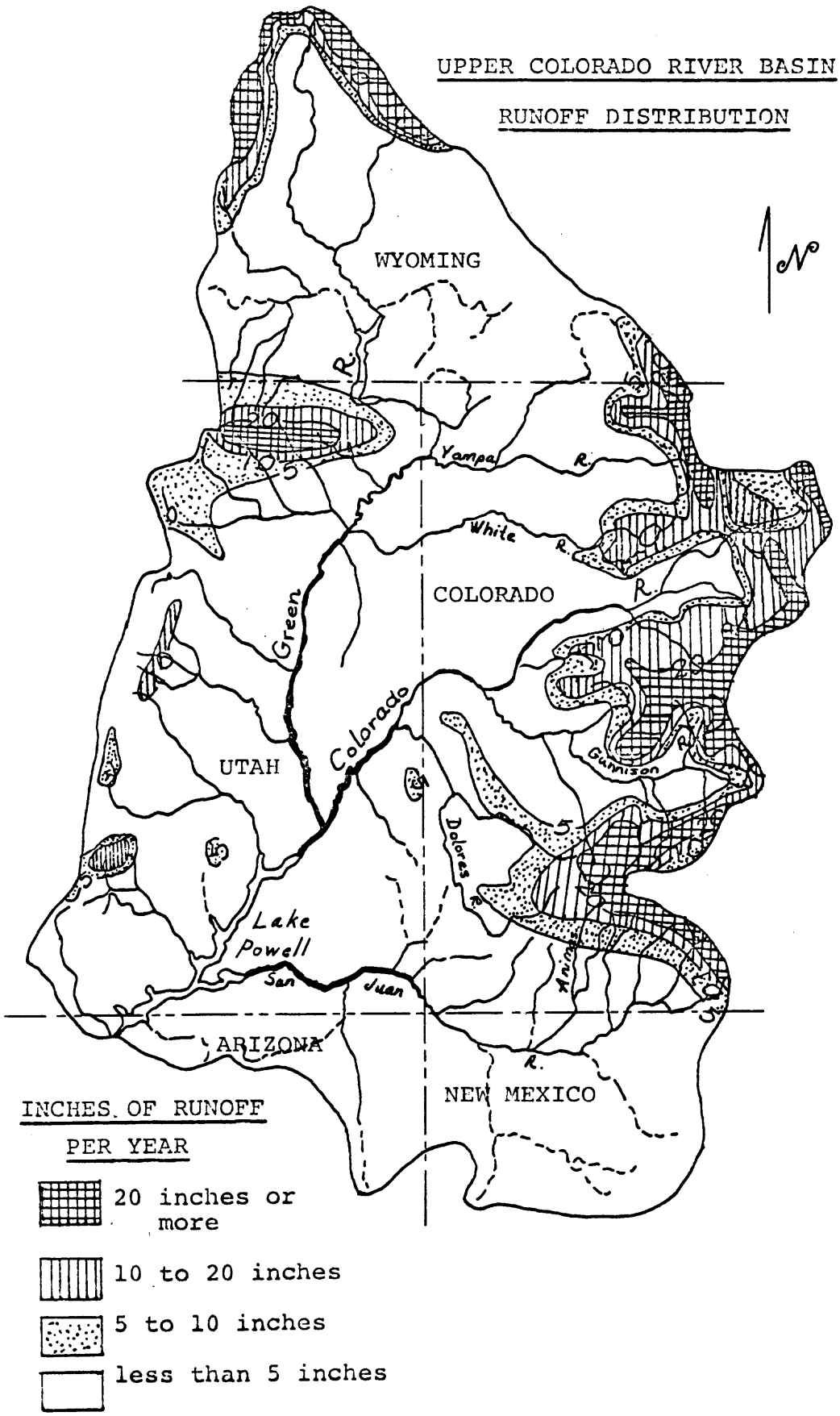
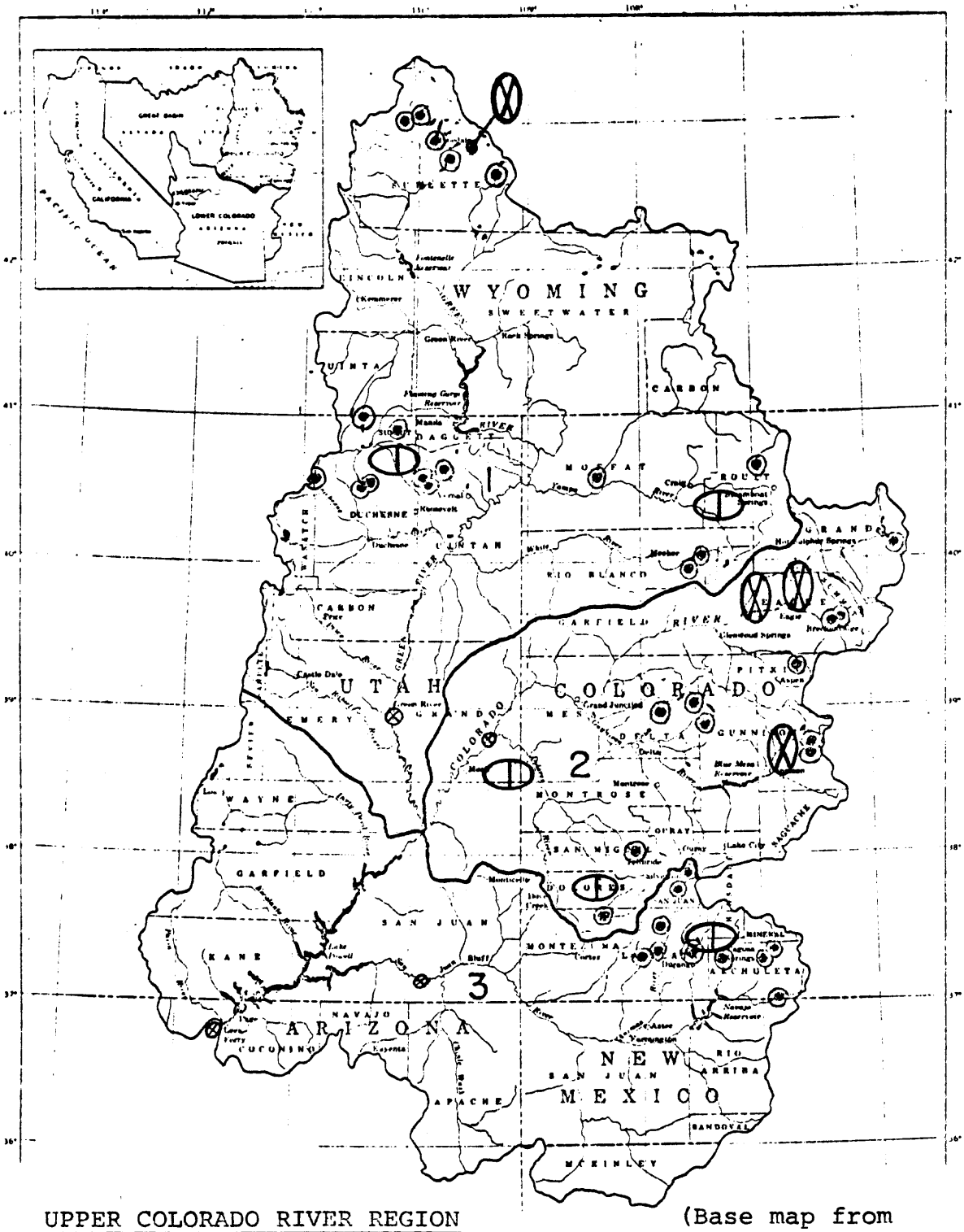

UPPER COLORADO RIVER BASIN
RUNOFF DISTRIBUTION
N
WYOMING
COLORADO
UTAH
ARIZONA
NEW MEXICO
Green
Colorado
Yampa
R.
White
R.
R.
Gunnison
R.
Dolores
R.
Lake
Powell
San
Juan
R.
Animas
R.
INCHES OF RUNOFF
PER YEAR
20 inches or more
10 to 20 inches
5 to 10 inches
less than 5 inches

Figure 3



UPPER COLORADO RIVER REGION

(Base map from Upper Colorado Region Framework Study.)

- Existing Ring-width Chronologies
- Proposed Sites for Chronologies
- Stream Gages with Good Records
- Principal Gaging Stations of Inflow and Outflow for Lake Powell

Figure 4

2. Uinta Mountains in Southwestern Wyoming and northeastern Utah, 9%
3. Yampa and White Rivers headwaters in south-central Wyoming, 14%
4. Main stem Colorado River headwaters in north-central Colorado, 18%
5. Gunnison River headwaters in central Colorado, 16%
6. Dolores River headwaters in west-central Colorado, 5%
7. San Juan River headwaters in southewstern Colorado, 14%

These seven subareas contribute about 85% of the total outflow from the UCRB. There are good chronologies for the Wind River Mountains, the Colorado River main stem, and the Gunnison River. New sites which will be investigated during the first field season are in the Unita Mountains, Yampa and White Rivers area, Dolores River area, and San Juan area. Also, in east-central Utah, a site will be selected for a centralized regional-control site.

At each site, ten trees will be cored, two cores from each tree. The specific site selection and actural coring will be done with C. W. Stockton and M. A. Stokes of the Laboratory of Tree-Ring Research. The cores will be taken to the Laboratory for measurement and dating as detailed in Stokes and Smiley (1968). Initial data reduction and screening will also be performed at the Laboratory.

The standardized ring-width chronologies will then be integrated with the streamflow data at UCLA. Two statistical approaches will be used. Standard multivariate regression techniques in conjunction with principal component analysis (Stockton 1971, Stockton and Fritts, 1971a) will be used to relate seasonal streamflow to the ring widths of the 3 previous years. The resulting regression relationships will be used to reconstruct streamflow series back to the beginning of the ring-width chronologies.

Then using overlapping years of streamflow data and tree-ring chronologies as two sets of variables canonical analyses (Glahn, 1968) will be used to determine the best linear combination between the two sets of variables. This

function will produce the maximum correlation. The resulting information can be used to reconstruct the tributa flow while including the serial tendencies if both runoff tree-ring series in the reconstruction.

By using the "response function" approach of Fritts et. al. 1971, demonstrated in Stockton 1971, the response the trees to climatic inputs will be compared to the resp of runoff. This procedure will allow detailed examination of the responses to climate of both systems. Also the re sults of this procedure will serve as a means for testing the validity of the reconstructed records.

PERSONNEL AND CONSULTING AGREEMENT

Gordon C. Jacoby, Hydrologist, UCLA, has been reviewing streamflow trends in the Upper Colorado River Basin during the first year at the Lake Powell Project. He has selected and investigated various tributary basins and determined where the best long-term flow data are available. These data stations will be used in the proposed study. He has done statistical analyses of streamflow data and is familiar with tree-ring techniques. He is involved with the two other hydrology subprojects and will oversee the tree-ring studies and integrate them into the overall hydrology program.

Depending on the progress of the other two hydrology subprojects, he will analyze the effects of streamflow trend study results on a time-available basis.

The major portion of the tree-ring work will be done on a consulting agreement basis at the Laboratory of Tree-Ring Research in Tucson, Arizona. The principal investigator on the consulting program will be Charles W. Stockton. He is a Research Associate at the Laboratory and has previously worked on streamflow reconstruction studies in the UCRB. He will be devoting half of his time during the next two years to the streamflow reconstruction program of the Lake Powell Project.

UCLA will provide a field vehicle and non-personal equipment for the field-work program of the Laboratory of Tree-Ring Research.

References

Fiering, M. B., Streamflow Synthesis, Harvard University Press, Cambridge, 139 pages.

Fiering, M. B. and B. B. Jackson, Synthetic Streamflows, Water Resources Monograph, no. 1, Am. Gephys. U., Wash. D.C. 1971.

Fritts, Harold, C., D. G. Smith, and M. A. Stokes, "The Biological Model for Paleoclimatic Interpretation of Mesa Verde Tree-Ring Series, "American Antiquity", 31, No. 2, part 2, pp. 101-121, October 1965.

Fritts, Harold C., T. J. Blasing, B. P. Hayden and J. E. Kutzback, "Multivariate Techniques for Specifying Tree-Growth and Climate Relationships and for Reconstructing Anomalies in Paleoclimate", Jour. Appl. Meteorol., Vol. 10, Part 5, pp. 845-864, 1971.

Glahn, H.R., "Canonical Correlation and its Relationship to Discriminant Analysis and Multiple Regression", Jour. Atmos. Science, Vol. 25, Part 1, pp. 23-31, 1968.

Mandelbrot, B.B., and J. R. Wallis, "Noah, Joseph, and Operational Hydrology", Water Resources Research, 4, No. 5, pp. 909-918, 1968.

Mandelbrot, B. B., and J. R. Wallis, "Some Long-Run Properties of Geophysical Records", Water Resources Research, 5, No. 2, pp. 321-340, 1969.

Schulman, Edmund, "Tree-Ring Hydrology of the Colorado River Basin", University of Arizona Bulletin, Laboratory of Tree-Ring Research Bulletin #2, XXI, No. 4, 54 pages, October 1, 1945

Stockton, C. W., "The Feasibility of Augmenting Hydrologic Records using Tree-Ring Data", Ph.D. Dissertation, University of Arizona, 1971, 172 pages.

Stockton, C. W., and H. C. Fritts, "Augmenting Annual Runoff Records using Tree-Ring Data", HYDROLOGY AND WATER RESOURCES IN ARIZONA AND THE SOUTHWEST, Vol. 1, Proceedings of the 1971 meetings of Arizona Section of the American Water Resources Association, and the Hydrology Section of the Arizona Academy of Science, April 22-23, Tempe, Arizona, pp. 1-12, 1971a.

Stockton, C. W., and H. C. Fritts, "An Empirical Reconstruction of Water Levels for Lake Athabasca (1810-1967) by Analysis of Tree-Rings", Preliminary Report for the Peace-Athabasca Delta Project, Edmonton, Alberta, Canada, 55 pages, 1971b.

Stokes, M. A. and T. L. Smiley, An Introduction to Tree-Ring Dating. The Univ. of Chicago Press, 73 pages, 1968.

The UCLA-endorsed coversheet for subproposal number 5, Evaporation, has been incorporated into the coversheet for all three UCLA-funded subproposals, and the information on it has been relocated to page 133.

EVAPORATION

ABSTRACT

The net loss of water from Lake Powell due to evaporation is presently estimated by the Bureau of Reclamation at 425,000 acre-feet for 1971 and at full reservoir capacity would be an estimated 650,000 acre-feet. These figures are net evaporation, gross evaporation less that which would naturally occur in the rivers without the existance of Lake Powell.

The gross evaporation for 1971 is estimated as at least 511,000 acre-feet and at full reservoir capacity would be at least 770,000 acre-feet (Jacoby, 1971).

The Bureau of Reclamation presently is operating three stations on the Lake to record data for evaporation calculations, as shown in Figure 1. These stations are recording information for calculations based on the mass-transfer method. The Bureau of Reclamation shares our interest in improving the accuracy of evaporation determination. The Lake Powell Project proposes to aid in establishing and monitoring one additional mass-transfer station on the Lake and to work in conjunction with the Bureau of Reclamation in upgrading their existing stations.

Also, it is proposed to establish at least two radiation stations. The data from these stations will be integrated with the data from the other stations and with data from the limnology subprojects to calculate evaporation using the energy-budget method.

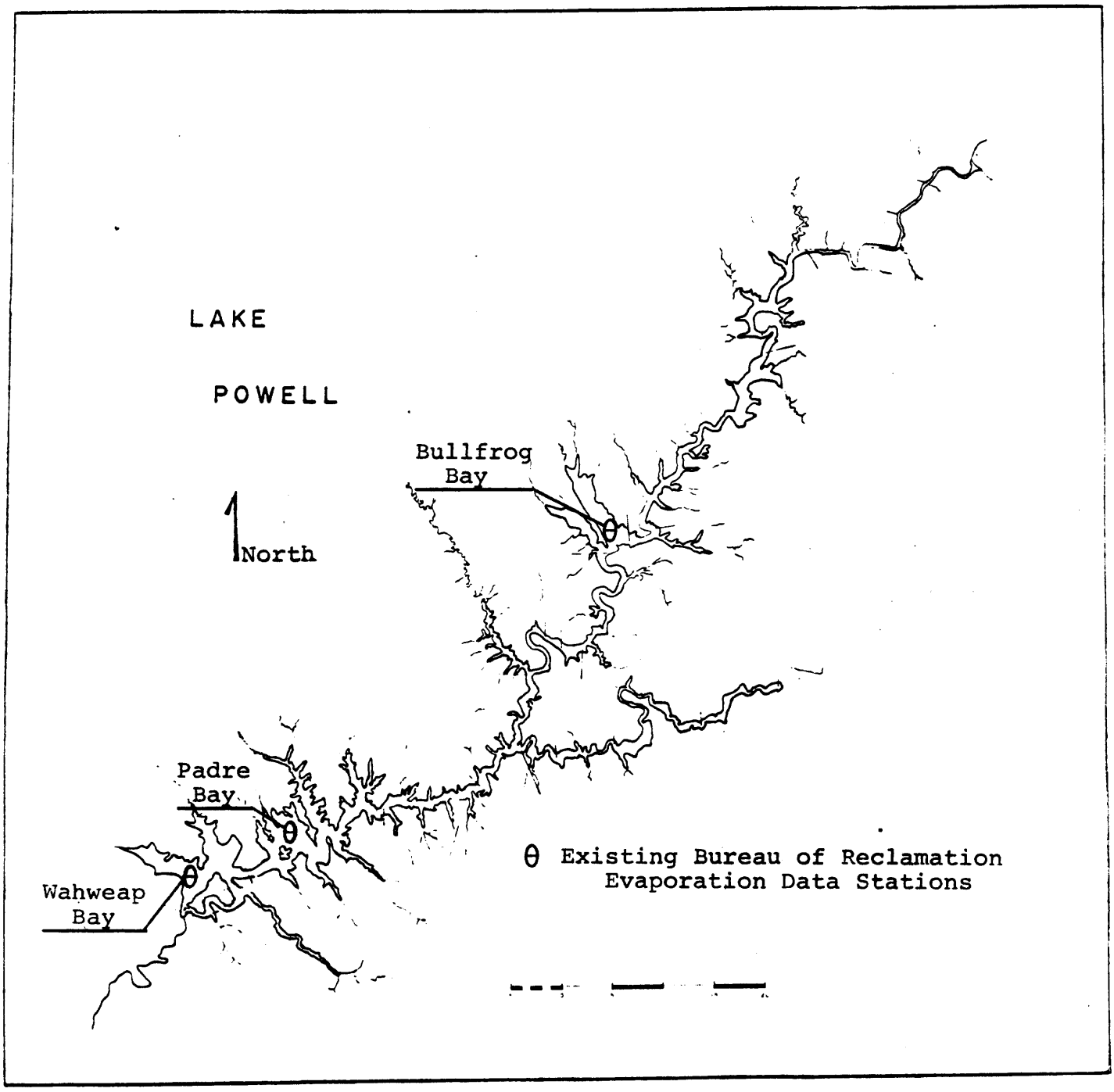

LAKE
POWELL
Bullfrog Bay
North
Padre Bay
Wahweap Bay
θ Existing Bureau of Reclamation Evaporation Data Stations

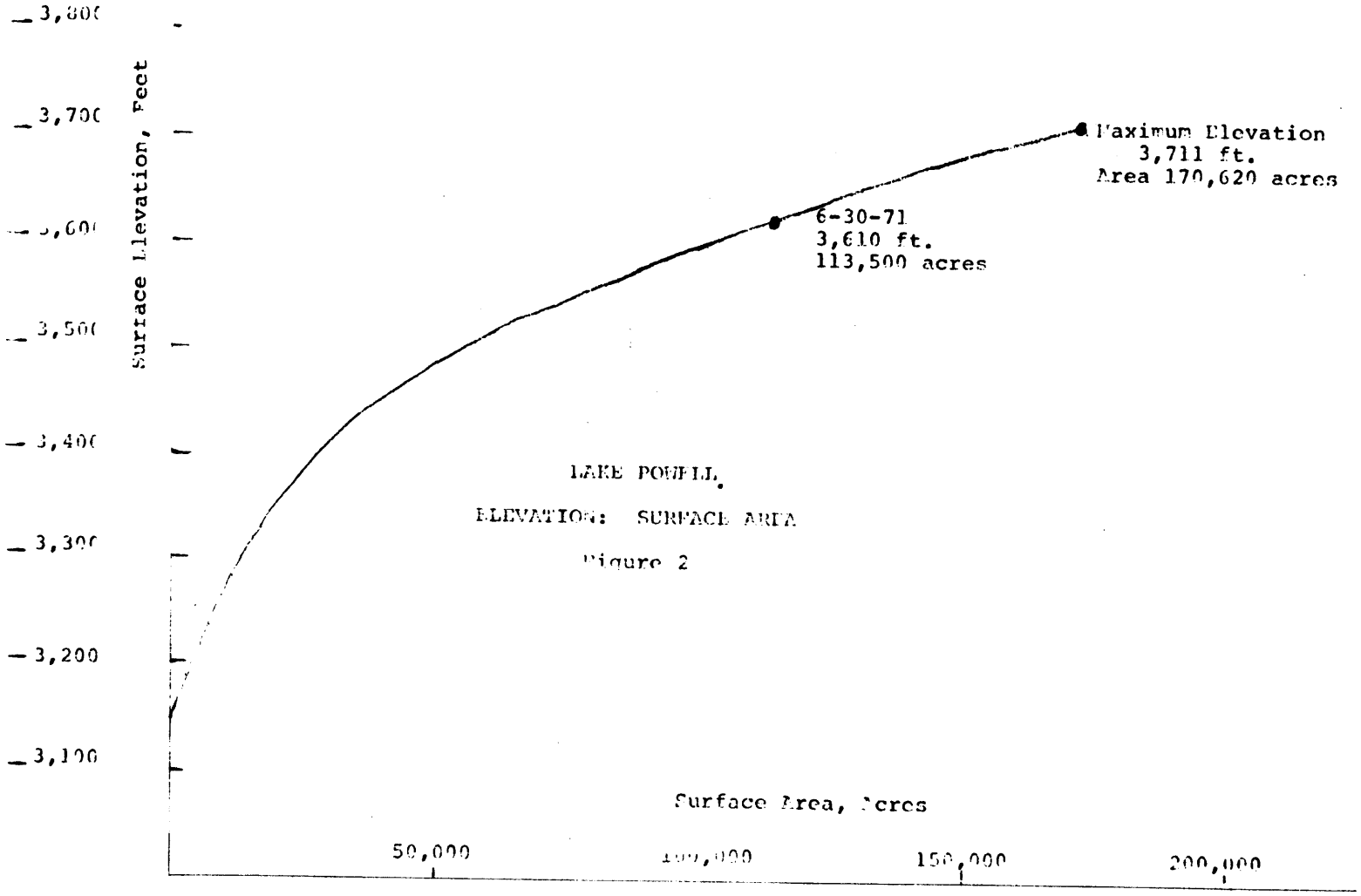
Figure 1

RATIONALE

Evaporation from a body of water is directly proportional to the surface area. Figure 2 is a plot of surface area as related to elevation of the Lake surface. It can readily be seen that above the 3600-foot elevation each foot increase adds considerable new surface area; approximately 600 acres per foot increase in elevation.

Assuming the gross evaporation to be 4 1/2 feet of water per year (Meyers and Nordenson 1968), a conservative figure, there would be an additional evaporation loss of 2,700 acre-feet of water for each foot increase in Lake surface elevation. Using the estimated net evaporation figure, at full capacity, of 650,000 acre-feet, it can be calculated that approximately 2,300 additional acre-feet of water will be lost by evaporation for each foot increase in Lake level above 3600 feet (Jacoby, 1971).

Greater accuracy and knowledge of evaporative losses from Lake Powell will aid in beneficial management of the Lake. Also, the knowledge gained will be valuable in making decisions about other water storage projects in the Colorado River Basin and other similar regions.



LAKE POWELL

ELEVATION: SURFACE AREA

Figure 2

INTRODUCTION

There are three basic methods of computing evaporation from open bodies of water. They are based on mass transfer, energy budget, or evaporation pans. A brief description of the three approaches follows.

In the pan method, evaporation pans are located on land or floating on the lake. It is assumed that there is a predictable ratio between the pan evaporation and the evaporation from the larger body of water. This ratio is termed the pan coefficient. It is applied to the measured loss from the lake. The pan method produces its best results for longer time periods, e.g., annual evaporation losses.

The mass-transfer method is based on measuring the physical amount of water vapor moving away from the body of water. Vapor pressure, barometric pressure, wind and temperature differences furnish the necessary information for this method. However, there are empirically determined coefficients used in the calculations. Studies of Lake Hefner, Lake Mead, and the Salton Sea indicate that these coefficients are not universally applicable constants. Therefore, it is best to have a parallel evaporation study using other methods to help converge on coefficients applicable to the particular body of water under study. The more rigorous mass-transfer equations require data on vapor pressure and wind gradients. The less rigorous equations utilize single measurements and rely upon theoretically derived exponents or exponents determined empirically from other studies. The mass-transfer approach is likely to be the best of the three methods for shorter weekly or daily evaporation calculations.

The energy-budget approach determines the energy flux through the water body and changes in energy storage. The net input minus output and storage change is assumed to be used to evaporate the water. Radiometers are used to measure net solar energy input. Water temperatures at inflow and outflow points and the flow quantities are used to measure energy advected through the water body. Data on the temperature distribution throughout the body of water are used to calculate changes in stored energy. Vapor pressures and air temperatures are used to calculate the ratio of energy conducted away as sensible heat to the energy used in

evaporation. The energy-budget method is useful for estimating evaporation for weekly to annual values. Also, information gained from energy-budget studies can be used to determine empirical coefficients used in mass-transfer studies.

To date, the estimations of evaporation for Lake Powell have been based upon nearby pan stations and mass-transfer studies. The latter have been of the single measurement type rather than measuring gradients. At present, because of the efforts and interest of the Bureau of Reclamation and the temperature data from the limnology subprojects of the Lake Powell Project, it is a very opportune time to institute a comprehensive evaporation study of Lake Powell.

PROPOSED RESEARCH

It is proposed to develop data stations at Lake Powell which will record information to calculate evaporation losses by both the mass-transfer and energy-budget methods. The development of these stations will be done in close cooperation with the Bureau of Reclamation as a continuation of their ongoing program.

There will be a two-phase effort. Phase one will be an evaluation of instrumentation and installations. The second phase will be full installation of all instruments and data collection for the entire Lake. The calculations of evaporation will be largely based on data collected in the second phase.

The Bureau of Reclamation will continue its mass-transfer studies and the Lake Powell Project will conduct complementary energy-budget studies.

METHODS

A. One standard form for the mass-transfer equation for evaporation is as follows:

$$E = \frac{C(e_1 - e_2)(w_2 - w_1)}{(T - 273)\ \ln (H_2/h_1)^2}$$

where C = constant; E= evaporation (in/hr); e_1 = vapor pressure at h_1 (in of Hg); e_2 = vapor pressure at h_2 (in of Hg); w_1 = wind speed at h_1 (mph); w_2 = wind speed at h_2 (mph); T = mean temperature between h and h_2 (°F); h_1 = lower height (2 m); and h_2 = upper height (4m).

Other forms of mass-transfer equations require water temperature and barometric pressure. To gain maximum flexibility in calculation methods, data will be obtained for both types of equations.

The Bureau of Reclamation is pursuing a program to improve their data stations to collect 2-level data for mass-transfer calculations. The digital recorders for the Lake Powell Project will be used to record both mass-transfer data and radiation data at each raft installation.

B. One standard energy-budget equation for evaporation is as follows:

$$E = \frac{(Q_s - Q_r - Q_b) + (Q_v - Q_\theta)}{\rho L\ (1 + R)}$$

where E = evaporation (cm); Q_s = solar radiation incident to water surface; Q_r = solar radiation reflected from water surface; Q_b = net loss of long-wave radiation energy by water body to atmosphere; Q_v = energy advected into water body; Q_θ = energy stored in water body; ρ = density of water; L = latent heat of evaporation; and R = Bowen ratio.

$(Q_s - Q_r - Q_b)$ will be measured by net radiometer and radiation data will be available from the station at Page.

$$(Q_v - Q_\theta) = \frac{1}{A}(\Sigma IT_I - \Sigma OT_O - \Sigma ET_E - \Sigma ST_S)$$

where A = surface area of the body of water; I = inflow; T_I = mean temperature inflow; O = outflow; T_O = mean temperature of outflow; E = evaporation (estimated and adjusted by reiteration); T_E = mean temperature of evaporated water; S = change in storage of body water; and T = mean temperature of water in storage change.

The advected and stored heat constitutes the heat content of water and water vapor physically moved through, added to, or depleted from the system. The rates of flow will come from gaging-station data, results of the bank storage study, and the reiteration mentioned above. The temperatures of these quantities will come from the data-recording stations and the other Lake-temperature data measured by the Dartmouth dynamic-limnology section.

Through the Bureau of Reclamation temperature recorders will be made available to the project. These instruments will be installed at the two major inflow points of the Lake and monitored by the Lake Powell evaporation subprojects personnel. Outflow temperature is available from the U.S.G.S. station at Lee's Ferry, see Figure 3. Changes in Lake volume are monitored by the Bureau of Reclamation.

R, the Bowen ratio, is the ratio of the sum of energy conducted as sensible that to the energy used in evaporation. This ratio can be expressed as follows:

$$R = \frac{0.61\ P(T_w - T_a)}{1000\ (e_w - e_a)}$$

where P = the atmospheric pressure; T_w = the temperature of the water; T_a = temperature of the air; e_w = saturated vapor pressure of air at T_w; and e_a = vapor pressure of air at T_a.

The air temperature and vapor pressure of the air will be recorded at the data station sites described in subsection A. Atmospheric pressure will be recorded at Halls Crossing which is centrally located at the Lake, see Figure 3. Barometric pressure does not vary too greatly and this one central site should be sufficient.

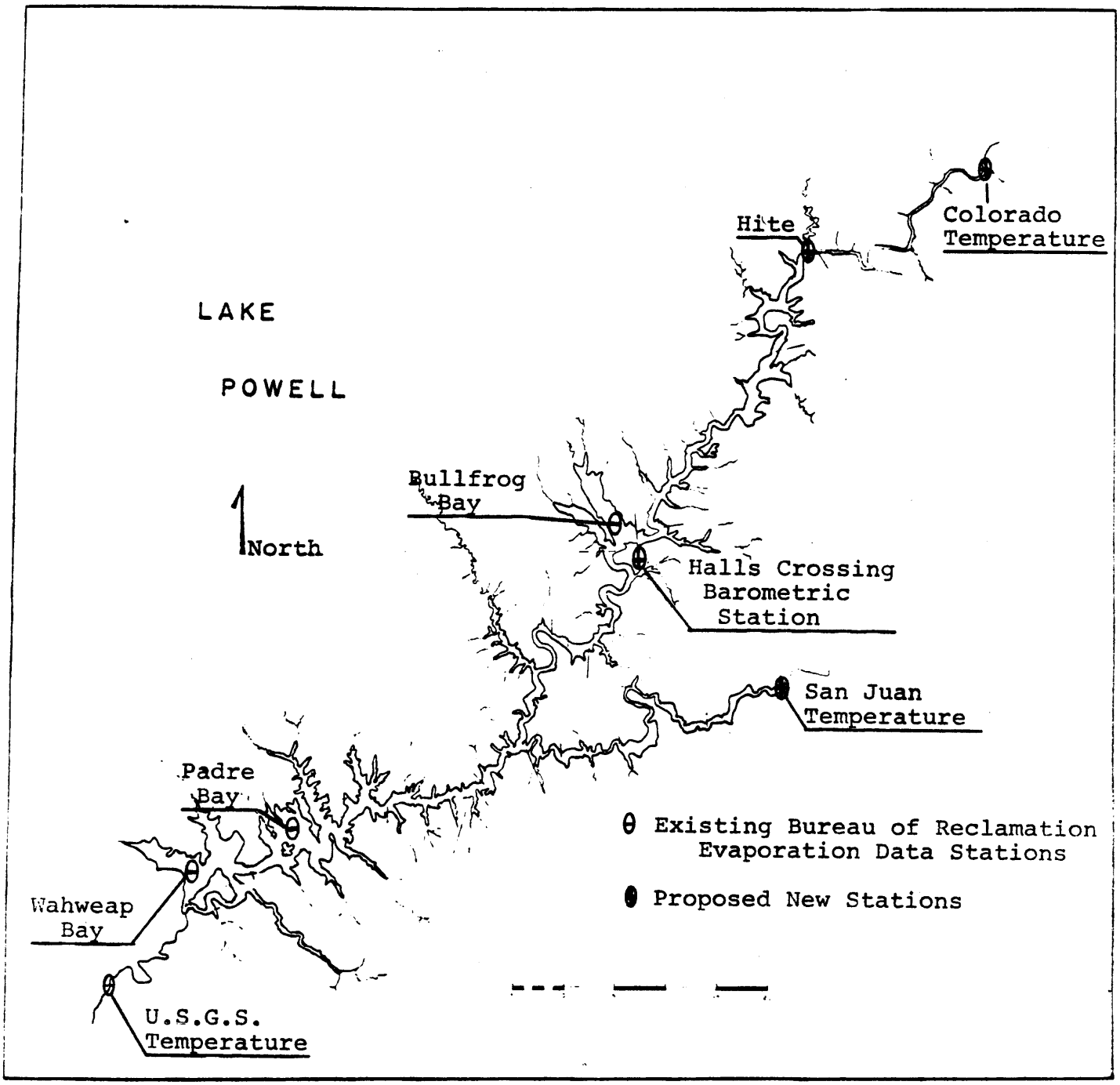

LAKE
POWELL
North
Hite
Colorado Temperature
Bullfrog Bay
Halls Crossing Barometric Station
San Juan Temperature
Padre Bay
Wahweap Bay
U.S.G.S. Temperature
Existing Bureau of Reclamation Evaporation Data Stations
Proposed New Stations

Figure 3

C. Most of the instruments for data collection will be mounted on stable raft platforms anchored at strategic sites on the Lake (see Figure 3). Three of the four rafts are already in place as part of the existing Bureau of Reclamation study. A fourth, near Hite, will be added. There will also be a land-based barometric station at Hall's Crossing.

One of the Lake Powell Project technicians, also serving the air quality subproject, will assist in the installation and monitoring of the instrumented rafts.

The temperature of the Lake is very important to energy-budget evaporation calculations. Surface temperatures will vary from place to place due to the size and complex shape of the Lake. Data on surface temperature will be measured at the raft sites. Supplemented data on surface temperature will be available from the limnology subprojects as they cover other areas of the Lake. See Figure 4 for limnology stations where data will be collected. In addition, information from remote sensing coverage taken last year in the infrared portion of the spectrum will yield data to suface temperature distribution. Data on the vertical temperature distribution and heat content of the Lake will also be available through the measurement program of the limnology subprojects.

With the data collected as described above, a much closer calculation can be made of the evaporation losses from Lake Powell. It has been estimated in other studies that a maximum accuracy of 95% can be achieved for periods of a month or more using the energy-balance methods. For shorter periods, the mass-transfer method will be used.

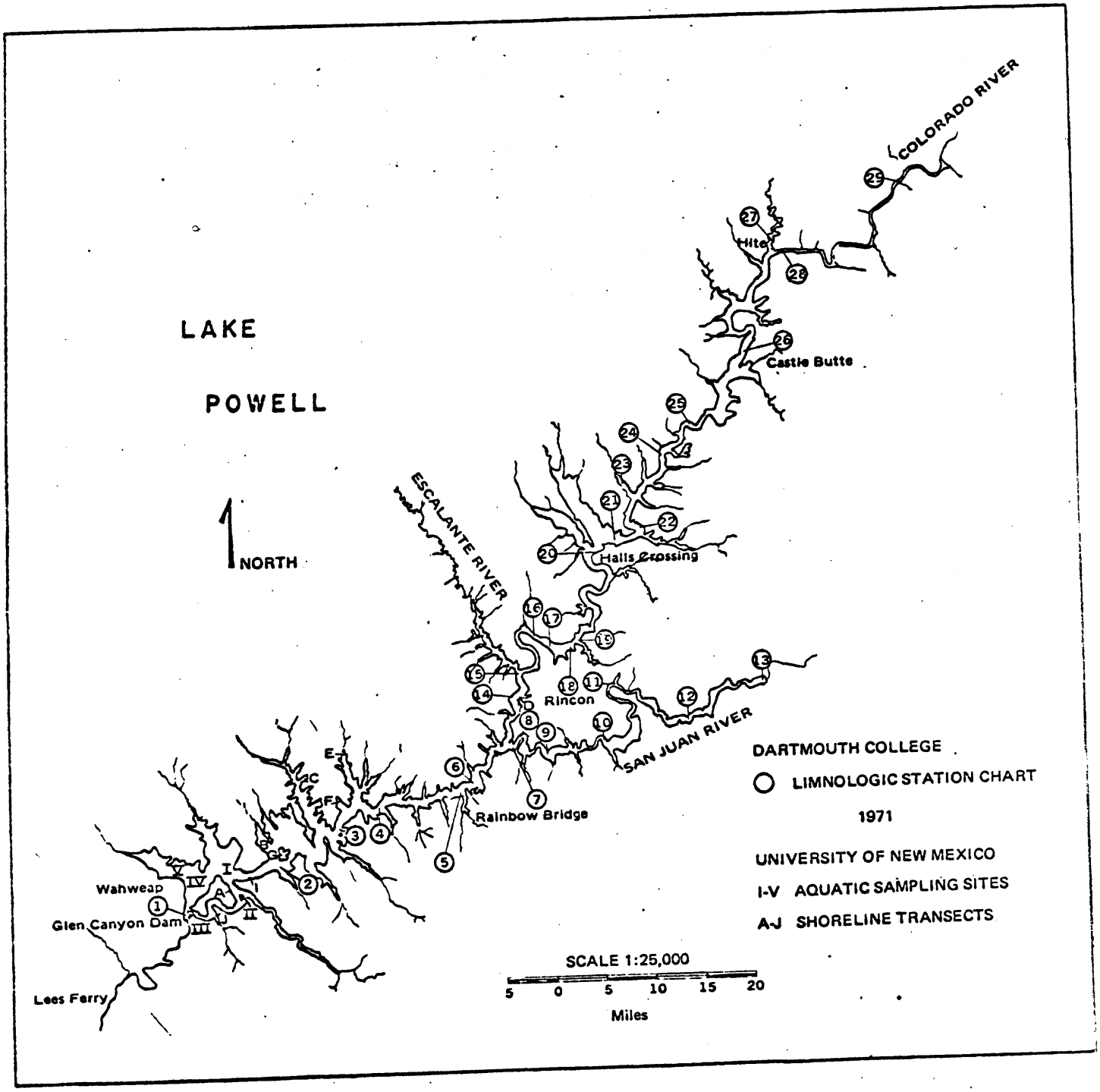

LAKE
POWELL
NORTH
COLORADO RIVER
Hite
Castle Butte
ESCALANTE RIVER
Halls Crossing
Rincon
SAN JUAN RIVER
Rainbow Bridge
Wahweap
Glen Canyon Dam
Lees Ferry
DARTMOUTH COLLEGE
LIMNOLOGIC STATION CHART
1971
UNIVERSITY OF NEW MEXICO
I-V AQUATIC SAMPLING SITES
A-J SHORELINE TRANSECTS
SCALE 1:25,000
5 0 5 10 15 20
Miles

Figure 4

PERSONNEL

The principal investigator for the evaporation subproject will be Gordon Jacoby. He will spend approximately half of his time on this program. The first summer will be spent in evaluating instruments and making test installations of the recording devices. A part-time electronic technician will be available to assist in setting up the instruments. This technician will assist, as necessary, in troubleshooting the installations during the year. The monitoring of the installations and data collection will be done by Jacoby during the next year and a half.

The data collection program will yield an enormous amount of data that will require sophisticated data reduction techniques. A consulting statistical programmer will be retained to develop the software for data reduction.

BIBLIOGRAPHY

1. Anderson, E. R., Energy-budget Studies, water-loss investigations; Lake Hefner technical report, U.S. Geol. Surv.,Prof. Paper 269, 1954.

2. Harbeck, G. E., Jr., M. A. Kohler, G. E. Koberg, and Others, "Water-loss Investigations: Lake Mead", U.S. Geological Survey Prof. Paper 298, 1958.

3. Hughes, Gilbert H., "Analysis of Techniques Used to Measure Evaporation from Salton Sea, California", U.S. Geol. Survey, Prof. Paper 272-H, pp. 151-176, 1967.

4. Jacoby, G. C., 1971. Unpublished data for Lake Powell.

5. Kohler, M. A. & L. H. Parmele, "Generalized Estimates of Free-water Evaporation", Water Res. Research, V. 3, No. 4, pp. 997-1005, 1967.

6. Meyers, J. S., and T. J. Nordenson, "Evaporation from the 17 Western States", U.S. Geological Survey,Prof. Paper 272-D, 1962.

7. Veihmeyer, F. J., "Evapotranspiration" in Handbook of Applied Hydrology, Ver Te Chow ed., McGraw Hill Book Co., 1964.

The UCLA-endorsed coversheet for subproposal number 6, Streamflow Trends, has been incorporated into the coversheet for all three UCLA-funded subproposals, and the information on it has been relocated to page 133.

BANK STORAGE ABSTRACT

The general purpose of this subproject proposal is to more accurately determine the quantity and location of water that has infiltrated into bank storage from the Lake. Further we, would like to assess the availability of this water for future use. Also, the economic and engineering aspects of recovery of this water from bank storage will be analyzed.

Bank storge is controlled by primary and secondary porosity and permeability. Evidence suggests that secondary hydrologic properties in the rocks surrounding Lake Powell are extremely important. These secondary features are fracture zones. Air photos and field studies will be used to map these fracture zones. Information from wells in similar geologic settings will provide data to estimate the properties of the formations at Lake Powell. Better evaluation can then be made of the bank storage.

In addition, suggested well sites will be furnished to the Bureau of Reclamation for their planned observation-well program.

RATIONALE

Bank storage is a phenomenon that occurs in every reservoir, lake and stream in the world. In many cases the storage is negligible. In some cases, like Lake Powell, the bank storage may be a major proportion of the total storage in the reservoir. In the latter case knowledge of distribution and availability of the stored water is essential for good management of the reservoir. If the bank storage water is readily available for return to the reservoir as the water level recedes, the storage can be regarded as part of the overall reservoir storage. If it will not return to the reservoir readily it must be regarded as a water loss.

The importance of this project is reflected in the fact that the present estimated bank storage at Lake Powell (as of July 1, 1971) is about 39% of the present volume of the water in the Lake. This is a huge amount of water, and its economic worth to the water users of the Southwest is self-evident.

The determination of infiltration into bank storage is very challenging due to the complex and extensive shorelines of Lake Powell. The present techniques are necessarily limited to "difference" estimates. That is, bank storage is that water which is not accounted for by measurements of inflow, outflow, Lake level, and estimates of evaporation. It is clear that the present amount of water in "bank storage" is larger than was expected several years ago, and the estimates of the upper limits of bank storage are subject to revisions.

The problem is best described by the following table estimated by the Bureau of Reclamation (Bureau of Reclamation, Region 4, 1971, Bank Storage and Residual Losses, Lake Powell").

Period	Elevation of Lake Surface	Increase in Height	Bank Storage Increase	Bank Storage Accumulation
3/1/-12/31/63	3410		579,000	579,000
1/1-12/31/64	3492	82	1,185,000	1,764,000
1/1-12/31/65	3535	43	1,023,000	2,787,000
1/1-12/31/66	3532	14	716,000	3,503,000
1/1-12/31/67	3527	6	537,000	4,040,000
1/1-12/31/68	3539	12	552,000	4,592,000
1/1-12/31/69	3572	33	268,000	4,860,000
1/1-12/31/70	3600	28	1,106,000	5,966,000
1/1-6/30/71	3621	21	361,000	6,327,000

Here it is seen that an increase of 28 feet in 1970 resulted in infiltration of over 1,000,000 acre-feet, although the trends between 1966 and 1971 indicate that a tapering-off would be expected. Clearly, the situation governing infiltration around Lake Powell is complex. The present estimated bank storage very nearly is equal to the estimate based upon regional slopes of the water table prior to the impoundment, and estimates of pore space volume in the surrounding rock. Since the end of infiltration is not in sight, the hydraulic situation is not restricted to simply filling adjacent pore space or primary porosity.

Secondary porosity and permeability, that due to joints and fractures in the surrounding geologic formation, are undoubtedly major factors in the bank storage situation.

Therefore the distribution and availability of water in bank storage is not uniform throughout the formations surrounding the lake. There are fracture zones where the major portions of water will be stored.

In the next 2 years, we wish to concentrate on the problem of finding those particular regions close to the Lake in which there are likely to be large quantities of infiltrated water and then to extrapolate from the hydrologic parameters of existing wells in similar sites and similar formations to estimate the volume and distribution of infiltrated water.

Also, the information gained will be furnished to the Bureau of Reclamation for use in an observation-well program which they are presently considering.

GENERAL SITUATION

Water levels in wells near the lower end of Lake Powell have been monitored by the Bureau of Reclamation since the beginning of the reservoir filling. The data from these wells show the variability in transmissibility of the Navajo sandstone, the most important geologic formation with respect to bank storage. Also, data from Cooley et al., 1969, p. A47, show a range in transmissibility from 450 to 6480 gallons per day per foot. This range is qualified in that publication by the statment that the lower figure is most representative. The most important point is that primary permeability in the Navajo sandstone is low and secondary permeability where the Navajo is fractured is high.

In its first year of effort, the Lake Powell Project arranged air-photo coverage of the Lake and the adjacent area. This coverage revealed much more pervasive fracturing in the surrounding formations than had been described in publications to date. There can be little doubt that secondary permeability due to fracturing is an extremely important factor in the large bank storage at Lake Powell. The Bureau of Reclamation observed in a 1971 report that

> "...the existence of more numerous subsurface facture zones could help explain the apparent more rapid rate at which the water has travelled from the lake...."

The geological situation around Lake Powell is a large structural basin formed by the Chinle formation. Upper portions of the chinle comprise some claystones, mudstones, and limestones which have a low primary porosity and permeability. This geology is generally agreed upon (Cooley et al., 1967; Doelling, 1969; Murdock and Calder, 1969: Heintz and Stokes, 1964).

The main breach of this basin is the Colorado River Canyon at Lee's Ferry. However, two important factors must be mentioned:

> "...complex intertonguing and rapid facies changes are prevalent in the sedimentary rocks and form some of the principal controls on the ground-water hydrology". (of this region) (Cooley et al., 1969)

Secondary porosity and permeability, due to factures and joints, are often more important than primary porosity, due to texture.

The effect of bank storage as depicted by the Bureau of Reclamation is shown in Figure 1. An elaboration on this diagram is shown in Figure 2. In this latter figure, the boundary lines between ground water, ABC, and ACD are zones of diffusion or mixing rather than sharp lines of separation.

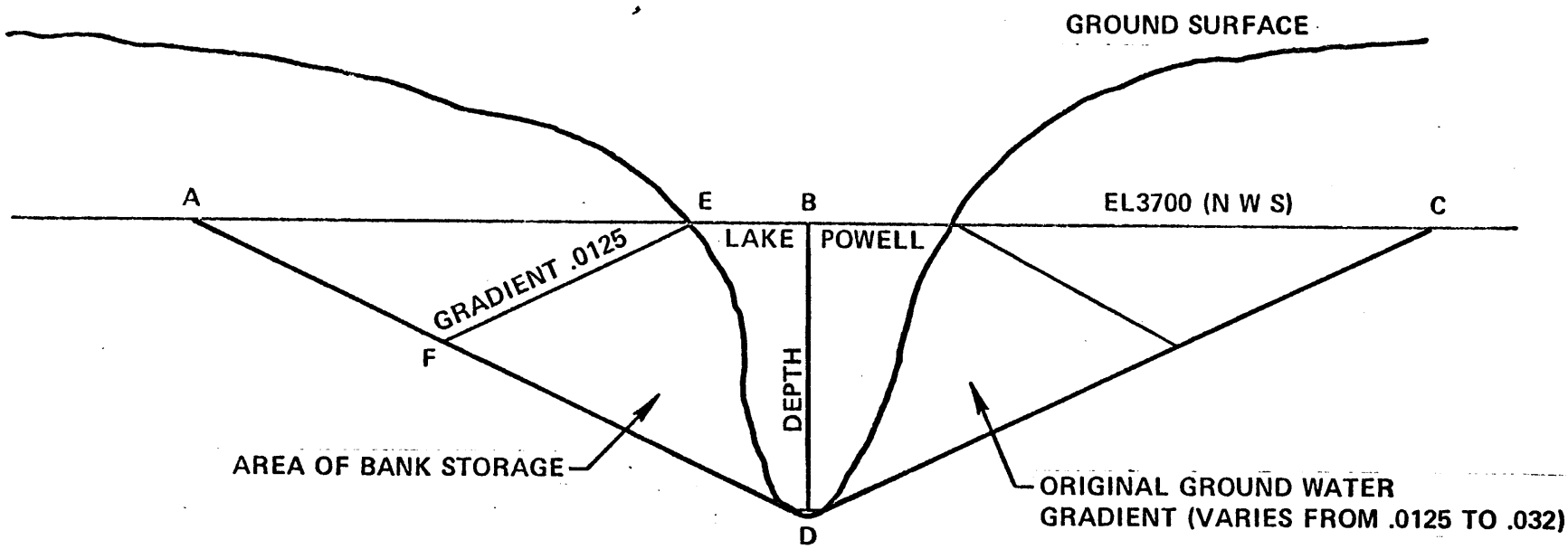
Before the existance of Lake Powell, ground water in the various hydrologic basins adjacent to the Colorado and lower San Juan Rivers used to flow into the canyons of these two rivers. Cooley et al. (1969) p. A40 states this conclusion for the regions on the south shore and Doelling (1969) for the regions in San Juan County to the north of Lake. This flow pattern is as shown in Figure 2a. The center line through the Colorado River Canyon is meant to imply that the flow pattern is symmetrical along both sides of the canyon. This two-dimensional diagram represents three-dimensional areal precipitation, concentrated on the higher areas feeding linear canyons, areal sources feeding line sinks.

This areal precipitation is low and the inflow through springs and small tributaries was not a major contribution to Colorado River flow. However, there was and is enough precipitation input to the water table to maintain the regional slope and some flow as depicted in the diagram.

Rising the water level in Lake Powell altered the adjacent ground-water flow regime by replacing the former exit zone, or linear sink, for the ground water with a new source.

After reviewing available information, the hydrology subproject of the Lake Powell Project makes the follwoing interpretation of the hydrodynamic situation around Lake Powell. Because of low precipitation in the immediate region, the raising of the water level in the Lake is a rapidly occurring event with respect to the movement of large amounts of ground water to the former canyon. Therefore, area ABC will be filled with Lake water and will constitute a bank storage zone. The Lake and bank storage fill a former exit zone for the ground water. The basin-like geological configuration of the Lake Powell area, as described above, does not have a discernable new exit zone

LAKE POWELL
BANK STORAGE STUDY



SECTION OF END AREA USED IN CALCULATING
BANK STORAGE AT LAKE POWELL

Figure 1

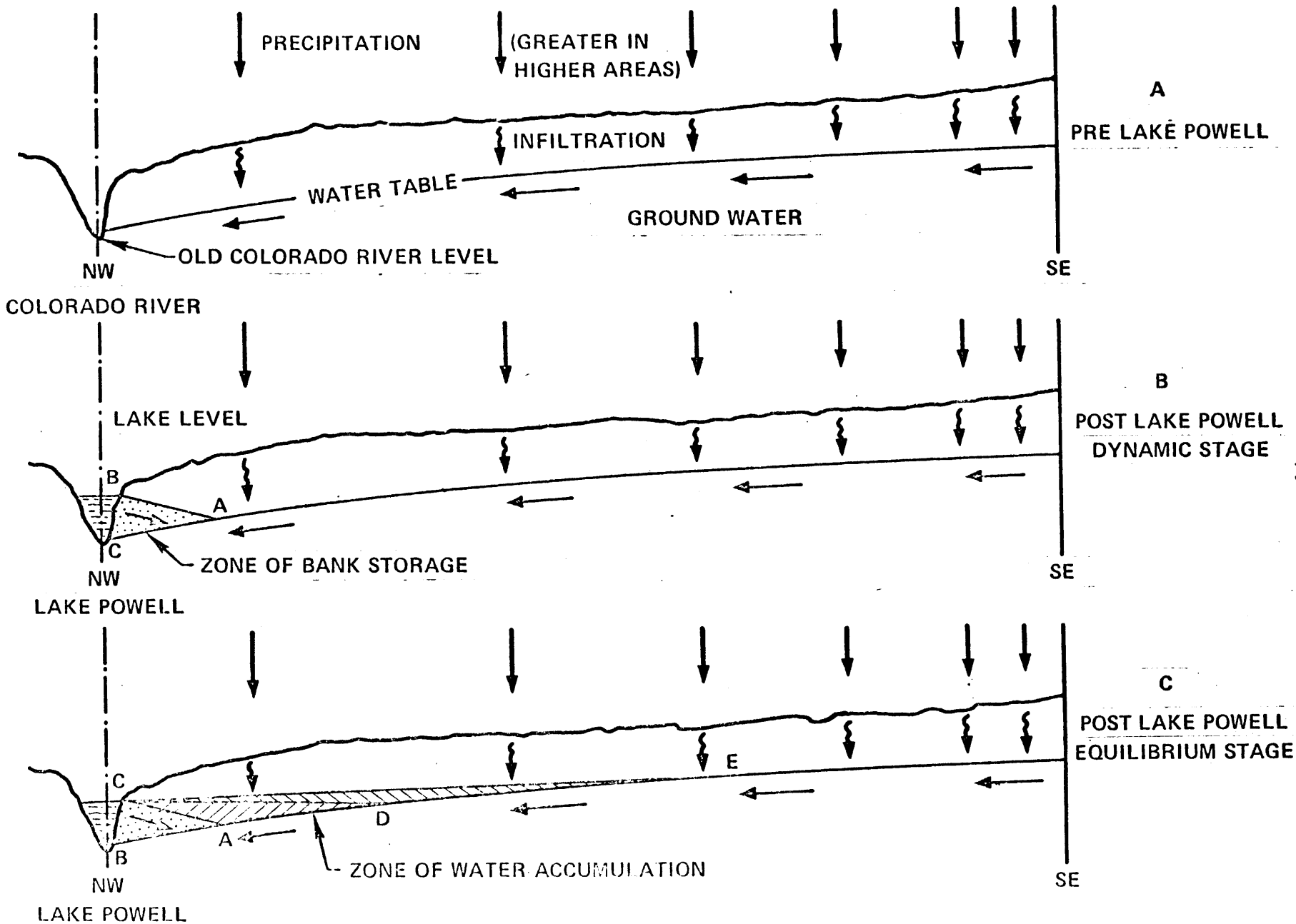

PRECIPITATION
(GREATER IN HIGHER AREAS)
INFILTRATION
WATER TABLE
GROUND WATER
OLD COLORADO RIVER LEVEL
NW
COLORADO RIVER
SE
A
PRE LAKE POWELL
LAKE LEVEL
B
A
C
ZONE OF BANK STORAGE
NW
LAKE POWELL
SE
B
POST LAKE POWELL
DYNAMIC STAGE
C
E
D
A
B
ZONE OF WATER ACCUMULATION
NW
LAKE POWELL
SE
C
POST LAKE POWELL
EQUILIBRIUM STAGE

Figure 2

for the ground water. Therefore, the impoundment of river water in the Lake is leading to an impoundment of the ground water in the area. This latter impoundment will fill area ACD with predominantly ground water. There will be a diffusion zone along BA and AC between Lake water and ground water. The filling of area ACD will take longer than area ABC. Eventually, the area CDE will be filled with only ground water, but the filling of this last area will only occur in the distant future. Eventually, equilibrium may be achieved by the ground water reaching a new and presently undetermined exit zone.

In summary, the situation is that of replacing a sink with a source and having no presently obvious new sink for these two sources, the Lake water and the ground water.

METHODS, LAKE POWELL PROJECT

Through the cooperation of the Air Force, we now have aerial coverage enabling us to map regional structures, especially fracture patterns. This knowledge aids us in defining zones where secondary permeability may cause extensive infiltration into the substrate of the reservoir. On the basis of these aerial photographs, field investigations will be made to actually map the fracture systems.

Initially the aerial coverage will be studied and preliminary overlay maps of the fractured zones will be made. Then using these maps as a guide the field studies will map the fractures using standard structural geology techniques. The comparison of field maps with preliminary overlays will facilitate more detailed maps of the zones of fractures or secondary porosity. These detailed maps will be made of the entire area adjacent to the Lake and extending about 5 miles away from the shoreline. The mapping will be primarily based on the air photographs and supplemented by mapping done from land studies, conducted by four-wheel drive vehicle, and shoreline studies, conducted by boat based parties. Then estimates can be made of the areal extent and thickness of fracture zones.

Structural analyses will be made to aid in the interpretation of the extensiveness of the more permeable zones. As insight is gained into the stress systems that produced the fractures and joints the accuracy of the mapping of inaccessable areas will be enhanced. This enhancement will occur because there is some predictability in the response of specific rock formations to known stress systems.

Well records are available from the U.S.G.S. on pumping tests and hydrologic characteristics of wells in the same formations that surround Lake Powell. Information on wells near the Lake is also available from the Bureau of Reclamation and the National Park Service. This information will be examined and extrapolated to estimate the hydrologic properties of the rocks around Lake Powell.

Estimates of porosity and permeability and volumes of rocks of different characteristic will then be used to evaluate existing and potential bank storage. Flow rates will be calculated to ascertain the availability of water in bank storage.

METHODS, COOPERATIVE

In the summer and fall of 1971, analyses of water from Lake Powell and some seepages around the Lake were made by the Dartmouth limnology section of the Lake Powell Project. These seepages were considered as representative of ground water in the area. This concept was confirmed by the UCLA hydrology section by comparing the Dartmouth data (Reynolds et al., 1971) to previously published data from wells in the Navajo sandstone. This ground water is distinctive from the Lake water as shown in Figure 3.

Therefore, it has been shown that if water samples were obtained from wells near the Lake shore, a distinction could be made between Lake water and ground water, areas ABC and ACD in Figure 2. In the diffusion zones the proportions of Lake and ground water could be established. A much greater insight into bank storage quantities and rates would be gained.

The only way to obtain samples from the bank is to drill observations wells near the Lake. This project will furnish, as a result of the mapping and field work, selected drilling sites to the Bureau of Reclamation. That agency is extremely interested in the bank storage situation and is presently considering a drilling program to collect data for bank storage studies.

In the course of the Lake Powell Project field studies the accessibility to the sites by vehicle and drilling equipment will be established.

In cooperation with the Bureau of Reclamation, observation wells may be drilled and maintained at a few selected sites where infiltration is likely to be high. Water samples can be taken from these wells at periodic intervals to be chemically analyzed.

Water level indicators could be installed at each observation well. The rate at which the water level responds to changes in Lake level could be used to calculate the transmissibility of the rock between the well and the Lake. These calculations would use standard hydrologic equations which fall under the general heading of tidal efficiency. These equations relate the changes of water level in a well near a large body of open water to the

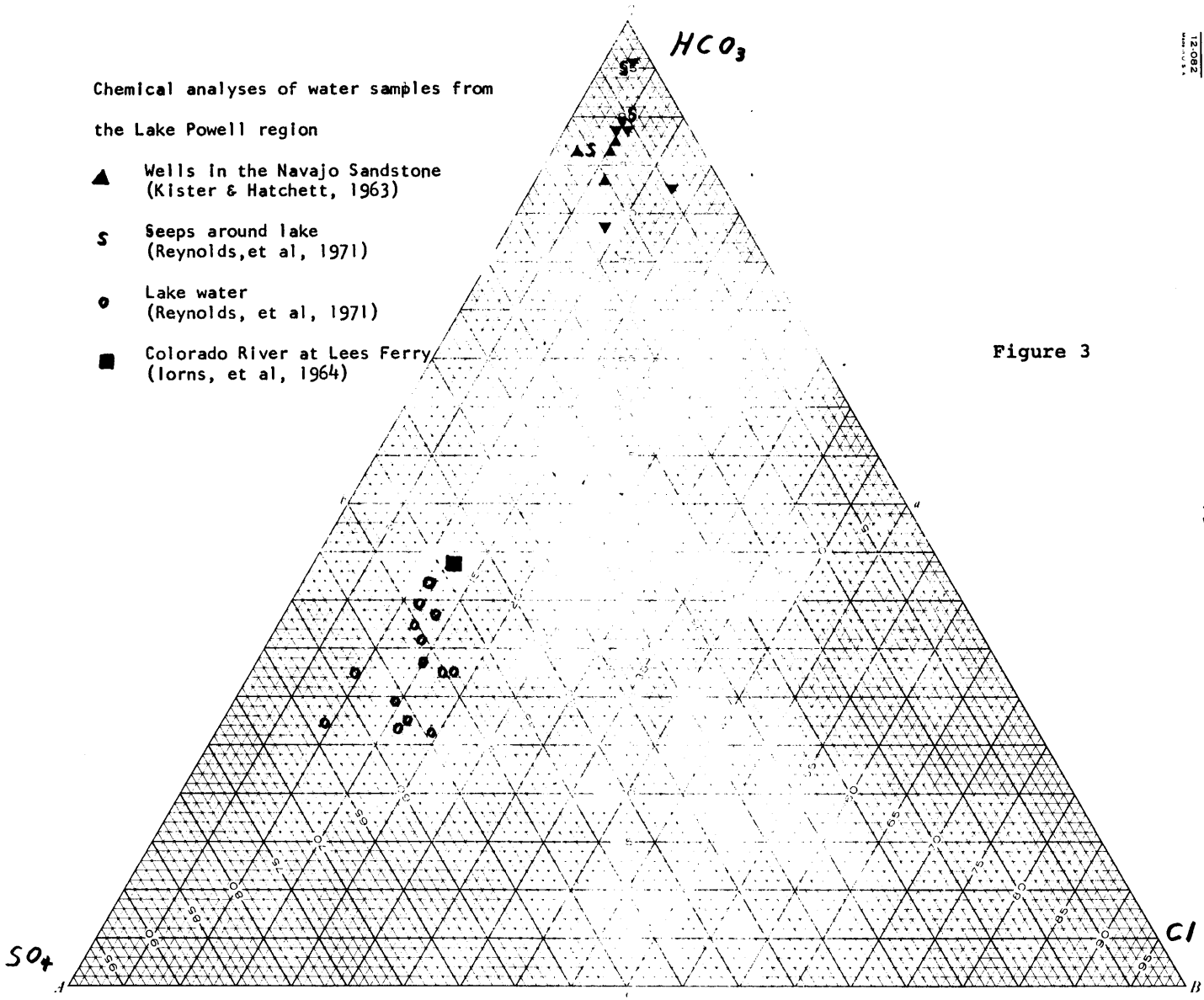

Chemical analyses of water samples from
the Lake Powell region
Wells in the Navajo Sandstone
(Kister & Hatchett, 1963)
Seeps around lake
(Reynolds, et al, 1971)
Lake water
(Reynolds, et al, 1971)
Colorado River at Lees Ferry
(Iorns, et al, 1964)
HCO_3
SO_4
Cl
A
B

Figure 3

hydraulic characteristics of the connecting aquifer or hydrostratigraphic unit, which in this situation is primarily the Navajo sandstone.

Water samples, analyses, and water-level records would be circulated within the other sections of the Lake Powell Project. They would be of particular interest to the New Mexico and Dartmouth sections.

The data from the initial pumping tests and the tidal response of the wells would give two approaches to determining the transmissibilities of the rocks surrounding the Lake.

PERSONNEL

O. L. Anderson and John Handin will conduct most of the field mapping program. They will work together in the structural interpretation of the fracture zones. Detailed maps and air-photo overlays will be constructed by students. G. Jacoby will assemble hydrologic data on wells in similar geologic settings and do the volumetric evaluations. He will also act as liason with the Bureau of Reclamation to aid them in their planning of an observation-well program. He will coordinate the evaporation study with the bank-storage study and assemble the necessary data for an overall water budget.

BIBLIOGRAPHY

1. Bureau of Reclamation, Region 4, Bank Storage and Residual Losses, Lake Powell.

2. Cooley, M. E., J. W. Harshbarger, J. P. Akers, W. F. Hardt, and O. N. Hicks, "Regional Hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah", U.S. Geological Survey, Prof. Paper 521-A, 1969.

3. DeWiest, R. J. M., "Geohydrology", John Wiley and Sons, Inc., 366 pp., New York, 1965.

4. Doelling, H. H., "Preliminary Study of the Groundwater in the San Juan Project Area, Utah and Colorado", in "Mineral Resources, San Juan County, Utah, and Adjacent Areas", Utah Geological and Mineralogical Survey Special Studies 24, 1969.

5. Harshbarger, J. W., D. D. Lewis, H. E. Skibitzke, W. L. Heckler, and L. R. Kister, revised by H. L. Baldwin, "Arizona Water", U.S. Geological Survey Water-Supply Paper No. 1648, 1966.

6. Hintze, L. F. & W. L. Stokes, Geologic Map of Southeastern Utah, Utah State Land Board, 1964.

7. Murdock, J. N., and Lloyd Calder, "Bank Storage--Lake Powell", Bureau of Reclamation, 1969.

Subproject Numbers 7, 8, and 9

7: Physical Limnology 8: Lake Geochemistry and 9: Sedimentation

7: Physical Limnology of Lake Powell

8: Lake Powell Geochemistry

9: Sedimentation in Lake Powell

three components of

COLLABORATIVE RESEARCH ON ASSESSMENT OF

MAN'S ACTIVITIES IN THE LAKE POWELL REGION

Amount Requested	Proposed Duration	Requested Starting Date
7: 61,920 8: 67,516 9: 51,860	2 Years	May 15 1972

Total Amount Requested: $181,296

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PHYSICAL LIMNOLOGY OF LAKE POWELL

Water Circulation

During its incipient stages of impoundment, Lake Powell has been assured of thorough mixing of its water by the fact that it still retained its lively river (lotic) regime. In other words, the through-flow of the Colorado River forced mixing of the water column by mechanical means. This process has been well-documented by the work of the Utah Fish and Game Commission and the U.S. Bureau of Reclamation (Section 8 Program, Colorado River Storage Act). However, as the Lake has filled, the attenuation of these mixing currents has allowed the Lake to assume more and more of the circulation characteristics of a true lake, that is the stratification and stability of quiet water. Under these circumstances, the water within the Lake mixes seasonally according to the state of heating or cooling of its surface. This thermal mixing process in Lake Powell so far has been observed occurring once a year, during the fall and winter cooling period (warm monomictic mode). However, in recent years there have been increasing indications that this thermal mixing process has not been sufficient to reach and mix the deepest portions of the Lake (Stone et al., 1967). This trend is suggested by the existence and persistence of high salinity water (>800 mg/ at the bottom throughout the year. In other words, because of its increasing depth, its unusual geometry and the attenuation of the river currents within it, Lake Powell may be developing a stagnant body of water at its bottom, i.e., one which does not mix with the surface waters at any time during the year. Such a condition is called "meromixis" in the vernacular of limnology. Meromixis has some important consequences on the physics, chemistry, and biology of a lake;

1. The stagnant water at a lake bottom eventually consumes its supply of dissolved oxygen and becomes anaerobic, literally becomes without oxygen.

2. To the extent that oxygen is vital in normal aquatic life processes, its absence precludes these normal biological processes.

3. In the absence of dissolved oxygen, new forms of life appear, notably SO_4 reducing bacteria, which modify the chemical characteristics of the water. Specifically, biogenic meromixis is usually accompanied by the production of H_2S, a toxin to normal aerobic biology.

4. The modified chemistry of stagnant water usually leads to an increase in salinity.

5. Increased salinity implies increased density and stability of the affected water.

6. In general, then, stagnant, unmixed water sets up a chain of chemical-biologic reactions which tends to increase its propensity for stagnation. That is, a positive feed-back mechanism is initiated which tends to perpetuate the stagnated condition.

As applied to Lake Powell, more indirect consequences of a meromictic condition within the Lake can also be anticipated:

1. Because stagnant water is characteristically corrosive, the intake of such waters by the turbines at Glen Canyon Dam would affect the longevity and maintenance schedule of the power station. This problem has already been encountered in recent man-made lakes (McFie, 1971).

2. Mid-water withdrawal currents induced by the power penstocks owe their distribution and configuration to the stability of the water column behind the dam (Elwin, 1971). To the extent that meromixis stabilizes the water column, it will therefore modify withdrawal current trajectories.

3. Similarly, the inflowing turbidity currents in the upper reaches of Lake Powell would have to accommodate themselves to the meromictic stability of the Lake.

4. The overall water quality of the Lake would be changed considerably by meromixis, thus affecting its potential as a coolant in heat exchangers and its suitability for downstream irrigation.

5. The inorganic and organic chemical processes presently extant in the Lake would be seriously modified or precluded by the interjection of meromictic stability. This in turn would alter the Lake's present mode of chemical fractionation and/or homogenization (see chemical limnology subproject).

6. The chemical composition, properties, and distribution of the bottom sediments would be conditioned by the existence and contact with anerobic water.

7. The existence of anerobic water at depth within the Lake would affect the Lake fisheries, especially the deep-water species.

8. Because the downstream fisheries on the Colorado River below Glen Canyon Dam are nutured by Lake Powell water, input of any anerobic water downstream would decidedly affect the quality of these fisheries.

Previous experience with man-made lakes which have gone meromictic has shown generally deleterious effects on the Lake and its resource potential (McFie, 1971; Biswas, 1971; Leentvaar, 1971). In view of the profound implications of meromixis in Lake Powell, a thorough comprehension of the Lake's circulation, past, present, and future, is necessary. Is meromixis an imminent or a remote possibility? What hydrologic manipulations can be practiced to preclude or minimize the threat of meromixis?

The expressed purpose of this study, therefore, is to provide the basline data on the circulation and currents within the Lake as it approaches full volume. This historical sequence of data will then be analyzed to ascertain the long-term, steady-state circulation of the Lake, including its inherent tendency for meromixis. With sufficient information regarding the state of stability and circulation of the Lake volume-control techniques or perhaps withdrawal-current routing can be designed to arrest the onset of a meromictic condition. Such information would also be of use in the maintenance and utilization of the fisheries within and associated with Lake Powell. In general terms, then, the rational planning of the Lake as an economic, recreational, and esthetic resource is contingent on the thorough knowledge of the Lake's basic physical characteristics.

Scope of the Proposed Study

To implement the goals stated above, a simple, but continuous program of monitoring the crucial stability parameters of the Lake must be maintained. This program builds on the rich store of data already collected and complied by the Utah Fish and Game Commission and the Bureau of Reclamation under the auspices of the Section 8 Program, Colorado River Storage Act. In typical fresh-water lakes, the paramount stability factor is temperature. In sea-water,salinity also becomes important. In Lake Powell, turbidity must be added besides temperature and salinity. Unlike the ocean, Lake Powell's salinity varies qualitatively, as well as quantitatively. The amount, kinds, and distribution of salts within the Lake are the separate concern of Dr. Robert Reynolds, who is collaborating in this effort. His data will necessarily complement the present study.

To obtain the thermal history of the Lake, synoptic temperature profiles will be obtained four times a year, during the crucial states of seasonal thermal development--period of maximum inflow (spring), period of maximum thermocline (fall), period of maximum bottom temperatures (early winter) and period of maximum mixing (late winter). This sampling schedule is already three-fourths completed foe the 1971-72 annual

cycle. In addition, six recording thermographs have been and will continue to be installed at strategic depths near the dam to monitor temperature changes between the periods of synoptic sampling. With the fine-scaled temperature series available by this means (hourly temperatures for 400 days), the existence and extent of thermal waves and seiches within the Lake may be discerned.

With respect to turbidity distributions, they have been and will continue to be measured concurrently with the temperature sampling program. A satisfactory turbidometer (Whitney-Montedora) has already been employed and techniques developed for its use. It appears that the upper Lake will be richly structured by turbidity, the natural consequence of the silt-ladened waters entering the Lake. Turbidity may indeed provide a key tracer for water masses in the upper reaches of the Lake.

The water movements within the Lake will be measured directly by a standard current meter. Each temperature and turbidity station will also be profiled with respect to its water motions. The entire discharge of the Colorado River must transit through each cross-section of the Lake. The position and speed of this main current and countercurrents will hopefully be outlined by these measurements.

In composite, then, the temperature, salinity, and turbidity distribution within the Lake along with the associated currents should come together to form a coherent picture of the Lake's circulation. Existing models of steady-state flow (Elwin, 1971) may thus be tested with the above data. If sufficient fit is obtained with these models, their predictive power may be employed to answer or assess the questions posed in the Lake Geochemistry subproject.

Personnel

The Senior Investigator in this phase of the study, Noye M. Johnson, will conduct most of this proposed study personally with the help of undergraduate and graduate assistants (occasionally). A sabbatical leave during 1972-73 will be used in part on this program.

Equipment and Travel

The budget for this study includes as new items a current meter and depth recorder. The depth-recording equipment is to be installed on existing temperature probes and turbidometers. This was found necessary to increase the accuracy of temperature and turbidity measurements in deep, open waters. The films, film processing, and computer expenses are for the existing recording thermograph equipment. Four trips to Lake Powell per year are provided for.

References Cited

Biswas, S. (1971) Limnological observations during the early formation of Volta Lake in Ghana, Abstracts of Papers, International Symposium on Man-made Lakes, May 3-7, 1971, Knoxville, Tenn.

Elwin, E. E. (1971) Estimation of reservoir withdrawal currents, J. Hy., ASCE.

Leentvaar, P. (1971) Lake Brokoponda, Abstracts of Papers, Symposium on Man-made Lakes, May 3-7, 197. Knoxville, Tenn.

McFie, H. H. (1971) Biological, chemical and related engineering problems in completed and proposed large storage lakes of Tasmanian hydro-electric power developments, Abstracts of Papers, International Symposium on Man-made Lakes, May 3-7, 1971, Knoxville, Tenn.

Stone, R.; K. Nutter; J. K. Summers; C. Thompson and A. F. Regenthal (1967) Glen Canyon Reservoir Post-Impoundment Investigation, Prog. Rept. 5, Utah Fish and Game Commission.

The Dartmouth-endorsed coversheet for subproposal number 8, Lake Powell Geochemistry, has been incorporated into the coverhseet for all three Dartmouth-funded subproposals, and the information on it has been relocated to page 183.

I. SUMMARY OF RESEARCH AND OBJECTIVES

The chemical limnology of Lake Powell will be studied by a combination of field and laboratory methods. The objectives are to establish the time-dependent distribution of chemical species in the Lake, and to verify and quantify the kinds and amounts of ions that may be (a) precipitated by chemical reactions in the Lake, (b) extracted by reaction with the suspended sediment and/or reservoir rocks, and (c) added to the Lake as a result of (b) above, or added by direct solution of the Lake bed. It is anticipated that the Lake has not yet achieved a steady-state composition, hence an important part of these studies consists of providing data on the probable, final, steady-state chemical limnology of the reservoir. A final steady-state chemical model of Lake Powell will incorporate appropriate mechanisms such as biological controls, introduction of new sediments, and patterns of salinity currents. The success of the study will depend heavily upon articulation of the work with the findings of D. E. Kidd, N. M. Johnson, and C. L. Drake. Close cooperation is anticipated with Bureau of Reclamation scientists whose research will complement many aspects of the proposed study. The research will be relevant to the understanding of other artificial reservoirs on the Colorado River, and to other similar lakes in related climatic regimes.

The purposes of the proposed research can be classified into several categories, and these are enumerated below:

1. <u>To ascertain whether or not the bottom waters will continue to increase in salinity</u>. Significant further increases in dissolved solids could lead to stable stratification of the Lake and to the development of anerobic conditions at depth. This would have grave consequences for the success of the Lake as a recreational enterprise, and could drastically reduce the possibilities of game or commercial fish production. In addition, esthetic qualities of the region immediately below the dam could be seriously degraded.

2. <u>To provide basic information on the probable future quality of water delivered to the Colorado River below the dam</u>. Processes such as solution from the Lake bed and evaporation cause increases in salinity and degradation of water quality. Precipitation of calcium carbonate and silica, and possible ionic extraction due to authigenic reactions with the bed and the reservoir walls, diminish salinity and increase the water quality. Extraction of nutrients such as phosphate, nitrate, potassium, and silica

may alter aquatic ecosystems below the dam and in the Gulf of California. The probable final steady-state fluxes of these constituents through the Lake should be predictable from the findings of the proposed research.

3. To evaluate probable future water losses due to bank storage. At the present state of knowledge, either cementation or decementation reactions seem possible in the reservoir walls and in the bed sediments. Cementation could lead to the effective sealing of the reservoir against further water loss, and this possibility will be examined.

4. To determine the locations and rates of sedimentary filling due to bank-wash and/or slumping. Locally derived sediment may be a significant factor in the overall rate of siltation of the reservoir. Studies of these processes are necessary to any conclusions concerning the probable useful life of Lake Powell.

II. PROPOSED STUDIES, METHODS, AND BACKGROUND

Equilibrium Chemical Model

An equilibrium chemical model of Lake Powell water has been constructed. A computer program has been written that produces, from a water analysis and pH, the effective pCO_2, the activities of the free ions CA^{+2}, Mg^{+2}, Na^{+1}, K^{+1}, SO_4^{-2}, HCO_3^{-1}, CO_3^{-2}, and the activities of the complex ions $CaHCO_3^{+1}$, $CaCO_3^0$, $CaSO_4^0$, $MgHCO_3^+$, $MgCO_3^0$, $MgSO_4^0$, $NaSO_4^{-1}$, and $NaHCO_3^0$. The mathematical techniques used are those suggested by Garrels and Thompson (1962) for sea water. The output from the program allows the computation of refined estimates of the degree of saturation of a water mass with respect to calcium carbonate, magnesium carbonate, and calcium sulphate. For Lake Powell waters, the dominant complexing species is SO_4; the model has been developed in its complete form so that it is applicable to the higher salinities found in the waters of the various tributaries.

The computer model makes use of published data for ion association constants, and these are subject to some uncertainties at the present time. A laboratory study is necessary in order to evaluate the accuracy of the model. Various aqueous solutions will be prepared whose compositions are similar to Lake Powell water. Direct measurements of free ion activities will be made by appropriate ion electrodes, and these will be compared with the calculated activities from the model. No electrodes are presently available for activity measurements of

ions such as HCO_3 and SO_4. Information on these ions will be obtained by other types of experiments. For example, the calculated results from the model will be compared with data on calcite precipitation in the laboratory which will be accomplished by varying pCO_2, and will be monitored by measurements of a_{Ca} and specific conductance. Activity of SO_4 will be checked by measuring the solubility of $CaSO_4$ and $BaSO_4$ in the simulated Lake Powell water. Exhaustive tests of the sort outlined above on a series of synthetic standard solutions, and on Lake Powell water, should indicate the quantitative reliability of the chemical model. Some refinement of published complex ion association constants should emerge from the studies, and these will be incorporated into the final form of the model.

Preliminary work has been conducted along the lines suggested above. For one standard solution, measurements of a_{Ca}, a_{Mg}, a_{Na}, a_{Cl}, agreed within ±3% of the values predicted by the model. Calculated specific conductance agreed within 0.5%, and a_{SO_4} was 7% different from measured values. Apparently, the model is quite accurate in its present form. More data are required on a wider variety of solutions, but the preliminary results are sufficiently encouraging to justify the studies suggested above.

Calcium Carbonate Precipitation

The probable precipitation of calcium in Lake Powell has emerged, from our preliminary work, as one of the most important chemical processes in the Lake. Carbonate precipitation has been observed in Lake Mead (Howard, 1960) and in Flaming Gorge Reservoir (USGS Prog. Rept. 5, 1971). Irelan (1971) notes that preliminary annual salt budget data for Lake Powell suggest carbonate precipitation here also. Results from our water analysis program, as refined by the computer chemical model, indicate that surface water in Lake Powell is over-saturated with respect to $CaCO_3$, and that deeper waters, though under-saturated, would become markedly over-saturated if allowed to equilibrate with normal atmospheric CO_2 pressures, or if they were subject to CO_2 withdrawal by photosynthesis. Finally, during a field trip to the Lake in September, we observed a white "bath tub ring" above water line which seems identical with the one observed at Lake Mead, and which has been shown to contain calcium carbonate (Howard, 1960).

All of these evidences strongly suggest that calcium carbonate is presently precipitating in Lake Powell. A preliminary view of this process, which will require testing, ascribes carbonate precipitation to biological activity in the epilimnion. Several elements of this hypothesis have been confirmed by the findings of D. Kidd. The hypothesis is as follows: Impoundment of Colorado River water allows the

settling of suspended sediment with a concomitant increase in the thickness of the euphotic zone. The waters contain abundant nutrients so sunlight might be considered as the initial limiting ingredient in this aquatic ecosystem. Photosynthetic production in upper waters extracts CO_2, raises the pH, and initiates $CaCO_3$ precipitation. Diatoms in the phytoplankton populations cause a withdrawal of SiO_2 (silica precipitation has been noted in Lake Mead and in Flaming Gorge Reservoir; annual budget data for Lake Powell also indicate significant SiO_2 loss in the reservoir). The transfer of organic detritus to deeper water causes high pCO_2 values there because of respiration; precipitated $CaCO_3$ redissolves and produces high concentrations of bicarbonate at depth. Some silica may be liberated in the process, and this may partially explain high values for SiO_2 at depth that have been noted in our analytical data. During the period of winter mixing, permanent loss of SiO_2 and $CaCO_3$ occurs by incorporation in the bottom sediments. If, however, the Lake were to escape mixing for a year or two, it is possible that such a process of vertical salt transfer could cause the development of a stable meromictic condition. This would soon lead to an anerobic environment at depth. R. F. Wilson (personal communication) of the Bureau of Reclamation, has pointed out that anerobic bottom water has already developed at Flaming Gorge Reservoir. Of course, other explanations exist that could account for high HCO_3 and SiO_2 at depth, namely, dissolution of the Lake bed, and salt transport by saline density currents. Our analytical and research programs will evaluate these possibilities, and test the hypothesis outlined above.

The discussion so far has assumed that carbonate precipitation in Lake Powell can be treated as an equilibrium process. But preliminary results in our laboratory indicate that Lake Powell waters show a marked resistance to calcite precipitation. Samples of Lake water were purged with nitrogen for 1 day, and no precipitation was detected, despite the fact that under these conditions the waters were over-saturated with calcite by an order of magnitude. Nuclei in the form of crushed calcite were introduced, and these caused no apparent change in the system. Apparently, the metastable conditions are not caused by low nucleation rates, but by slow crystal growth processes. Pytkowicz (1965) has noted that, in sea water, magnesium inhibits calcite precipitation. Adsorption of phosphate or organic material on calcite nuclei may also inhibit calcite precipitation. Quantitative annual estimates of calcite precipitation in the Lake are made considerably more complicated if the time required for achievement of equilibrium is of the same order as the resident time of water in the Lake.

Quantitative studies of calcite precipitation will be made in synthetic and natural Lake Powell water. The calcite

saturation index (SI) is defined as the ion activity product divided by KSP for calcite. Experiments will be performed in which SI will be controlled by varying pCO_2 (pH), a_{Ca}, and a_{HCO_3}. Precipitation rates will be studied by means of specific conductance, and continuous recordings for pH and a_{Ca}. The experimental objective is to obtain quantitative values for the precipitation rate as a function of SI. Precipitation from a mass of water moving through the Lake could then be treated as an integrative process, initiated by algal photosynthesis, and terminated by egress through the pentstocks at the dam. Doubtless, exact treatments are greatly complicated by water movement down the Lake at depth in an unsaturated condition, time duration, and completeness of mixing, biological productivity indexes, and other factors not now apparent. Even so, data on calcite precipitation rates are one fundamental portion of any final successful chemical model of the Lake.

Three-Dimensional, Time-Dependent Chemistry of Lake Powell

Our analytical program will study the quantitative water chemistry in the Lake. Specific conductance and pH measurements will be made at the time of collection, and all other measurements will be performed in our laboratory at Dartmouth. Calcium, magnesium, sodium, and potassium will be determined by atomic absorption spectrophotometry. Carbonate and bicarbonate contents will be measured by the standard methods of acid titration in conjunction with a pH meter and glass/calomel electrodes. Chloride will be measured by means of a potentiometric titration with $AgNO_3$ that is followed with a silver-sensitive electrode (Orion). Silica will be measured colorimetrically by the molybdate blue method (Rainwater and Thatcher, 1960) utilizing a Coleman Model 14 spectrophotometer. Suphate will be determined by a method recently developed in our laboratory. The sample is eluted through a H^+-saturated cation-exchange column and roughly titrated up to pH = 5. The sample is then mixed with an equal volume of dioxane, to lower the solubility of $BaSO_4$, and titrated with $BaCl_2$. The endpoint is detected conductimetrically. These methods have all been tested and refined, and our laboratory facilities are presently ready for routine analyses of water samples.

Stations will be monitored four times per year at the following locations: (1) Glen Canyon Dam, (2) Wahweap Bay, (3) Last Chance Bay, (4) Rainbow, (5) the mouth of the Escalante, (6) Hall's Crossing, (7) Bullfrog Bay, (8) Castle Butte, (9) Tapestry Wall, and (10) Hite. Water samples will be collected from the surface and at depth. These will be analyzed in our laboratory and the results will be refined by the computer chemical equilibrium model. Data on Lake Powell chemistry

will be augmented by the incorporation of presently published and future analysis by the Utah State Fish and Game Commission, the Bureau of Reclamation, the U.S. Geological Survey, and D. E. Kidd and L. D. Potter from the UNM study group.

Contacts have been made with Bureau of Reclamation personnel, and they have stated their willingness to collaborate with us in portions of our field work and sampling programs. Easy interchange of analytical data will occur, and our sampling program will be conducted in such a way as to complement their studies by including different stations and analysis for some ions presently not on their schedule. Some of our data will be useful to John Hendrick (Bureau of Reclamation) in his attempts to model the stratification and three-dimensional flow characteristics of the reservoir.

The three-dimensional, time-dependent chemical data will be correlated with the findings of D. Kidd on biological productivity, and with the results of N. Johnson's studies of density current movement in the Lake. The analytical program will keep watch on any development towards an anerobic condition at depth, and contribute basic insights into the causes of the present distribution of chemical species in the Lake. Ideally, a successful synthesis of the results of the combined project limnological studies will form the basis of estimates of the final, steady-state chemical configuration of Lake Powell, and of the long-term effects of the reservoir on the quality of Colorado River water below the dam.

Wall-Rock Cementation

Water samples will be collected four times per year from the seepage through the rocks that anchor the Glen Canyon Dam. In addition, waters will be collected from drilled wells near the Lake shore. The UCLA group will collaborate closely on this research. They are interested in studying rates of encroachment of Lake water on the local water table, and they will use analytical data on well samples for this purpose. We will carefully examine the same data, as well as analyses from the dam seepage in order to obtain quantitative data on any ionic gains or losses sustained by the Lake water during its percolation through the subsurface bedrock. Such studies, coupled with a knowledge of the total water chemistry, should make it possible to document the occurrence of precipitation reactions, such as calcification and silicification, or of solution processes. Findings of this sort will indicate the desirability of developing an additional program that is directed toward estimating the rate of precipitation or solution. The latter will be deferred to a future proposal, and at the present time, research will be concentrated on detection of the processes.

Reactions of cementation or dissolution in the reservoir wall and bedrocks exert controls on the permeability of the rocks and hence on rates of water loss due to bank storage. Knowledge of the rates involved should make it possible to predict the future steady-state situation with respect to subsurface water losses from Lake Powell.

Sedimentary Sources and Alteration of Sedimentary Mineralogy

X-ray diffraction studies will be performed on clay and silt-sized fractions of bottom sediments and on suspended mineral matter in the Lake. The studies will be performed for two reasons, and these are (1) to detect the existence of any authigenic phases in the sediments, and (2) to evaluate the contribution to the total sedimentary budget of local materials from bank-wash or slumping.

At the presently prevailing values of ionic strength and pH in Lake Powell, there exists the possibility of mineralogical alteration of the particulate mineral matter in the Lake. Chemical reactions could involve the formation of zeolites as well as qualitative changes in the clay mineralogy (for example, analcite and sepiolite, respectively). Because such reactions would generally involve gains and losses of ionic species, they could influence the overall chemistry of the Lake water. The propsect of important findings here cannot be evaluated at the present time. The analytical work will be routine and rapid, and sedimentary collections will be on hand. These studies seem desirable because they can be conducted with a minimum of effort and expense, yet they could yield important information on mechanisms that regulate portions of the chemistry of the Lake.

The major effort in the sedimentary studies will be in evaluating the role of sediment filling due to sediments derived locally by processes of slumpage and bank erosion. The Chinle formation appears to be the dominant lithology that is involved in such processes, and preliminary work has indicated that the most abundant clay mineral in this formation is regularly interstratified illite-montmorillonite. The abundant clays in the Colorado and San Juan Rivers appear to be montmorillonite and/or randomly interstratified illite-montmorillonite. The two clay suites, local and river-derived, are easily distinguished by X-ray diffraction (Reynolds and Hower, 1970). Quantitative estimates of the relative abundances of the two types of illite-montmorillonite will be made by X-ray methods, and these data will be correlated with (a) proximity to regions of Chinle Formation at or below water, and (b) sediment thicknesses as disclosed by Drake's profiler studies. The study should allow us to evaluate the relative importance of local sediments in the total sedimentary

accumulations, and consequently, to produce refined estimates of the rate of sedimentary infilling of the reservoir.

III. FACILITIES AVAILABLE

The Earth Sciences Department at Dartmouth College has most of the facilities required for the proposed research. Analytical equipment includes a Perkin-Elmer Model 306 Atomic Absorption spectrophotometer, a Coleman Model 14 spectrophotometer for colorimetric determinations, wet chemistry and radioisotope tracer laboratory equipment, a General Electric XRD-5 X-ray diffractometer, and a set of Orion ion electrodes. R. C. Reynolds has an outlet to the Dartmouth General Electric 635 computer in his office, and clay separation and preparation facilities. Capital expenditures indicated in the budget will augment an existing small but well-equipped water analysis laboratory.

IV. BUDGET COMMENTS

Several items in the prepared budget require elaboration and comment. These are listed below.

1. Computer time: A sum of $4000 is budgeted for computer time over the 2-year period. It is anticipated that this amount of time is required for processing analytical data through the chemical equilibrium model, and for day-to-day data reduction from the experimental programs that are involved with testing the model, and determination of calcite precipitation rates. Modeling of the three-dimensional, time-dependent Lake chemistry will become feasible before the termination of the grant, consequently allowance for this activity has been made in the computer budget.

2. Spare Portable pH Meter: The project currently owns a portable pH meter for on-the-spot pH measurements and bicarbonate titrations. It is porposed to purchase a spare so that failure of one instrument will not compromise the efficiency of field work.

3. Orion Model 801 pH Meter: The project currently owns an Orion 407 portable expanded scale pH meter. It is used for ion activity measurements in conjunction with Orion ion electrodes. Purchase of the 801 is desirable because (a) this laboratory instrument can be used while the portable device is in service in the field, and (b) the model 801 is a much more sophisticated instrument with digital readout, multichannel inputs, and accuracy and sensitivity specifications that are significantly superior to those of the more inexpensive portable Model 407.

4. Electric Drive for Sharples Supercentrifuge: Dartmouth College owns a Sharples supercentrifuge which is presently set up for a compressed air drive. Samples of clay from Lake water require clarification of large (25 liters) amounts of water. Rather than transport this water to Hanover, we propose to install the centrifuge on the project vessel. An electric drive can be purchased to be used in place of the air drive, which requires a compressor of prohibitive size for the vessel. This item is, therefore, included in the budget.

5. Sargent Model SRLG Recorder: Studies of calcite precipitation kinetics will be greatly simplified by recording various monitoring sensors such as pH and calcium ion activity. Laboratory precipitation runs will require many hours, or even days. The recorder will make it unnecessary to visually read instruments on a rigid time schedule, and will provide better averaging statistics on measurements than could be obtained from the usual meter-type readings.

6. Refrigerated Water Bath: This device will be used to maintain constant temperature conditions during conductimetric and ion electrode measurements of association constants and of precipitation rates. Ambient temperatures in the laboratory are quite variable ($\pm 3^{o}C$), and correlation of experimental data with the literature requires measurements at fixed temperature conditions. In addition, measurements are required at low temperatures similar to those encountered in the deep portions of Lake Powell.

7. Salaries: The Senior Investigator (Reynolds) plans to spend 1 month full-time on the project during the summer of 1972 and 2 months during the summer of 1973. In addition, one term of sabbatical leave will be devoted to the work and will be supported half-time by Dartmouth College; hence additional compensation at the rate of one-sixth of the annual rate is requested for the spring of 1973. As is usual in such cases, approximately one-quarter full-time will be spent on the project during the remaining periods of time within the 2-year tenure of the research.

The budget includes salary for a half-time technician for 8 months during each year. The technician will assist in the laboratory research phases of the study, and will perform routine water analyses.

One full-time graduate student will work on the project for 2 years, and it is intended that his work will constitute the subject matter of his Ph.D. dissertation. Allowance is made in the travel budget for suitable field work on Lake Powell.

REFERENCES CITED

Garrels, R. M., and Thompson, M. E. (1962) a chemical model for sea water at 25°C and one atmosphrere total pressure: Amer. Jour. Sci. 260, 57.

Howard, C. S. (1960) Chemistry of the Water, Chapt. L in Comprehensive survey of sedimentation in Lake Mead, 1948-49: U. S. Geol. Survey Prof. Paper 295, 115-124.

Irelan, B. (1971) Salinity of surface water in the Lower Colorado River - Salton Sea Area: U. S. Geol. Survey Prof. Paper 486-I, 40 p.

Rainwater, F. H., and Thatcher, L. L. (1960) Methods for collection and analysis of water samples: U. S. Geol. Survey Water-Supply Paper 1454, 301 p.

Reynolds, R. C., and Hower, J. (1970) The nature of interlayering in mixed-layer, illite-montmorillonites: Clays and Clay Minerals 18, 25-36.

(1971) Quality of Water, Colorado River Basin: Progress Report No. 5, 156 p.

The Dartmouth-endorsed coversheet for subproposal number 9, Sedimentation in Lake Powell, has been incorporated into the coversheet for all three Dartmouth-funded subproposals, and the information on it has been relocated to page 183.

SEDIMENTATION

Summary of Research Objectives

The sediments and sedimentary processes of Lake Powell will be further studied in the field and in the laboratory. The eventual objectives of this research are to determine the sedimentation rates and distribution of the sediments in the Lake, their nature and origin, the methods of deposition and time variable rates of change of sources. These factors will be significant in determining the life of the reservoir and its usefulness in fulfilling its varied functions of regulation, recreation, irrigation, and power generation. The work must of necessity be closely correlated with that of N. Johnson, R. Reynolds, and D. Kidd to relate short-term factors and to the work of O. Anderson and G. Jacoby for possible relationships to secular changes in flow of the Colorado River and its tributaries. This portion of the project will also serve in part as a support function for studies of chemistry of the sediments and nature of density currents in the Lake. Close cooperation is foreseen with the Bureau of Reclamation for portions of the study.

The proposed research can be categorized in several ways:

1. Distribution of Sediments in Lake Powell

A reconnaissance seismic profiler survey of most of the Lake was made during the summer of 1971. Since most of the sediment appeared to be concentrated in the former channels of the San Juan and Colorado Rivers, the majority of the data are from these channels. Preliminary analysis of the data indicates that approximately 10^5 acre-feet of sediment are in the old channel of the Colorado and approximately one-third of this amount is on the bottom of the San Juan portion of the Lake. The total compares well for the period since the closing of the Glen Canyon Dam with the 20-year average amount of supsended sediment which travelled through this portion of the river system per year as given in the Comprehensive Survey of Lake Mead, 1948-49 (USGS Professional Paper No. 295).

The profiler work will not be continued under this proposal, but should be resumed at some future time, with concentrated efforts on those areas where sedimentary thicknesses are greater--near the ends of the Lake and behind underwater barriers--particularly pronounced in the areas of Chinle outcrop, primarily near the upper and lower Rincons and in the vicinity of the big bend of the San Juan. Arrangements have been made for comparing measurements of the low frequency (3.5-7.0 kc) O.R.E. seismic profiler used by the Dartmouth group with the

high-frequency (50 kc) Bendix echo-sounding equipment of the Bureau of Reclamation. When this work resumes, it is hoped that joint measurements may be made especially in the major slump areas as the greater directionality of the high-frequency equipment would supplement the greater penetration of the lower frequency gear to good advantage.

2. Nature and Origin of the Sediments

Short gravity cores were taken in a number of locations during the 1971 field season. X-ray mineralogical studies of these and the surrounding country rock show a great uniformity of character, with the exception of samples from the Chinle formation, which are quite distinct. The sediments are quite fine-grained and a uniform reddish tan color when first brought to the surface, except in the slump areas and near the upstream ends of the Lake, where more sand is present.

It is difficult to determine annual variations from these short cores, so it is planned to take longer piston cores during the following field seasons. These cores will be available for bacteriological and geochemical study as well as for sedimentological examination. Annual variations should be relatively easy to determine. Some will be related to variations in flow rate of the Colorado and San Juan systems upstream. Some should correlate with the turbid layers, or density currents, in the water being studied by N. Johnson. These turbid layers will be sampled and will be examined geochemically by R. Reynolds. Some variations should be related to algae productivity being studied by D. Kidd. Some 40% of the silica in the river waters is removed in the Lake, undoubtedly by algae, and the tests of these algae, with annual variations related to productivity, will end up in the bottom sediments. These is a possibility of annual and secular variations in precipitates, but it is too early to say just what these must be. There may be variations in the organic content of the bottom sediments related to major rises in Lake level. Much of the history of the Lake waters can be read in the sediments of the bottom. It may be early, because of the relative youth of the Lake, but it should be possible to establish some future trends.

3. Methods of Deposition

The mechanisms by which the sediments reach their final resting places have not yet been fully determined. Where slumping has occurred, the mechanism is obvious, but the extent of turbidity current flow as a result of slumping is unknown. The total contribution of density currents and the variation of sedimentation as a function of time of year

and total flow require study. In some areas, such as Hite, the quantity of sediment found in 1971 was less than was present during the Bureau of Reclamation survey of 1968. The means by which this sediment moved and its eventual locus of deposition are not known. Some of these effects are transient and a function of the fact that the Lake is still filling. However, transient effects will be with us for a long time because of slow filling of the upper part of the Lake and because of annual variations of flow.

4. Time-Variable Rates of Change of Sources

There is a correlation between flow rates and sedimentary load, but the correlation is not linear. Flash floods may bring down enormous amounts of material in very short time amounts that are out of proportion in terms of the flow of water. A considerable body of data has been collected over the years by the U.S. Geological Survey, which needs to be analyzed in terms of annual variations related to snowmelt and the production of sediments by flash floods. Many of the rapids on the Colorado are caused by the large amounts of material carried into the channel by tributaries during flash floods. This material must now end up in the Lake.

If decent relationships can be established between variations in annual flow and sediment load, then it should be possible to make better prediction of future trends using the secular variations in climate to be studied by G. Jacoby.

FIELD PROGRAM

Since the time constants of the sedimentary processes are somewhat longer than other processes, and the record is less ephemeral, it should be possible to blend the field program with others in the project. Sampling in the turbid layers in the water should be conducted simultaneously with and at the same locations as the optical turbidity measurements of N. Johnson. Bacterial examination of the sediments will require that cores be taken while the bacteriological group of D. Kidd are aboard to sample the sediments. The remainder of the activities can be carried out as a boat and people are available.

PERSONNEL

The Senior Investigator in this portion of the study, Charles L. Drake, will participate in the field program on the Lake, and will supervise the undergraduate and graduate assistants who will be involved both in the field work and the data reduction.

EQUIPMENT AND TRAVEL

The budget includes equipment for the obtaining of longer cores of the Lake bottom and for obtaining large volume samples of water from the turbid layers within the water column. A major item of capital equipment is a recording echo-sounder which will provide depth information until such time as sub-bottom profiling can be resumed.

Subproject Number 10

Air Quality

AIR QUALITY AND WATER MANAGEMENT IN THE LAKE POWELL REGION

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

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Endorsements

Principal Investigator	Department Head	Approving Administrative Official
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AIR QUALITY

Abstract

Municipalities such as Page, Arizona, and Glen Canyon City, Utah, and recreational development, all enabled by Lake Powell, are changing the air quality of the area.

Since water management decisions such as the construction of the dam result in a significant future effect on the air quality, it is important to measure the present air quality in order to provide a reference for changes in that air quality caused by alternative water management and resulting alternative sources of air pollution (motorboats, for example). A model of air quality as a function of alternative water management decisions should be developed that allows the calculation of air quality change induced by such alternative water management decisions.

This proposal describes a program of measurement of those important air quality parameters that are currently not being measured by others in the Lake Powell region:

1. Aerosol
   a. Concentration
      i. Number

2. Gas Concentration
   a. Carbon Monoxide
   b. Hydrocarbons
      i. Total
      ii. Alkanes
      iii. Alkenes--Terpenes
      iv. Arenes

3. Noise

4. Turbidity

The above measurements will be made at a specified location at Lake Powell such that they will be comparable with all existing measurements. Calculation of future air quality and measurement of the present elevated background air quality will also be made on subcontract.

Introduction

Construction of Glen Canyon Dam on the Colorado River led not only to the birth of Lake Powell but also to the nearby construction towns of Page, Arizona, and Glen Canyon City, Utah. The rising of Lake Powell since 1964 has been accompanied by an increase in recreation, including both automobile and motorboat use. The assured water availability in Lake Powell is allowing the construction of the 2310 megawatt Navajo Generating Station on Antelope Creek, a small tributary of the lake. The municipalities, automobiles, and motorboats are changing the air quality of the area, easily shown by measurements of total aerosol number concentration being at least an order of magnitude larger in Page than at a nearby background location.

Of course, the background air quality changes, without the direct influence of man, by the natural variation of wind-blown dust, emission of terpenes by vegetation, and precipitation.

The evaluation of the background air quality, its variations, and the air quality change caused by man's activity on and around Lake Powell is necessary to carry out task c,iii, described on Page b of the narrative: 4.. Impact of the impoundment and resulting activities upon the quality of life in the Lake Powell region; c. . Effect of resultant air quality upon the Lake Powell recreational area. Measurement of base line atmospheric data in order to evaluate future atmospheric-lake interactions. Visibility is the most obvious example of an air quality parameter that is crucial to the recreation value of the Lake Powell area. If man degrades visibility there, the recreation value degrades similarly.

The increasing emission of contaminants by man's activities, especially motorboating, is increasing the flux of various substances from the atmosphere into the lake. An example is the lead in gasoline. The evaluation of the atmospheric input of various substances into the lake is important to tasks 2a and 2c described on Page b of the narrative: 2. Useful water lifetime and quality of the impoundment; a. The changing biological, physical and chemical systems of Lake Powell arising from natural causes and from man's ongoing activities at the lake; c. Biological-physical interactions of heavy metals in Lake Powell.

Since Lake Powell leads to both recreation and coal-fired thermal electric power generation, which conflict in air quality, it is important to measure air quality and its change in order to carry out task 3c on Page b of the narrative: 3. Impact of the impoundment and resulting activities on water utilization in the Lake Powell region; c. Economic effects on recreation, power production, and irrigation.

Since water management decisions such as the construction of the dam result in a significant future effect on the air quality, it is important to measure the present air quality in order to provide a reference for changes in that air quality caused by alternative water management and resulting alternative sources of

air pollution (motorboats, for example). A model of air quality as a function of alternative water management decisions should be developed that allows the calculation of air quality change induced by such alternative water management decisions.

Air quality is determined by the parameters listed in Table 1.

The constituents of air comprise aerosol and gases. Aerosol comprises all those solid particles and liquid droplets that range in size from 10 angstroms to 100 microns. An aerosol parameter of interest to air quality is its chemical composition, which may also vary with the aerosol size. The health significance of aerosol depends both on its size distribution, determining the distribution of deposited aerosol in the respiratory tract, and its chemical composition, determining the health effect of a particle once it is deposited on the wall of the respiratory tract. The aerosol concentration may be measured by either number per unit volume of air or mass per unit volume of air. More information is contained in the parameter size distribution which is the number or mass concentration in several size intervals within the overall size range. Aerosol is generated in the Lake Powell area by blowing sand, automobiles, motorboats, space heating, burning dumps, industry, and forest fires; after 1974, another source will be the Navajo Generating Station.

The Arizona State Department of Health includes the following constituents in its analysis of aerosol composition: benzene soluble component, nitrate, sulfate, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, and zinc. The Senior Investigator on this subproject believes that the above list should also include mercury, phosphorus, selenium, and beryllium. As far as this subproject is concerned, there is not enough justification for the additional measurement of these last four elements. For example, the 37 ppb mercury (Hg) concentration in Black Mesa coal[1] would lead to the emission of 773 grams Hg per day from the Navajo Generating Station if it is conservatively assumed that all of the Hg in the coal will be volatilized upon combustion and emitted from the stack. If it is further assumed: 1) that the stack plume will pass over Lake Powell 40% of the time; 2) that a given parcel of water in the lake will be under the plume for 4 days; 3) that all of the Hg in the plume deposits upon the surface beneath it; and 4) that the present volume of the lake is 14,753,000 acre feet, then the resulting Hg concentration in the lake water would be about 7×10^{-5} ppb, 4 orders of magnitude less than the 0.5 ppb maximum acceptable concentration for drinking water recommended by the World Health Organization. Potential concentration of Hg in bottom sediment and aquatic biota is not estimated here.

Before specific gases are discussed as air quality parameters next, it is noted that part of the chemistry of solid aerosol is the layer of adsorbed gases. This gas-adsorbing characteristic of solid aerosol is significant in the transfer of certain gases to the wall of the respiratory tract, and hence the health effect of this adsorbed gas.

Table 1

Air Quality Parameters

1. Aerosol
   a. Composition
   b. Concentration
      i. Mass
      ii. Number
   c. Size Distribution
2. Gas Concentration
   a. Ammonia (NH_3)
   b. Carbon Monoxide (CO)
   c. Hydrocarbons (HC)
      i. Total
      ii. Alkanes
      iii. Alkenes--Terpenes
      iv. Arenes
   d. Hydrogen Sulfide (H_2S)
   e. Nitrogen Dioxide (NO_2)
   f. Nitric Oxide (NO)
   g. Oxidant
      i. Ozone
   h. Sulfur Dioxide (SO_2)
   i. Water Vapor (H_2O)
3. Noise
4. Radioactivity
5. Turbidity
6. Visibility
7. Wind, Surface
   a. Direction
   b. Speed

Among the gases listed in Table 1 as air quality parameters, carbon monoxide (CO), hydrocarbons (HC), nitrogen dioxide (NO_2), oxidant, and sulfur dioxide (SO_2) are of obvious significance since they are subject to national ambient air quality standards. Nitric oxide is listed because it is the important precursor of NO_2, and around Lake Powell, automobiles and motorboats are large sources of NO, despite conversion of much of it to NO_2. Hydrocarbons are divided into various types because of the importance of (1) methane, an alkane, to the total hydrocarbon concentration; (2) ethylene and terpenes, all alkenes, to anthropogenic and natural sources of reactants in gas-to-aerosol conversions and photochemical reactivity in general; and (3) arenes such as carcinogenic benz-a-pyrene. Water vapor is listed here as an air quality parameter amongst the gases, even though it is usually listed as the meteorological parameter relative humidity, because it determines the aerosol size distribution for an otherwise specified aerosol chemistry. Ammonia and hydrogen sulfide, although present in extremely low concentrations, are included because of their importance in the nitrogen and sulfur cycles and because of the role of NH_3 in the conversion of SO_2 to sulfate (SO_4). The specific gases in Table 1 chosen as air quality parameters are emitted by both natural and anthropogenic sources, and these gases are considered to be the most important to the health of regional biota and the welfare of man. The main sources of CO, HC, NO, and NO_2 around Lake Powell are automobiles and motorboats. The terpene class of hydrocarbons come from aromatic vegetation. Oxidant is produced

naturally but sources of HC and NO_2 lead to specific photochemical reactions that produce additional oxidant. The only significant source of SO_2 will be the Navajo Generating Station in 1974, which will also be a significant source of NO and NO_2. NH_3 and H_2S will not be measured in this subproject because of their lack of importance to the relationship of air quality and water management in the Lake Powell area.

Although noise is not usually considered to be an air quality parameter, it is included here because (1) it is so important to the aesthetic quality of the environment around Lake Powell, (2) it will increase with increasing population, industry, and recreation (motorboats), and (3) it is transmitted through the air medium.

The radioactivity in the air is carried by gases and aerosol. Radioactive gases include krypton-85, radon, and thoron. Total beta activity in the aerosol collected on a filter with a high volume sampler at Page in 1969 was low enough to indicate to the Arizona State Department of Health that there was no problem, and to suspend such measurement that same year. Underground nuclear device testing in Nevada is an occasional source of leaked radioactive contamination in the region around Lake Powell, capable of elevating the radioactivity of the atmosphere above the background level for a relatively short period of time. Since coal contains radioactivity, the Navajo and the proposed Kaiparowits Generating Stations will be sources of slightly radioactive fly ash. In order to assess if these sources are appreciable, it is conservatively assumed for the Navajo Generating Station that (1) the emitted fly ash is mixed throughout a limited layer that extends from the ground to the height of the plume at about 2000 feet above terrain, (2) horizontal mixing occurs across 0.5 km, and (3) mean wind speed is 3 meters per second. The fly ash emission rate at full load will be 7.25 tons per day or 6.58×10^6 grams per day. The volume of air through which this fly ash is mixed is about 0.915×10^6 cubic meters per second. The resulting fly ash concentration is 830 ug/m^3. The maximum concentration of four bone-seeking radioactive isotopes in the fly ash are given in Column 2 of Table 2. Based on the assumptions above, the volume concentration of radioactivity for each of these four isotopes is given in Column 3 of Table 2.

Table 2

Resulting Maximum Atmospheric Concentration of Certain Radioisotopes to be Emitted in the Fly Ash from the Navajo Generating Station

Isotope	Maximum Concentration in Fly Ash (pc/g ash)	Volume Concentration in Air (pc/ml)	Radioactivity Concentration Guide (RCG) (pc/ml)	Ratio of Calculated Volume Concentration to RCG (%)
^{226}Ra	2.9	2.4×10^{-9}	2×10^{-6}	0.1
^{228}Ra	5.0	4.2×10^{-9}	1×10^{-6}	0.4
^{228}Th	5.0	4.2×10^{-9}	2×10^{-7}	2.0
^{232}Th	4.9	4.1×10^{-9}	1×10^{-6}	0.4

The most restrictive values from the Radioactivity Concentration Guide (RCG), promulgated by the Federal Radiation Council, for these isotopes in air outside restricted areas are given in Column 4 of Table 2. As can be seen in Column 5, the calculated concentrations are much lower than the RCG values, with the closest case of ^{228}Th being 50 times lower.

Based on the above calculation, it is recommended that there be no measurement of airborne radioactivity in this subproject.

Turbidity is the atmospheric aerosol loading that attenuates incident solar radiation by scattering and absorption. Turbidity is quantified by a coefficient, defined as

$$B = \left[\frac{\log_{10} \frac{1}{F} \frac{I_o}{I}}{d}\right] - ak\frac{P}{P_o}$$

from the transmission equation

$$I = \frac{I_o}{F} 10^{-(ak\frac{P}{P_o} + B)\, d}$$

where I = incident solar radiation intensity
I_o = extraterrestrial solar radiation intensity
F = reduction factor for mean solar distance
a = 0.0674 = atmospheric extinction coefficient of pure air including ozone per unit optical path length
k = factor to allow for the differences between the optical path length of the atmosphere for air, haze, and ozone

d	k
≤ 3	1.0
6	0.97
10	0.924

P = ambient pressure
P_o = sea level pressure
B = turbidity coefficient for haze, dust, etc.
d = relative optical path length = $\frac{1}{\sin h}$
h = apparent elevation angle of sun

Visibility is the quality that allows one to see distant objects, and its numerical value is often called visual range. This parameter is probably the one most obvious to the layman and it can be measured without instruments. Visibility is limited by the light scattered by gas molecules and aerosol into the path, and by the light absorbed in the path by these same gas molecules and aerosol, between the object and the observer's eye, reducing the contrast between the object and its background surroundings. Visibility is considered in the horizontal while turbidity is the roughly analogous parameter in the vertical. All aerosol sources mentioned above can potentially affect visibility. Also sources of NO, NO_2, and SO_2 can affect visibility after these gases have converted to aerosol in the atmosphere.

Surface wind determines the spatial pattern of distribution of any local pollution superimposed on the background air.

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1314 WEST PEACHTREE STREET N.W. • ATLANTA, GEORGIA 30309 • [illegible]
CABLE: DAMEMORE TELEX: [illegible]

January 18, 1972

Dr. Eric G. Walther
Museum of Northern Arizona
Fort Valley Road
Post Office Box 1389
Flagstaff, Arizona 86001

Dear Dr. Walther:

It is my understanding that you and I have agreed to a complete exchange of Air Quality data obtained in our respective measurement programs in the Page, Arizona-Lake Powell area.

I am looking forward to working with you regarding these programs and offer my full cooperation to fulfill the goals of the projected studies.

Thank you for your interest in our work.

Yours very truly,

DAMES & MOORE

Bob

Robert G. Allen
Chief Engineer

RGA:ds

Table 3

Existing Air Quality Measurement

Parameter	Agency	Station Location	Sampling Frequency	Method
1. Aerosol composition Benzene soluble component Nitrate Sulfate	ASDH	Clarkdale Davis Dam Flagstaff Grand Canyon Holbrook Joseph City Leche Tuba City	Every 6 days	Various
2. Aerosol composition Arsenic Cadmium Chromium Cobalt Copper Iron Lead Manganese Molybdenum Nickel Zinc	"	"	Every month	"
3. Aerosol mass concentration	"	"	Every 6 days	High volume gravimetric
4. Aerosol mass concentration	Dames & Moore	Page Airport	Every day	"
5. Aerosol mass concentration	"	"	"	Tape sampler

Table 3 (cont.)

Parameter	Agency	Station Location	Sampling Frequency	Method
6. Aerosol mass concentration	Utah State Dept. Health(USDH)	Wahweap	Every day	High volume gravimetric
7. "	"	Bull Frog Basin	"	"
8. Aerosol size distribution	Dames & Moore	Page Airport	"	Anderson cascade impactor
9. Aerosol dustfall	"	19 sites around No. Arizona and Southern Utah	Every 2 months	Sticky foil
10. Nitrogen dioxide	Arizona State Dept.of Health	Grand Canyon Village	Every 6 days	24-hour bubbler
11. "	"	Davis Dam	"	"
12. "	Utah S.D.H.	Wahweap	Continuous	"
13. Nitrogen oxides	Dames & Moore	Page Airport	2 per week	1-hour bubbler Saltzman
14. Oxidant	"	"	2 per day	10-min. bubbler Haagen-Smit
15. "	Arizona State Dept.of Health	Grand Canyon Village	Every 6 days	24-hour bubbler
16. Ozone	Utah S.D.H.	Cedar City	Every month	Rubber strip
17. "	"	Bull Frog Basin	"	"
18. "	"	Padre Bay	"	"
19. "	"	Wahweap Bay	"	"
20. "	"	Cedar City	"	"
21. Sulphur dioxide	Dames & Moore	Page Airport	Continuous	Conductimetry
22. "	"	"	2 per day	24-hour bubbler

Table 3 (cont.)

Parameter	Agency	Station Location	Sampling Frequency	Method
23. Sulphur dioxide	Dames & Moore	19 sites	Every 2 months	Lead peroxide candle
24. "	A.S.D.H.	Grand Canyon Village	Every 6 days	24-hour bubbler
25. "	"	Davis Dam	"	"
26. "	U.S.D.H.	Wahweap	Continuous	Coulometric
27. "	"	Wahweap Bay	Every month	Lead peroxide candle
28. Sulphur dioxide	"	Padre Bay	"	"
29. "	"	Bull Frog Basin	"	"
30. "	"	Cedar City	"	"
31. Water (relative humidity)	Bureau of Reclamation	Page Airport	Continuous	Hair Hygrometer
32. Visibility	Dames & Moore	"	3 hr. each morn.	Integrating nephelometer
33. "	"	"	Every day	Observer and distant points
34. Wind speed & direction	Arizona Public Service	Glen Canyon City	Continuous	Anemometer and windvane
35. "	Bureau of Reclamation	Page Airport	"	"

History

The measurements of air quality that are presently being done by others are listed in the above Table 3.*

The programs shown in Table 3 are measuring the parameters listed in Table 4.

Table 4

Air Quality Parameters Presently Being Measured

1) aerosol
   a) composition
      - benzene soluble component
      - nitrate
      - sulfate
      - arsenic
      - cadmium
      - chromium
      - cobalt
      - copper
      - iron
      - lead
      - manganese
      - molybdenum
      - nickel
      - zinc
   b) concentration
      i) mass
   c) size distribution

2) concentration of certain gases
   a) nitrogen dioxide
   b) nitric oxide
   c) oxidant
   d) sulfur dioxide
   e) water

3) visibility

4) wind
   a) direction
   b) speed

Dames and Moore are also calculating the expected concentration of sulfur dioxide at ground level for various distances and directions from the generating station under various atmospheric conditions of stability and wind.

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* Ed. note: Of special interest is the work done at the Page Airport by Dames and Moore on aerosol mass concentration and size distribution, nitrogen oxides, sulfur dioxide, and visibility. Eric Walther and Dames and Moore have agreed to a complete exchange of air quality data obtained in the Page, Arizona-Lake Powell area. See p. 192. (O.L.A.) A similar agreement exists between Eric Walther and the Division of Air Pollution Control, Arizona State Department of Health.

The remaining parameters that are to be measured in this subproject are listed in Table 5.

Table 5

Air Quality Parameters to be Measured in this Subproject

1) aerosol
   a) concentration
      i) number

2) concentration of certain gases
   a) carbon monoxide
   b) hydrocarbons
      i) total
      ii) alkanes
      iii) alkenes
           terpenes
      iv) arenes

3) noise

4) turbidity

Design of Proposed Subproject

Measurement Part

The parameters listed in Table 5 will be measured at a specified location at Lake Powell.

The recommended sampling intervals for these measurements are listed in Table 6.

Table 6

Recommended Sampling Intervals for Air Quality Measurements

Air Quality Parameter	Recommended Sampling Interval
1) aerosol a) concentration i) number	Sample once per day before sunrise.
2) gas concentration a) carbon monoxide b) hydrocarbons	Sample once per day at 1400 Mountain Standard Time
3) noise	Sample continuously all day Wednesday and Saturday.
4) turbidity	Sample six times in one clear morning of each week.

The instrumentation will be housed in a 1964 Dodge camper, owned by the Atmospheric Sciences Research Center of the State University of New York at Albany and stationed near Lake Powell during regular measurements. When a regular measurement is not being made, the camper can be driven to other locations to determine the spatial pattern of various parameters. The camper will be air conditioned to provide a reasonably constant temperature for instrument stability, and it will contain a generator to provide electric power for the instruments. Such occasional trips to obtain a spatial pattern of the various parameters will require brief interruptions of the recommended sampling intervals for aerosol number concentration and the concentration of hydrocarbons and CO (see Table 6).

Methods of Measurement

Turbidity

This parameter will be calculated from the measurement of incident solar radiation intensity I with a pyrheliometer at wave length λ = 0.5 micron. In the equation

$$B = \left[\frac{\log_{10}\left(\frac{1}{F}\ \frac{I_o}{I}\right)}{d}\right]^{-ak\frac{P}{P_o}}, \quad d = \frac{1}{\sin h}$$

and h is the apparent elevation angle of the sun. The measurement will be made several times during a clear day each week. I_o is obtained by extrapolating I on a plot of I versus d to d=0. K=1.0 for $d \leq 3$. The ambient atmospheric pressure (p) will be obtained from a barometric instrument located at Page, and its extrapolation to sea level will yield P_o. Wavelength λ was chosen at 0.5 micron to minimize the water vapor absorption of solar radiation since the effect of aerosol is that of interest in this program.

Aerosol Number Concentration

The aerosol number concentration will be measured at least once each day before sunrise with a portable instrument called a particle detector. This instrument operates off small self-contained batteries. It humidifies an air sample to saturation and then subjects the saturated air to an adiabatic expansion. The resulting 400% super-saturation causes the water vapor to condense on all aerosol down to a minimum radius of about 10 angstroms. After several milli-seconds, all the aerosol has grown to at least 0.1 micron (u) radius and is therefore capable of attenuating the light beam between a lamp and a photo-cell. The size distribution of background aerosol is such that most of the particles are smaller than 0.1 micron radius. These small particles do not significantly attenuate visible light. Greatest attenuation per particle is achieved by particles between 0.1 and 1.0 u. The measurement is made before sunrise in order to eliminate those particles produced by sunlight-induced gas to aerosol conversion.

Gases

The gas concentrations will all be measured with a gas chromatograph. A column packing such as Poropak Q will be used to separate most of the hydrocarbons of interest while the terpenes will be separated in a column packed with Diatoport S 60-80 mesh, 2% carbowax 20M, and a 5% silver nitrate substrate. Carbon monoxide is measured by separating it from other gases, converting it to methane on a nickel catalyst in a hydrogen carrier, and measuring the resulting methane pulse in a flame ionization detector at a retention time different than that for the natural methane in the air sample.

Noise

This parameter will be measured by placing a sound level meter at a location near the camper but far enough away to eliminate the recording of sound from the camper itself and all other equipment in this program. The sound level, weighted on the A scale to most closely represent human hearing, will be recorded for 24 hours. The resulting plot will yield the maximum, minimum, and mean values for the day.

Recommended Instruments

The important characteristics of the equipment required for this background air quality measurement program are listed in Table 7.

Table 7

Recommended Instruments for the Measurement of Certain Air Quality Parameters

Parameter	Instrument	Company	Model	Power	Sensitivity	Recorder	Price
Turbidity	Pyrheliometer	Science Assoc.	640	Internal		Yes	$ 300
Aerosol number concentration	Small particle detector	Gardner Assoc.	Type CN	Battery	100 per cm^3	No	500
Gases	Gas Chromatograph	Perkin Elmer	990	2.4kw (117v)	0.01 ppm CO	Strip chart	8,075
Noise	Sound level meter.	General	1551-C	Battery	24dB		645
	Graphic level recorder.	Radio Co.	1521-B	35w(115v)		1521-B	1,575
	Calibrator	"	1562-A	Battery			265
					Total		$11,360

Computational Part

All of the background air quality data obtained from the above measurements in this subproject and from existing measurement programs will be combined for statistical analysis of parameter averages, maxima, minima and frequency distributions for each day, week, month, and year.

The above analysis will be performed by Dr. Michael D. Williams of the John Muir Institute for Environmental Studies under subcontract. The subcontract work description is attached.

Dr. Williams will also compute future air quality in the Lake Powell region based on predicted new sources of air pollution that will potentially contaminate the air of this region, e.g., coal-fired thermal-electric generating stations, motorboats, automobiles, other industry.

Relationship with Other Subprojects

The data obtained herein along with those air quality data obtained in on-going measurement programs will be helpful to the lake geochemistry, biological limnology, and heavy metal subprojects for the estimation of the atmospheric input of nitrate, sulfate, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, and zinc into Lake Powell.

This data will also be the reference for any data obtained in contaminated air in the Lake Powell region. Combined with past data obtained in other measurement programs, this data will provide the measure of air quality needed for epidemiological studies concerned with the relationship between respiratory disease and air quality.

The computation of future air quality in the Lake Powell region is important to the two following subprojects for their analysis of economic impact and resource management: 1) Integrative systems analysis for the Lake Powell Project; and 2) An analysis of the regional economic development enabled by Lake Powell.

Potential Users of this Background Air Quality Data

Besides being used by the six other subprojects mentioned above, this data will probably be used by the:

1) Environmental Protection Agency
2) Arizona State Department of Health
3) Utah State Department of Health
4) New Mexico Environmental Improvement Agency
5) Dames and Moore, meteorological consultants to the participants in the Navajo Power Project
6) Four Corners Regional Commission
7) Bureau of Reclamation
8) National Park Service
9) Colorado Plateau Environmental Advisory Council
10) Coconino County Health Department, Arizona
11) Atmospheric Sciences Research Center, State University of New York at Albany
12) Advisory Commission on Arizona Environment
13) ISSUE? (Interested in Saving Southern Utah's Environment
14) The Enchanted Wilderness Association

Presentation of Results

If this subproject is funded as of 15 May 1972, capital equipment will be ordered right away and the computational par will begin immediately. There will be a delay of 2-6 months f the delivery, installation, and check-out of the equipment.

Regardless, every half year there will be a progress report submitted by 31 December and 30 June. As soon as data is available on the background air quality parameters, it will be presented in the progress reports along with that data available from all the other on-going programs and it will include maxima, minima, and means for each day, week, month and year. Some of the data analysis will be manual and some will be machine computed. Upon approval of each progress report by the coordinators, a copy will be furnished to each of the subprojects and potential users listed above.

References

1) Jones, James R., 1971, Letter of 8 June, 1971, from J. R. Jones, Director, Environmental Quality, Peabody Coal Company, to R. H. Robinson, Southern California Edison Company, Los Angeles, California.

2) Peters, R. J., 1970, Laboratory analysis report to Salt River Project, Trapelo/West, Richmond, California.

3) Harley, John H., 1968, Radiation Hazards, Section 5 in Dangerous Properties of Industrial Materials, edited by N. Irving Sax, Van Nostrand Reinhold Company, New York, pages 133-193.

SUBCONTRACT

from the

NORTHERN ARIZONA SOCIETY OF SCIENCE AND ART, INC.

to

THE JOHN MUIR INSTITUTE FOR ENVIRONMENTAL STUDIES

for

certain computational work and analysis to be performed by

MICHAEL D. WILLIAMS of THE JOHN MUIR INSTITUTE

to be given in support of the scientific effort of Eric Walther of the Museum of Northern Arizona, who is responsible as Principal Investigator of Subproject 10, Air Quality and Water Management in the Lake Powell region.*

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*Ed. note: This subcontract is the essential core of a subproject proposal (budget $88,284) submitted by M. Williams to the Coordinators at the Denver meeting. The Steering Committee voted to deny funding for this subproject, since the data it would produce would not be needed as soon by other investigators as certain other data. The sense of the Steering Committee vote was to postpone the beginning of this work, not to deny its validity to the Project. The subproject submitted by Walther (Background Air Quality) had a proposed budget of $116,120, and it was formally submitted to the Coordinators originally under the sponsorship of JMI, although Walther is a member of the MNA staff. The Steering Committee approved the total amount of the Walther proposed budget. In subsequent meetings of the Committee, it was the sense of the discussion (but not acted upon by formal vote) to try to incorporate the core of Williams' work within the approved allotment of Walther's budget. The principal parties evolved a plan to do this. At this time, the Director of the MNA (NASSA) decided that the Walther proposal was to be funded by NASSA, not JMI, and the Steering Committee approved the transfer of responsibility unanimously. The planned incorporation of Williams' work into Walther's proposal was not accomplished without pain, but an agreed upon plan between Walther, Williams and the Director of the MNA resulted in this formal subcontract. Thus formally, at least, Williams reports to Walther who reports to the Coordinator of Natural Sciences. (O.L.A.)

Objectives

New sources of contaminants including additional automobile and motorboat usage, and increased power production in the Lake Powell region are expected to introduce large quantities of contaminants into a relatively uncontaminated region. In order to assess the significance of these contaminants two objectives must be achieved: 1) a clear understanding of the present situation with respect to existing contaminants must be obtained, and 2) an identification of the most important contaminants and their interactions with natural systems and human uses of the area must be achieved. The goal of this subcontract is to address both of these problems. The first will be approached by making measurements of the existing contaminant situation above ground level and through guidance of the choices of sampling equipment and sampling locations in the surface measurement programs. Furthermore the data analysis and display systems will also be designed under this subcontract. The second problem will be faced through a combination of a computational program and some very limited surface data collected near existing plants. The specific goal will be to estimate the impact of the contaminants on visibility and the rates of deposition of some airborne contaminants such as sulfates, nitrates, phosphorus, sodium, potassium, and heavy metals. This material is expected to be useful to other subgroups including those concerned with the economic and recreational impact of air pollution and those concerned with the biology of Lake Powell. For automobiles and motorboats in the area of Lake Powell, the dispersion of carbon monoxide, hydrocarbons, nitrogen oxides, and aerosol will be computed, using available meteorological information and estimated source strengths. For the future coal-fired thermal-electric generating station near Page, the dispersion of nitrogen oxides and specific aerosol constituents will be computed because such information has not been published by Dames and Moore.

BACKGROUND AND RATIONALE

Plume Opacity Considerations

The new coal-fired electric generation plants adjacent to Lake Powell, identified as the Navajo and the Kaiparowits, are to be located in an area of high scenic value. Further, other areas within sixty miles include Grand Canyon regions where scenic values are paramount. Studies of power plant plumes suggest that relatively high visibility-degrading concentrations can occur at distances of sixty miles or more.[1] Indeed, such plumes have been known to produce severe degradation of visibility in comparable areas. Since the plants at Lake Powell will be very large by usual standards, the demands upon the control technology will be great.

There are many factors which influence the opacity of a plume. The principal ones are: 1) the dispersion which influences the amount of material along the line of sight; 2) the index of refraction of the particle; and 3) the size distribution of the particles.[2] Some of these factors are controlled by the characteristics of the source. For example, the kind of particulate control devices available will influence both the number and the size distributions of the emitted particles,[3] while the amounts of sulfur and nitrogen oxides which escape the collectors will influence the kinds of particulates and the average index of refraction present at differing distances down-wind from the power plant. The control options available are much influenced by the kind of contaminent.[4,5,6] External to the source, the relative humidity and sunlight will influence the rate at which sulfur oxides and nitrogen oxides convert to particulates,[7] while the meteorological conditions dictate the plume dispersion.[8] These many factors, which simultaneously determine the variation of the plume opacity with distance from the source, must be separately understood for application to specific impact models.

At present there are two major power plants in the Southwest from which clues can be obtained for the understanding of the impact of the proposed plants near Lake Powell (as well as elsewhere in the upper Colorado Basin). These are commonly termed the Mohave and the Four Corners plants. The one at Four Corners has a somewhat higher sulfur emission and much higher particulate emission than the Mohave plant. Comparison of these differing emission characteristics can give clues to the relative importance in impact calculations of such physical and chemical features.

In addition to the characteristics of the plume, it is also important to know the background light scattering along the line of sight. The background scattering dictates the present situation in terms of the distance at and clarity with which objects can be perceived. It will influence the degree to which additional visible degradation will interfere with existing uses. Thus it is important to obtain background air scattering.

The background scattering is measured indirectly by the turbidity (a more complete description of turbidity and its relationship to light scattering is presented in the discussion on surface air quality measurements). The turbidity drops dramatically with height in the first few hundred feet about ground level (9). This fact implies that light scattering and absorption also vary significantly with height. Since the optical path between a viewer and a distant object will normally be well above the surface over much of its length, it is important to know the light scattering above ground level.

From this discussion one can deduce that it is important to obtain background measurements of light scattering above ground level and to acquire a better understanding of the plume dispersion and plume chemistry. It is expected that detailed studies will be done on existing plumes which will precisely define smoke plume characteristics (the Lake Powell Project participants have recommended support for such a project designed by Dr. Williams, while officials from the Department of the Interior and the Environmental Protection Agency have pointed out the need for such a study).

If such a study is conducted, the accuracy of opacity calculations will be significantly enhanced. However, even without such a program, a considerable amount of information can be inferred about important characteristics through the use of theoretical models and data from diverse sources. For example, deposition rates of sulfur oxides and nitrogen oxides could be deduced from ground measurements which could then be correlated with meteorological data and plume photography programs to infer important properties of the plumes of existing plants. This would permit conclusions to be drawn about plumes which will be produced by the new plants. Thus, a computational program, an elevated background light-scattering measurement program, and a program of limited surface measurements near existing plants could be used to obtain important information for the Lake Powell Project.

Deposition of Airborne Contaminants

In addition to the effects on visibility, air contaminants may affect the environment in other ways. A great deal of

attention has been focused on the direct toxicity effects of some of the common air contaminants: sulfur oxides, oxides of nitrogen, and particulates. Furthermore, the deleterious effects of some airborne contaminants which are deposited in watersheds with subsequent unfortunate effects on the water chemistry have been observed (10). Potential deleterious effects of air deposition of nutrients on land areas have been suggested as possibilities by some authors (11). For this reason, it is important to understand what contaminants will be added to the ecosystem and under what circumstances. These additional burdens can then be assessed if the existing contaminant loads and their implications are understood. The prediction of these burdens then permits the identification of important features of a sampling program which may be required to give the background necessary for a future assessment of the significance of the additional contaminants.

The predictions of the additional burdens can be made with varying degrees of confidence depending on the nature of the specific contaminant. For nitrogen oxides, the deposition occurs in the nitrate form and the rate of conversion of nitrogen oxides to nitrates is not well understood. However, samples of snow collected near existing plants would be expected to contain measurable quantities of nitrates from which the deposition rate could be deduced. These rates could be used with the meteorological conditions at the time of deposition and the theoretical calculations of plume dispersion to extend the predictions to a variety of conditions. Thus an additional important piece of information could be obtained.

Data Analysis

The usefulness of data is considerably enhanced by appropriate statistical analysis. Such analysis can highlight significant information.

Relevance to Other Subprojects

The computational program together with the surface measurements near existing plants and the air measurements at Lake Powell could provide important information to several parts of the Lake Powell Project. The systems analysis people, for example, would have significant material on the influence of contaminants on visibility under various control options. They would be able to use this as a parameter in their studies of recreational use. The surface background air quality subproject would be benefitted by the knowledge of critical contaminants and their locations. The lake geochemistry and the biology groups would have information about potential important new inputs to their areas of concern.

Relevance to Other Groups

The information provided by the study would also benefit other groups including the Department of the Interior, the utilities, the EPA, and state control agencies. The Department of the Interior would be benefitted through an enhanced understanding of the interrelationships between the various activities, including the preservation of natural areas, maintenance of recreational areas, and exploitation of public resources with which it is now involved. The utilities would be benefitted by additional information on the efficacy of pollution control measures and an enhanced understanding of environmental effects of various management options. The EPA and state pollution control agencies are interested because of the importance to the design of their control programs. Members of each of these groups have expressed interest in this type of study.

Previous Theoretical and Experimental Studies of the Impact of Power Plant Emissions on the Southwest

During the first year of the Lake Powell Project (1971-1972), the principal work on the subject of the impact of power plant emissions on the Southwest was confined to estimations of emission rates of several contaminants, visibility degradation, and peak concentrations of toxic gases. The contaminants considered were limited to those described as constituents of the ash or coal in literature available at the time of the studies. The calculation of emission levels was based on studies of the emissions of those contaminants from other power plants. Emissions of many of the trace elements, normally present in coal, were not calculated because published data on their abundances in the coals of concern were not available. The USGS is presently conducting trace element analyses for the coals of concern. Their material will allow extension of the calculations to many other contaminants not yet considered.

Once the emissions were calculated, concentrations were estimated through the use of plume dispersion models. Meteorological data were used to define the frequency, location, and duration of particular dispersion models. This procedure yielded time-averaged concentrations of gaseous contaminants.

For visibility calculation, somewhat more detailed calculations were required. In this instance, size distributions were inferred from the size distribution of particulates available from fly ash collectors at the Four Corners plant, and known properties of the collection devices. The resulting distributions were then used to estimate the light-scattering properties of the fly ash on a per-unit-mass basis. These characteristics were used with dispersion models to estimate plume opacities many miles downwind.

These calculations were performed with several different conversion rates for sulfur oxides and nitrogen oxides. The calculations indicated that significant visibility degradation will occur at distances of up to 60 miles from the source of the plume. The results, in conjunction with regional wind data, suggested that significant visibility degradation will occur in Grand Canyon approximately 5% of the time by the plumes from the Navajo or Kaiparowits plants. Lake Powell would be affected much more frequently. These calculations must be considered as preliminary estimates which are merely suggestive of the nature of the problem. Several of the assumptions are subject to question, including the plume dispersion at large distances, the rates of particle agglomeration, the rates of conversion of gaseous matter, and the size distributions of the converted gaseous matter, and the size distributions of particulates emitted at Kaiparowits and Navajo. Data are expected to become available soon which will permit significant refinements in these calculations.

Some other groups have also been concerned with visibility degradation associated with these power plants. The workers from the EPA have predicted visibility reductions in Grand Canyon associated with the plumes from the Kaiparowits and Navajo plants (12). Their calculations are based on the assumption that the light-scattering characteristics were similar to that of normal haze and that there was no conversion of gaseous contaminants to particulates.

In addition to the work described above, there have also been some calculations performed with respect to visibility degradation associated with the Four Corners power plant. Estimates of the effects of fly ash on light scattering have been made by Wayne Ursenbach of Engineering Experiment Station of the University of Utah, based on ground-level particulate sampling near Farmington (13). Individuals from Bechtel Corporation and the New Mexico Environmental Improvement Agency have also made estimates based on somewhat different atmospheric models (14). Thus it is that although there is much work being done, much of it is based on questionable assumptions, and there is a great need for additional data to more precisely define the situation.

With respect to other aspects of the air contaminant picture, the situation is more complex. Maximum hourly averages resulting from the Navajo plant of the three principal contaminants, SO_x, NO_x, and particulates have been calculated by individuals from Bechtel Corporation and the air pollution control office of EPA, in addition to the author (16). Apart

from minor differences, the results are generally in agreement. However, for many contaminants, no calculations have been made, while for others important parameters such as deposition rates have not been estimated. Here, again, there is need for more work of the kind proposed here.

Studies of background air quality in the region have been limited to surface measurements. Nitrate and sulfate deposition rates have not been measured. Nor have there been attempts to compute air deposition of sulfates on surface waters even though the requisite data exist in some cases. Existing plume photography programs such as that now being carried out by the USGS at Four Corners have not been correlated with plume dispersion models and meteorological conditions. Furthermore, the surface measurements of gaseous contaminants near existing plants have not been correlated with meteorological conditions or plume dispersion models. Thus, it appears that useful information might be inferred from existing data if there were theoretical work to correlate it.

Method

The background sampling will be conducted through the use of a pyrheliometer which will be carried aloft in a small plane. In addition, gas samples will be collected for analysis by ground-based instruments. During each flight, several readings will be taken at different elevations, and above both forested and sparsely vegetated terrain.

For nitrate and sulfate sampling, some experiments will be performed on the rate of loss, if any, of nitrates deposited on snow. Then, following a snowfall near an existing source of nitrogen oxides and sulfur oxides, snow samples will be gathered in an area around the source. The samples will be stabilized and sent to Bob Reynolds of the lake geochemistry subproject for analysis. The deposition rate will then be calculated for each area and compared with the plume conditions revealed by meteorological records for the period following the snowfall.

With respect to data analysis, computer programs will be written to compute statistical parameters such as averages, maxima, and minima over the sampling periods. In addition, frequency distributions will be computed for each contaminant and each location. Furthermore, the meteorological data provided by Dames & Moore will be analyzed and an attempt will be made to correlate contaminant concentrations with meteorological conditions including wind direction, wind speed, and mixing layer heights.

For the calculational work, the emission estimates will be extended to all of the elements present in existing coal analyses. When the data on the fraction of a given element which escapes the collection devise is available that information will be used. In those instances where no such data are available, estimates will be based on the physics and chemistry of the element in question under the conditions which will exist in the collection device. For example, a gaseous material will escape an electrostatic precipitator so that the fraction of an element which is in a gaseous form will be released if the collection device is an electrostatic precipitator.

For very fine particles, the contaminant will disperse in a manner similar to the gaseous contaminants and plume dispersion models can be used. From plume dispersion models, the rate at which particles interact with surfaces can be estimated, and thus deposition rates on water surfaces can be calculated. In the cases where reactions must occur before the contaminant appears in particulate form, nitrogen oxides and sulfur oxides, reaction rates will be estimated and used to predict particulate contaminant concentrations after different plume travel times.

In addition, plume photographs will be studied to see what information they can add to plume opacity and plume dispersion models. As additional information on plume characteristics and behavior becomes available, it will be used to refine the opacity calculations. It will also be used to refine particle deposition rates.

References

1. Stephens, Thomas N. and McCaldin, Roy O. "Attenuation of Power Station Plumes as Determined by Instrumented Aircraft", Environmental Science and Technology, Vol. 5, No. 7, July 1971, pp. 615-621.

2. Robinson, Elmer, "Effect on the Physical Properties of the Atmosphere", in Air Pollution, edited by Arthur Stern, Academic Press, 1968, pp. 349-372.

3. "Gas Purification Processes", G. Nonhebel, ed. pp. 487-507.

4. U. S. Department of Health, Education and Welfare, "Control Techniques for Nitrogen Oxide Emissions from Stationary Sources", National Air Pollution Control Administration Publication No. AP-67.

5. U. S. Department of Health, Education and Welfare, "Control Techniques for Sulfur Oxide Air Pollutants", National Air Pollution Control Administration Publication No. AP-52.

6. U. S. Department of Health, Education and Welfare, "Control Techniques for Particulate Air Pollutants", National Air Pollution Control Administration Publication No. AP-51.

7. Calvert, Seymour, "Report on Air Pollution Potential of a Proposed Coal Burning Power Plant for the Victorville Area", for the Mohave Water Agency, October 20, 1969, p. 19.

8. Carpenter, S. B., Montgomery, Thomas L,, Leavitt, Jack M., Colbaugh, William C. and Thomas, Fred V., "Principal Plume Dispersion Models: TVA Power Plants," Journal of the Air Pollution Control Association, August 1971, 21, No. 3, pp. 491-495.

9. McCormick, Robert A. and Baulch, Dewitt M., "The Variation with Height of the Dust Loading over a City as Determined from the Atmospheric Turbidity", Journal of the Air Pollution Control Association, October 1962, Vol. 12, No. 10, pp. 492-496.

10. Letter to James Mullan from S. R. Hamilton, District Forester, Fish and Wildlife Branch, Ontario Department of Lands and Forests. September 9, 1971.

11. Deevey, Edward S., "Mineral Cycles", Scientific American, September 1970, Vol. 223, #3, pp. 149-158.

12. Comments by Paul Armstrong Humphreys at the Annual Meeting of the Colorado Plateau Environmental Advisory Council, September 2, 1971, Flagstaff, Arizona.

13. Testimony of Mr. Wayne Ursenbach before the New Mexico Environmental Improvement Baord, Santa Fe, New Mexico, September 1, 1971.

14. Testimony of Dr. Jerry L. Shapiro before the New Mexico Environmental Improvement Board, Santa Fe, New Mexico, September 1971.

15. Testimony of George White, Jr., before the New Mexico Environmental Improvement Board, Santa Fe, New Mexico, September 1971.

16. United States Department of Interior, "Environmental Impact Statement, Navajo Project - Draft", September 1971.

Subproject Number 11

Impact Analysis

ENVIRONMENTAL IMPACT ANALYSIS STUDIES FOCUSSING ON CURRENT AND PROJECTED CHANGES IN THE UPPER COLORADO RIVER BASIN

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

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ENVIRONMENTAL IMPACT ANALYSIS STUDIES FOCUSSING ON CURRENT AND PROJECTED CHANGES IN THE UPPER COLORADO RIVER BASIN

Abstract

The National Environmental Policy Act of 1969 (Public Law 91-190, approved January 1, 1970; 83 Stat. 852) requires government agencies to publish "environmental impact statements" for all public resource investments, and for all projects, public or private, which affect the public environmental domain. Civil servants within the appropriate government agencies are charged with preparing such statements which assess the effect of the proposed public enterprises upon the natural environment.

This subproject will analyze the value of recent environmental impact statements, and will attempt to define the construction of an effective impact statement, in order to:

1. Determine the relative extent to which research data specifically pertaining to the proposed enterprise and environment must be assembled and utilized;

2. Determine the relative extent to which it is possible to incorporate nonquantifiable values, such as aesthetics, in a way that can be useful for management decisionmaking;

3. Determine the extent to which it is possible to facilitate the "product orientation" of the mission of an interdisciplinary research group, such as the Lake Powell Project participants.

Research Objectives

The research objectives of the environmental impact subproject of the Lake Powell Project are listed below:

1. To appraise the accuracy, the recommendations for action, and the effect on policy decisions, if any, of recent environmental impact statements prepared by government agencies.

2. To determine to what extent specifically relevant scientific data are needed for a correct impact analysis statement, as compared to value judgments based upon general scientific knowledge.

3. To analyze certain particular methodologies for the construction of environmental impact statements, e.g., the Leopold et al. matrix model, that are now in use, for their effectiveness. Another new methodology to be examined is the one developed by the Battelle Institute.

4. To determine whether environmental impact statements have, in fact, helped to preserve the environment.

5. To propose an environmental impact statement for future developments in the Lake Powell region which would be considered helpful by the other participating investigators, and helpful, as well, to the environmental specialists in government agencies with jurisdiction in the Upper Colorado River Basin.

Rationale

The problem is how can an effective environmental impact analysis be incorporated into a cost-benefit equation, in order that a wise decision can be made about a public enterprise. The necessity for resolving this places government decisionmakers in an extremely awkward position, for no one, including agency employees, has been trained to make or to use environmental impact analyses. Nor are the nation's scientists in a position to advise them. The research needed to provide the data base and systems framework for the weighing of the human, social, and ecological consequences of a proposed action along with its economic and political benefits involves an interdisciplinary effort, something that is new to serious scientific research. And as well, it requires an applied focus, something which until recently was anathema to the "pure" scientists.

The resolution of the problem, then, is impaired by the following difficulties: (1) insufficient environmental research (leading to the necessity for constructing environmental impact estimates partly based upon piecemeal data and partly on conjecture, albeit often by highly qualified persons); (2) our inability to weight the quantifiable (economic costs and benefits) against the conjectured (environmental and social costs and benefits); and (3) a political framework and decisionmaking process which is just beginning to be adapted to accommodate environmental criteria.

The objectives of the proposed study have vital relation to the Lake Powell Project: first, the results of the other investigations of the Lake Powell Project will enable the investigators of this subproject to learn how good scientific data can best be incorporated into an environmental impact statement; second, in attempting to do this, we can identify the nature of the difficulties encountered by environmental specialists in government agencies charged with constructing environmental impact statements; and third, we expect to be able to distinguish between difficulties arising from insufficient data and difficulties arising from the inadequacies of the frameowrk of the environmental impact analyses and statements. The objective of this work will then be to resolve these difficulties to the extent possible.

Methods

1. Basic Studies

The methods of study will consist of three parts, all related to environmental impact statements relevant to the Lake Powell region: their retrieval, their analysis for completeness, their analysis for effect or potential effect.

a. Retrieval

Listings of environmental impact statements by government agencies apparently are not complete enough for our studies. Computer retrieval systems are contemplated by EPA and by the Council on Environmental Quality. These listings, where available, will be used. Direct personal contact with environmental specialists in the various agencies will be the chief way of locating the statements.

b. Completeness

By cross-comparing impact statements, and by using the results of the systems analysis model within the Project, statements will be analyzed in order to determine if relevant factors are included. In this regard, the matrix method discussed by Leopold et al. (1) will be very helpful.

Also, the guidelines developed by the Battelle Memorial Institute in a study for the Bureau of Reclamation will be studied and the implementation and effectiveness of these guidelines will be monitored. The usefulness of these and other guidelines to other agencies will be considered during the contacts and discussions with the various governmental agencies active in the Lake Powell region.

c. Effect

The effect or potential effect of an impact statement is judged by whether or not its implementation indeed protects the environment, or constrains the potential decisions of water management (2,3). Such effects require knowledge of many aspects of the natural and social systems involved, their interactions, and legal-political constraints. In order to assess effect, the systems analysis model of the whole Lake Powell Project will be used. This effort will be guided also by what is learned about similar problems by other agencies, such as, for example, those using techniques established by the U.S. Water Resources Council.

2. Internal Support of the Project

Many of the subprojects will be constructing submodels for the systems analysis model, and therefore will be seeking interactions and constraints for their submodels arising from environmental impact statements. Those in this subproject will work closely with the other participants as they gather their data. We will take the initiative in establishing these interconnections, but under the guidance of the systems analysis group.

We intend to establish the guidelines for an effective environmental impact statement suited to the data of the natural and social scientists of the Lake Powell Project, and the Lake Powell area.

3. External Uses

By learning about the effectiveness of impact statements external to the Project, and by learning how the various natural and and social sciences of the Lake Powell Project are gathered together in a common system, we believe we can make specific conclusions of use to environmental specialists in agencies of the region. These conclusions will enable them to be more effective in their key role in preparing environmental impact statements.

We will compare the methodology of environmental impact statements with the methodology of technology assessment. The model used for the latter will be that developed by the Stanford Research Institute, "Technology Assessment of Winter Orographic Snow Pack Augmentation in the Upper Colorado River Basin" (4). Mr. Leo Weisbeck of the Institute will serve as a consultant to the Project.

Relationships to Government Agencies

The intent of the research of this subproject is that of a scholarly activity, not that of direct action on government agencies. The results of the research will be incorporated within the systems analysis framework of the Project.

The Principal Investigator of this subproject is not authorized to submit correspondence, in the name of the Lake Powell Research Project, which would be construed as coming from an official commenting agency, and would thus necessarily become an official part of the file concerning an environmental impact statement by a government agency. Correspondence to government agencies, concerning items which would affect the files on environmental impact statements, from the Lake Powell Research Project, must be approved by the Steering Committee.

The Lake Powell Research Project is not a reviewing agency for impact statements, with the attendant responsibility under the National Environmental Policy Act. This subproject addresses itself to the study of how environmental impact statements are an institutional factor which influences water management and water resources development.

Personnel

The Principal Investigator, Dr. D. W. Aitken, has been associated with the Lake Powell Project since its early development, over 2 years ago, providing a continuity to his "integrative work"and participation. Dr. Aitken helped fund the early planning stages of this work in his former capacity as Scientific Coordinator (he is now the Director) of the John Muir Institute. During a portion of the first year of the actual funded Lake Powell Project (1971-1972), Dr. Aitken served as interim Co-Coordinator, removing himself from that position in favor of a social scientist (Dr. Jerrold Levy) who could take the major responsibility for developing the social science portions of the Lake Powell Project.

Dr. Aitken will be assisted by two very able consultants, in view of the specific objectives of the proposed research: Dr. Luna B. Leopold, Senior Research Hydrologist (and former Chief Hydrologist) for the U.S. Geological Survey and senior author of the matrix "Procedure for Evaluating Environmental Impact (1); and Leo W. Weisbecker, Senior Research Engineer for the Stanford Research Institute, and project leader for the Institute's "Technology Assessment of Winter Orographic Snowpack Augmentation in the Upper Colorado River Basin" (4).

Further assistance will be provided by an undergraduate student, yielding educational value to the proposed research, and relating it back to Aitken's departmental environmental studies program at California State University at San Jose (formerly San Jose State College).

Cited References

1. L.B.Leopold, F.E.Clarke, B.B.Hanshaw, and J.R.Balsley, "A Procedure for Evaluating Environmental Impact," U.S. Geological Survey Circular 645 (1971).

2. "Upper Colorado Region Comprehensive Frameowrk Study," a report prepared by Upper Colorado staff and Work Group chairmen of the Upper Colorado Region State-Federal Interagency Group, the Pacific Southwest Inter-agency Committee, and the Water Resources Council, and issued in draft form for review on June, 1971.

3. "Environmental Impact Statement on the Jim Bridger Thermal Electric Generation Project," BLM, 2nd draft, released on 9/30/71, describing a region lying approximately 35 miles NE of Rock Springs, Wyoming.

4. L.W.Weisbecker, "Technology Assessment of Winter Orographic Snowpack Augmentation in the Upper Colorado River Basin," draft report of Stanford Research Institute Project EGU-1037, compiled with the aid of National Science Foundation Contract NSF-C641 (quotations taken and referenced from the Review Draft, issued in August 1971. The final document will be issued sometime in 1972).

Subproject Number 12

Systems Analysis

INTEGRATIVE SYSTEMS ANALYSIS FOR THE LAKE POWELL PROJECT

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

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INTEGRATIVE SYSTEMS ANALYSIS FOR THE LAKE POWELL PROJECT

Abstract

The central task of this component of the study will be the development of both behavioral and optimization models for simulating theimpacts of alternative regional development and different resource management policies. The optimization model will incorporate the relationships and submodels provided by simultaneous equation representation of the various subprojects. In order for the relationships of any specific subproject to be compatible or consistent internally with the results of other subprojects, it is clear that a substantial degree of central direction is required. This direction will be one of the major tasks of the systems analysis group.

Objectives

The major goal of this subproject will be the creation of a quantitative systems analysis model for simulating the impacts upon the Lake Powell region of alternative water resource management policies. This subproject will address the sixth task in the total Lake Powell research project. This task deals with the development of a methodology for correlating the distinct research components essential to the achievement of the other Project goals, since it is through this methodology that the interactions between the research components involved will be exposed. Without these interactions, the realization of objectives cannot be complete and comprehensive. In order for the relationships of any specific subproject to be compatible or consistent internally with the results of other subprojects, it is clear that a substantial degree of central direction is required. This direction will be one of the major tasks of the systems analysis group.

Rationale

The impact of 20th Century man's activities on the Upper Colorado River Basin is clearly multidimensional. In fact, the recognition of this multidimensional nature and the interrelationships between the different dimensions is the basis for the interdisciplinary approach taken by the Lake Powell research project. The individual subprojects will determine the levels assumed by the specific elements within the vector of man's impact under alternative policies. The Lake Powell results, however, while useful in multidmensional form, will not in that form satisfy the total informational requirements

of decisionmakers who must consider these interrelationships if they are to formulate a complete picture of the processes being observed. Additionally, in order to achieve explicit decision rules for planning and evaluating public investments, weighting schemes must be developed for reducing the many-dimensional vector of impacts to a more manageable form--that is to say, a vector of lower dimensionality.

The Lake Powell Project has developed a truly interdisciplinary approach in which all the subprojects are functionally linked to the major goals. Continuation of this approach requires a comprehensive understanding of the interrelationships among the biological, physical, economic, social, and legal factors involved. It is also necessary to achieve an actual integration of the different disciplines involved and not simply an exhcnage of research results. This integration can only be achieved through personal interchanges among the researchers involved who come to the Project with different conceptual approaches to the problems under investigation. A complete involvement of each in the total project is essential. This involvement can lead to the modification of each investigator's conceptual approach and bring it into confirmity with the general objectives of the Project. This interdisciplinary approach promotes an interaction among the various disciplines involved from the earliest stages of the research, so that the entire research project proceeds in all stages under a common conceptual framework.

This approach also provides means for evaluating the relevance of various research components in the achievement of the general goals. Additionally, it provides strong ties among the different components and develops a language for communication between dissimilar disciplines. Exchanges between disciplines directly and through the systems analysis group group will also result in the utilization of a common technology of statistical techniques, computer facilities, and computer programs provided by the systems analysis group.

The methodology to be developed in the Lake Powell Research Project will also have an effect on the preparation of environmental impact statements for governmental projects which are required by the National Environmental Policy Act (PL-91-190). This study will assist in the development of the necessary methodology for environmental impact studies, in which the biological, physical, and socioeconomic aspects are integrated to achieve a comprehensive view of a wide range of Project consequences.

Theoretical Structure and Methodology

Systems analysis performs the task of coordination and unification of the separate research components which are required in any interdisciplinary project. Basic to this process is the "dependence of the systems approach on teams of experts from diverse disciplines, trained to cooperate with each other. The vehicle and language for this cooperation is systems analysis." (26) Implicit in the systems approach are two requirements: First, the specific organizing form has to be chosen from among the variety of alternative mathematical formulations available to the researchers. Secondly, methods must be chosen which will achieve the cooperation among the researchers which is essential to the successful application of the systems technique.

Systems Methodology

A listing of the standard mathematical techniques which have been employed in systems analysis research projects would include mathematical programming models, queuing theory, simulation, and alternative network techniques (11). The particular choice made by the researchers from among this list of systems techniques depends on the characteristics of the specific empirical situation with which the researcher is confronted and on theobjectives of his study. Most of the techniques given above are optimization techniques. Although simulation describes a body of systems approaches which have as their goal the positive description of the empirical situation under study and not necessarily the determination of some optimizing solution.

The Lake Powell Project has taken as its goals both the positive description of the totality of man's impact on the Lake Powell region under alternative management policies and the determination of an optimal management policy from among the alternative policies available to the decision-makers. These two goals require both the choice of a particular simulation model and also the choice of a particular optimization model.

The first goal of positive description will be accomplished by constructing a system of equations designed to represent the physical, biological, and social aspects of the Lake Powell region. In particular, where appropriate, simultaneous-equations estimation techniques which have been well-developed in econometric and biometric literature (1, 2, 13). Although simultaneous equations representations have found extensive practical applicability in economic and biological situations,

including the Lake Powell region (8), there are two criticisms which any investigator must resolve before applying this technique to any specific empirical problem (7). First, the investigators must consider whether or not the elaborate theoretical structure which is being created is warranted in light of the accuracy with which the data can be measured. That is to say, if the theoretical structure (i.e., the simultaneous equations representation) is greatly affected by small changes in the measurement of the variables entering the representation, and yet empirically those variables can be measured only with large errors, then such a sophisticated theoretical structure is unwarranted (23).

This question can never be fully answered until the actual data measurements are brought together with the model to provide the estimated result. However, initial discussions indicate that the measurement error in most areas of the Project is within acceptable bounds, and in any case an error estimate will be attached to the final Project results and the sensitivity of the Project's recommendations to those errors will be investigated.

The second criticism relates to the adequacy of the quantitative foundations of the various disciplines involved in the research. Although the physical and biological sciences involved in the Lake Powell Project have a secure quantitative basis in that most, if not all, of the variables that these scientists are measuring have been successfully quantified, such is not always the case in the social sciences, in which many variables have as yet only been described in qualitative terms. As an example, in considering the Water Resources Council's developmental goal of social well-being, usable quantitative measurements of such concepts as "security of life and health" are simply not available. The systems analysis component of the Project answers this problem by building upon the foundations of the physical, biological, and economic subprojects which to a high degree are adequate quantitatively, and then supplementing the quantitative representation, where appropriate, by a quantitative model, a device which has found use in economics in those areas where quantitative measures are not sufficient (3, 25).

As mentioned in the Narrative (pages II-21, II-22) these subprojects will allow us to create a model of the Lake and its environs. The Law and Political Science subproject and part of the Anthropology subproject will provide a description of the decision-making process which does not lend itself to quantification. One of the stated objectives of the former subproject (16-2) is the analysis of alternative legal and political mechanisms to optimize the equitable representation of competing interests in future river basin developments and to provide alternative institutional arrangements designed to achieve a given mix of social goals. One result of that analysis will be a description of the character and nature of the decisions that are rendered by each of the alternative decision processes considered. Likewise, the second year of the anthropological study will involve an analysis of the various tribal decision-making processes and the forces which seem to determine them. The systems analysis subproject will utilize these descriptions as inputs into the system model with the purpose of determining the implications of each for the Lake Powell region.

A comparison of alternative policies available to the decision-maker will be achieved by applying mathematical programming techniques. The system of equations developed to achieve the first goal will serve as the basis for the development of the coefficients in a mathematical programming framework. The major sectors in

the model will include different recreation activities, power production activities, and other industrial and agricultural activities. The major constraints of the model will include water availability, water quality, Lake levels, air quality, and other environmental factors. Optimization techniques such as mathematical programmingmodels require the specification ofan objective functionto be optimized. The objective function appropriate to a study such as the Lake Powell Project must include the social benefits and social costs associated with the production sectors (5, 18).

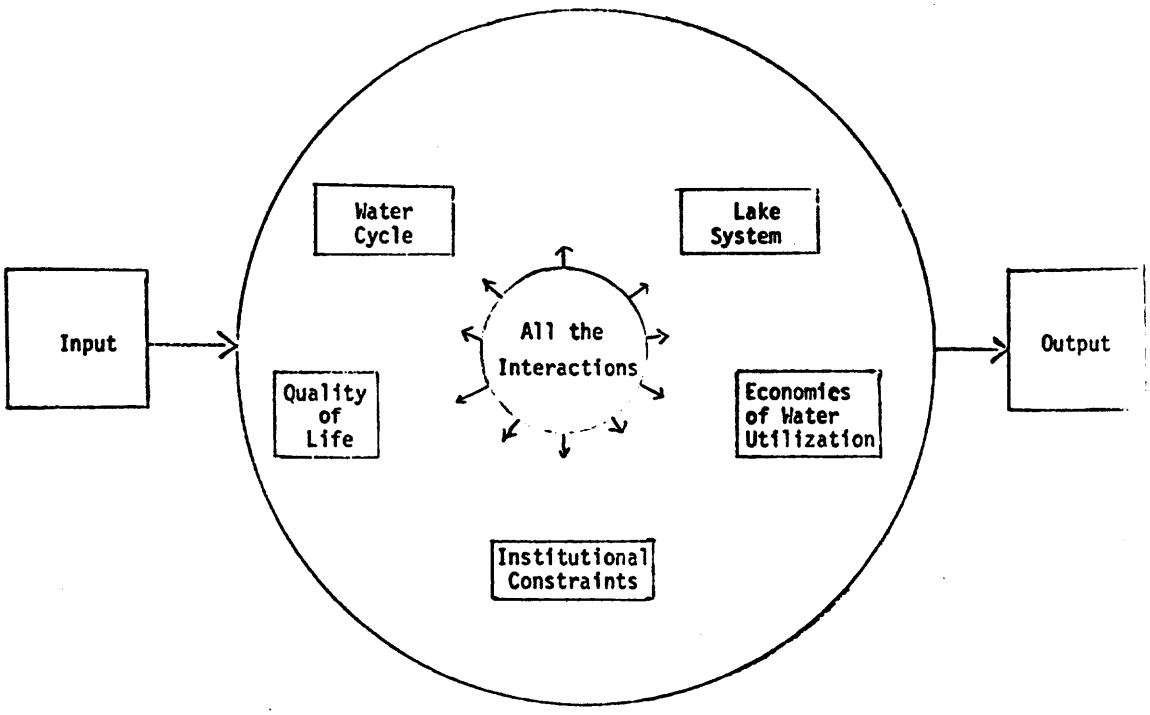
Cooperation and Procedures

The construction of the simulation model will be undertaken simultaneously from two directions. The investigators in the systems analysis group will proceed to formulate the general structure linking the various components in the Lake Powell Project (see discussion on pages 1 through 9 of the Narrative). At the same time, the investigators on each subproject, in conjunction with the systems analysis investigators, will begin development of the precise form to be taken by the relationship that they are involved in describing.

The responsibility of developing the systems analysis model is thus distributed in the following manner. The principal investigators in charge of the research components in each subsystem will collectively construct a model for their subsystem. The construction of each subsystem model will be guided by the systems analysis group to ensure the compatibility required for the general system. Another function of the systems analysis group will be to initiate the formulation of interrelationships to describe the interactions within each subsystem and between the five subsystems (see diagram on next page). The subsystem parameters will be estimated by the appropriate researchers in each case. The responsibility for developing the overall systems model which incorporates the subsystems and the interaction between them rests with the systems analysis group.

It is essential to the successful formulation of the system of equations that represent the entire Lake Powell region that the investigators on the systems analysis component become familiar with the actual research procedure employed in each subproject. For this reason, the systems analysis investigators will spend extensive periods with the various investigators while engaged in their fieldwork.

Systems Analysis Model



1. Water Cycle
   a. Stream Flows
   b. Lake Evaporation
   c. Bank Storage

2. Lake System
   a. Biological Limnology
   b. Physical Limnology
   c. Geochemistry of the Lake
   d. Environmental Hazards (heavy metals)
   e. Sedimentation

3. Quality of Life
   a. Air Quality
   b. Epidemiology
   c. Anthropology (social)
   d. Shoreline Ecology

4. Economics of Water Utilization
   a. Economic Anthropology
   b. Economics

5. Institutional Constraints
   a. Legal
   b. Political Science
   c. Tribal
   d. Environmental

Input
a. Environmental Questions
b. Water Management Questions
c. Water Policy Questions

Output
a. Environmental Consequences
b. Water Management Alternatives
c. Institutional Consequences

Personnel

Broadly speaking there are two different but related categories of activities to be performed. One includes the field work with the various principal investigators. The purposes of this field work are (1) to become familiar with the subprojects and the type of data that can be expected of each, and (2) to assist the investigators in formulating the relationships in their own area to make them compatible with the total project. The responsibility for this activity will rest with Shaul Ben-David who will spend 100% of his time during summer field seasons on this aspect of the project. The second category of activity involves the development of the system and the construction of the general model. In this activity Shaul Ben-David will be assisted by F. Lee Brown.

The principal investigators have had a broad range of experience in quantitative analysis including systems analysis techniques in the areas of mathematical programming and simultaneous equations representations. Both have had extensive experience with programming and utilization of digital computers. S. Ben-David has dealt extensively with large-scale public water projects under contracts with various federal and state agencies. F. L. Brown combines economic experience, also in the area of water resources research, with an extensive mathematical and economic background in the estimation and testing of econometric simulation models. He holds advanced degrees in Mathematics and Econometric Statistics. A. V. Kneese, an economist with long established credentials in the area of Natural Resources Economics and environmental quality analysis, will serve as a consultant on environmental economics to this subproject.

S. Karni, a professor of Electrical Engineering at the University of New Mexico, and an expert in systems research, with an extensive record of publications in the area, will serve as a consultant on systems analysis and will help in the development of the systems model.

REFERENCES

[1] Basmann, R.L., "An Expository Note on the Estimation of Simultaneous Structural Equations," Biometrics, Vol. 15, 1960.

[2] Basmann, R.L., "Remarks Concerning the Application of Exact Finite Sample Distribution Functions of GCL Estimators in Econometric Statistical Inference," Journal of the American Statistical Association, Vol. 58, 1963, pp. 943-976.

[3] Bassett, L., H. Habibagahi, and J. Quirk, "Qualitative Economics and Morishima Matrices," Econometrica, Vol. 35, April 1967 pp. 221-233.

[4] Beers, Roland F., editor, The Chesapeake Bay. Report of a Planning Study, Johns Hopkins University, Baltimore, Maryland, 1971.

[5] Ben-David, S. and O.D. Forker, "Toward the Year 1985: Interregional Competition in Dairy and Vegetable Production," December 1969, Special Cornell Series No. 9.

[6] Black, Guy, Energy, Air Quality, and the Systems Approach, George Washington University, Washington, D.C., 1970.

[7] Brunner, Karl, "Some Reflections on the State of Econometric Practice," Vielfalt der Wirtschaftspolitik (Sonderabdruck, Festgabe fur Richard Buchner), 1969, pp. 57-72.

[8] Center for Business and Economic Research, Brigham Young University, Four Corners Regional Commission Development Plan (draft), Provo, Utah, October 1971.

[9] Chapman, Duane and Robert V. O'Neill, Ecology and Resource Economics: An Integration and Application of Theory to Environmental Dilemmas, Oak Ridge National Laboratory, 1970.

[10] Cohen, A.S., et al., Chicago Air Pollution Systems Analysis Program, Argonne National Laboratories, 1971.

[11] Deninger, Rolf A., Systems Analysis for Water Supply and Pollution Control, Natural Resources Systems Models in Decision Making, G.H. Taebes, ed., Purdue University, Lafayette, Indiana, 1969.

[12] Deutsch, Ralph, Systems Analysis Techniques, Prentice-Hall, Englewood Cliffs, New Jersey, 1969.

[13] Dhrymes, Phoebus J., Econometrics, Statistical Foundations and Applications, Harper and Row, New York, 1970.

[14] Fan, Liang-Tseng, The Continuous Maximum Principle: A Study of Complex Systems Optimization, John Wiley and Sons, New York, 1966.

[15] Graduate School of Business Administration, UCLA, Mathematical Programming for Regional Water Quality Management, Los Angeles, California, 1970.

[16] Graves, G., et al., Application of a Large Scale Nonlinear Programming Algorithm to Pollution Control, Purdue University, Lafayette, Indiana, 1971.

[17] Harriston, Floyd K., and Richard E. Lund, Application of an Input-Output Framework to a Community Economic System, University of Missouri Press, Columbia, Missouri, 1967.

[18] Isard, Walter, and John Cumberland, editors, Regional Economic Planning: Techniques of Analysis, European Productivity Agency of the Organization for European Economic Cooperation, Paris, 1961.

[19] Kalman, R.E., et al., Topics in Mathematical Systems Theory, McGraw-Hill Book Co., New York, 1969.

[20] Kuhn, H.W., and G.P. Szego, editors, Mathematical Systems: Theory and Economics, Vols. I and II, Springer-Verlag, New York, 1969.

[21] McKean, Roland N., Efficiency in Government Through Systems Analysis, with Emphasis on Water Resources Development.

[22] McMillan, Claude and Richard Gonzalez, Systems Analysis: A Computer Approach to Decision Models, Richard D. Irwin, Homewood, Illinois, 1965.

[23] Morgenstern, Oskar, On the Accuracy of Economic Observation, Second Edition, Princeton, New Jersey, Princeton University Press, 1963.

[24] Patten, Bernard C., editor, Systems Analysis and Simulation in Ecology, Vols. I and II, Academic Press, New York, 1971.

[25] Qurik, J. and R. Ruppert, "Qualitative Economics and the Stability of Equilibrium," Review of Economic Studies, Vol. 32, October 1965, pp. 311-326.

[26] Taebes, Gerrit H., editor, Natural Resource Systems Models in Decision Making, Purdue University, Lafayette, Indiana, 1969.

[27] Theil, Henry, Economics and Information Theory, Rand McNally, Chicago, 1967.

[28] Thomas, Jimmie L., et al., A Computer Model of the Quantity and Chemical Quality of Return Flow, Utah Water Research Lab., Logan, Utah, 1971.

[29] Water Resources Center, Ohio State University, Systems Analysis for Great Lakes Water Resources: Proceedings of the Fourth Symposium on Water Resources Research of the Ohio State University, 1969.

Subproject Number 13

Economics

AN ANALYSIS OF THE REGIONAL ECONOMIC DEVELOPMENT ENABLED BY LAKE POWELL

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

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AN ANALYSIS OF THE REGIONAL ECONOMIC DEVELOPMENT ENABLED BY LAKE POWELL

Abstract

The major components of the developing Lake-related economy may be categorized as recreation-based, power-generation-based, and, to a lesser extent, irrigation-based. The primary task of the economic component will be to provide the results of (a) an investigation of the specific functional dependencies of economic variables such as regional employment, income, and income distribution upon the operating levels of the recreational (both private and public), power (both private and public), and irrigation activities, and (b) an investigation of the determinants of these latter activity levels themselves.

Introduction

Lake Powell serves as the base for significant economic activity in an area which would almost be economically barren otherwise. From a status of virtually nonexistent economic development, Lake Powell and the surrounding region have experienced and are continuing to experience a growing level of economic activity, as indicated by the development of a new center of business activity in Page, Arizona; the establishment of various marinas with steadily increasing sales volumes; and the increased availability of jobs which accompany the development of the recreational potential of the Lake and the introduction of the power plants and associated coal-mining operations which are in various stages of planning and construction. The economic component of the Lake Powell Project will provide explanations linking the creation of a large lake in a wilderness area with the observed economic changes experienced in the area.

Background

Public water resources development projects historically have been subject to the same evaluation principles as have all major public investments, namely, standards of national efficiency as measured in terms of the expected benefits and costs associated with and stemming from the project. On the basis of experience with previous water-related projects and the research efforts, both public and private, which have focused on these projects, there was developed a codified body

of rules and directions appropriate for water-based projects as to how the evaluation of these benefits and costs was to proceed (1, 18, 19). Glen Canyon Dam and its appending developments were evaluated and constructed within the framework provided by this set of operational instructions (20). The Glen Canyon cost-benefit analysis has been subject to many of the specific criticisms (2) which have plagued the analyses for all projects which have either been of sufficient scope or had sufficient opposition to have the spotlight focused upon them. Namely, there have been criticisms of specific conceptual measurement formulations and charges of unreliable and biased data.

However, there are criticisms of a more fundamental nature which can be and have been made against the general evaluation methodology which has justified Glen Canyon Dam as well as all other water-based projects which were approved under the national efficiency objective. Recently, modification of this "single objective" criterion has been proposed by the Water Resources Council (22, 23, 24) and the suggested changes, which have been accepted by the Office of Management and Budget and are in the process of being implemented, involve replacing the "single objective" criterion of maximization of net national benefits by a multiobjective standard which recognizes the importance of fulfilling society's preferences for enhancement of the environmental quality, social well-being, and regional development as well as national economic development. Although the task of successful project evaluation was complex when measured ultimately in terms of a single scalar of net national benefit, it becomes considerably more difficult when this single scalar is replaced by a vector of four components. As stated in the Cornell Case Study (10), "Empirical implementation of the four components of the multidimensional social welfare function required major additions to existing methodology."

The Lake Powell Project is primarily regional in scope, and for that reason emphasis has been placed upon the determination of the three innovative elements in the new multiobjective design for project and decision evaluation. In developing the regional consequences of alternative management programs for Lake Powell and its surrounding area, the economics component will concentrate on explaining and measuring the effects of these programs on the two objectives of regional development and social well-being. As defined by the Water Resources Council (22), the former of these objectives translates practically into changes in regional income and

employment while the economic aspect of the latter objective is primarily interpreted in terms of an "equitable distribution of real income, employment, and population" (22, p. 2).

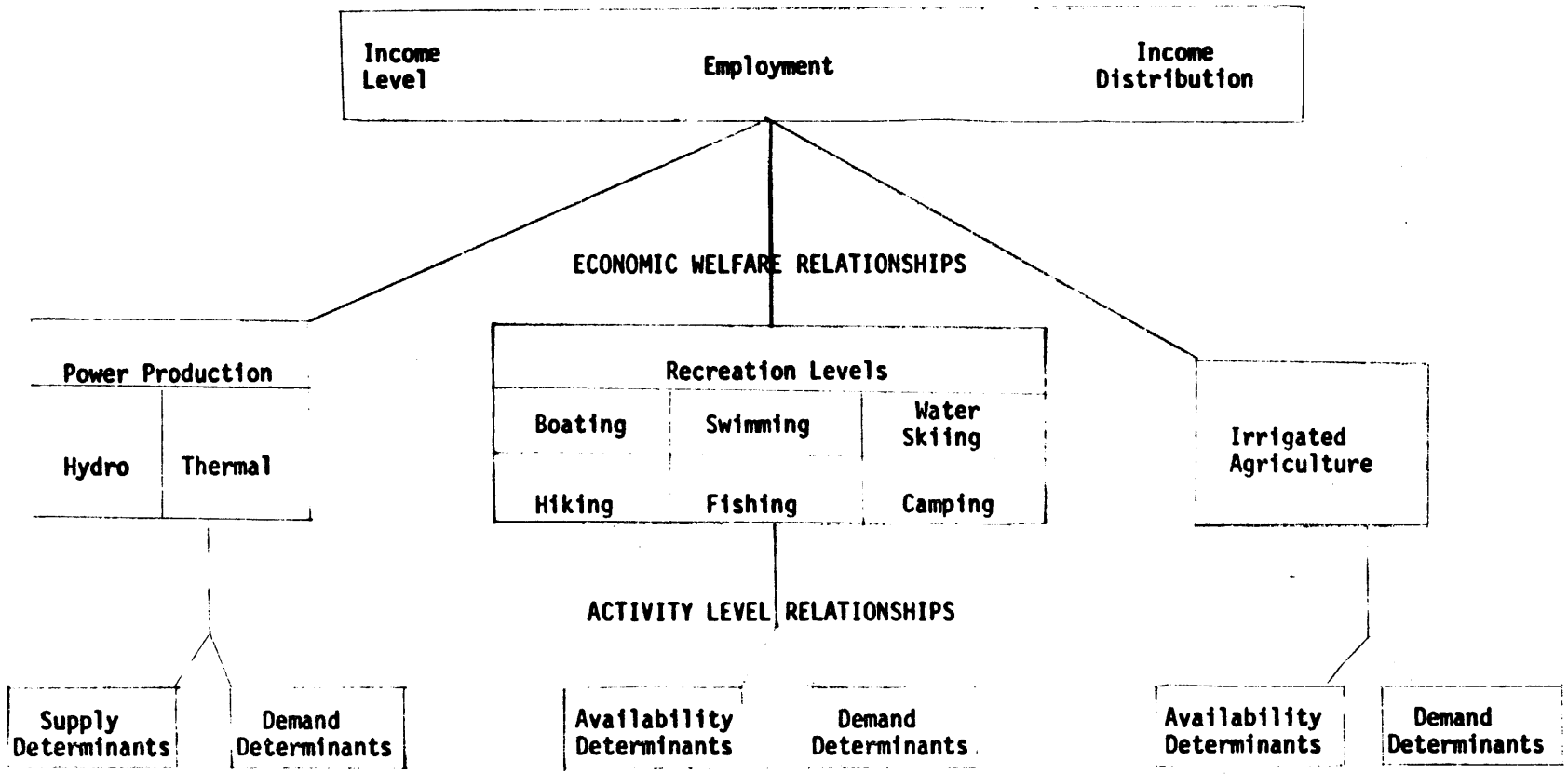
Objectives

The major components of the changing Lake-related economy may be categorized as recreation-based, power-generation-based, and, to a lesser extent, irrigation-based. The primary tasks, then, of the economic subproject will be to provide the results of (a) an investigation of the specific functional dependencies of the levels and distribution of regional employment and income upon the operating levels of the recreational (both private and public), power (both private and public), and irrigation activities, and (b) an investigation of the determinants of these latter activity levels themselves. The second task is required in any explanatory and predictive effort aimed at portraying the consequences of alternative management plans since with that purpose in mind simplistic projections from trends in the historical patterns of employment and income will not prove useful. Such extrapolations are based on the assumption that the underlying patterns of determining variables remain unchanged through time, but it is exactly this underlying pattern in which changes are created by alternative management plans. Thus, there is a requirement for construction of explanatory functional relationships linking the endogenous variables of employment and income to the levels of, for example, recreation services, and these latter variables to the demand for the various recreational services and the supply of such services which are themselves influenced by variables which are exogenous to the economic subsystem itself.

Theoretical Structure and Methodology

In order to give a more explicit description of the economic structure associated with Lake Powell, a diagrammatic illustration is utilized (see Figure 1 on the following page). Each connecting line in the illustration represents a relationship between the connected variables. The Economic Welfare Relationships are the connectives linking the levels of economic activity in the Lake Powell region to the economic indicators that the Water Resources Council has isolated as being chief determinants of regional development and economic well-being. The Activity-Level Relationships are the connectives linking supply and demand determinants to the levels of economic activity. In that case where there is no excess

Figure 1: Economic Subsystem for the Lake Powell Region



demand (positive or negative), the existing activity level, in economic nomenclature, becomes the equilibrium level of the output of the product or service.

The Economic Welfare Relationships

Recreation, power production, and, to a lesser extent, irrigated agriculture have considerable effect on the mean *per capita* income in the Lake Powell region as well as effects on the income distribution of the indigenous population. The levels of recreational use, power production, and irrigated agricultural production affect the regional income levels and income distribution directly through changes in employment levels and indirectly through the multiplier effect. Consequently, in order to obtain the desired information on the economic effects of the lake-related industries, two relationships must be considered. First, a linkage between alternative levels of production and employment figures must be developed. To this end actual planning data of the power consortium on projected employment values will be compared with national statistics on employment in the power industry in order to provide a check on the reliability of the power consortium projections. Recreational employment figures will be obtained through a synthesis of U. S. Census data, Navajo Tribal data, and direct enumeration by the Anthropology subproject. Agricultural employment information will be obtained primarily from secondary sources, specifically studies which are currently in progress on the Navajo Irrigation Project. Secondly, the relationships among income, employment, and income distribution are needed.The sources of information here are essentially the same as those above. The direct effects through employment will be augmented by non-employment related expenditures in the region by the power companies and this total sum compounded by the multiplier to achieve the total income effect in the region.

Since consumptive patterns of Navajos and Anglos may differ, thereby affecting the respective multipliers, it is important to determine the pattern of employment as distributed between these two sectors of the population. Information on the consumptive patterns of the Navajos will be provided by the Anthropology subproject. Consumptive patterns for non-Indians will be derived from U. S. Census data.

Activity-Level Relationships

Recreation

The recreational services made possible by Lake Powell include boating, swimming, water skiing, hiking, fishing, and camping. The determinants of the extent of availability of these services include:

a. The capacity and distribution of marinas and the boating services they provide

b. The capacity and distribution of launching ramps

c. The number and distribution of both developed and undeveloped campsite locationswhich in turn are affected by the Lake level

d. The capacity and location of commercial lodging facilities including motels, hotels, and trailer parks

e. The degree of accessibility to the previous four determinants.

These recreational services will be quantified and the relationships between the available capacity of each service and the five above-mentioned determinants will be estimated. Consideration will be given to interaction among the different services in the sense that increased boating potentially could affect the availability of fishing services. Data on undeveloped shoreline campsite availability will be provided by Loren Potter's shoreline study. Data on developed campsites, launching ramps, marinas, and accessibility will come from Park Service sources with information on the commercial aspect of marinas and lodging coming through direct contact with the operators. A compilation of the above information will provide a basis for projection for future availability under alternative policy decisions.

The strategy employed in the estimation of the site recreation demand is an extension of the basic Hotelling and Clawson approach (4) to recreation demand analysis using travel costs as a principal determinant. Modifications in this basic approach have resulted from subsequent recreation demand studies (5, 8, 11, 13, 17). Accordingly, the determinants affecting an individual's demand for recreational services at the Lake Powell site will include the following:

a. The costs of transportation and living expenses to be incurred while using the services

b. The physical effort expended in journeying to the Lake as measured by the distance traveled

c. The income level of the service user

d. The availability of substitute recreational sites

e. The environmental character of Lake Powell in the sense of:

- The aesthetic attraction of the Lake and its surrounding terrain
- The level of industrial pollution
- The degree of congestion associated with Lake use.

The aggregate site demand will be constructed from the individual demand functions utilizing national and regional population and income distribution data.

The relationshipsof the demand for each of the recreational services provided by the Lake to the determinants listed above will be constructed primarily by means of sampling procedures for eliciting information from the population of current users. Park Service data and mailing lists compiled by the operators of all marinas on Lake Powell will be used to determine sample sizes by type of recreational activity. In addition to sample size these will allow us to determine seasonal variations to determine the interviewing periods. Data will be gathered by a combination of personal interviews at the marinas and supplemented by questionnaires. The results will provide base-line information on the behavioral pattern of the recreational demanders prior to the introduction of the thermal power plants with their air pollution potential and the development of wide-spread recreational congestion on the Lake itself.

Changes in the behavioral pattern of the recreational demanders can be detected by comparing their behavior during the base-line period with their subsequent behavior following the introduction of thermal power plants in the Lake area and the increased congestion on the Lake. Additionally, should certain areas of the Lake such as the Hall's Crossing area remain essentially unaffected by power plants or congestion then these areas may serve as natural control areas for future comparisons. The impact of tourism on the Navajos will be assessed by the Anthropology subproject.

Power and Irrigated Agriculture

A number of studies relating to power production and irrigated agriculture in the Lake Powell region have been conducted in recent years. The factors determining supply and demand for power and irrigated agricultural activities will be developed primarily from these sources (3, 14). The levels of irrigated agriculture and power production determined from these sources will then be introduced into the economic welfare relationships along with the recreation levels.

Relationships

There are interrelationships between the economic component and other subprojects both with respect to conceptual functional linkages, e.g., morbidity in the epidemiology study is clearly a function of the income level of the population considered; and with respect to data-gathering operations, e.g., the terrestrial ecology study will provide information on campsite availability for the economics study. In addition to these two relationships, other prominent connections include pollution aspects of the air quality project and the cultural impact of changing income levels as part of the anthropological study. The Anthropology subproject will provide the essential data at the micro-level on income and employment and their determinants for those Indian communities which are included in the scope of the anthropological study.

Personnel

The economic study can be divided into two types of activities: (1) field work and (2) data analysis. Under field work the tasks include the construction of the recreation samples and the actual field interviews and data gathering from secondary sources such as the Park Service and the power consortium. These tasks will be directed by F. Lee Brown who will spend 100% of his time during the summer field seasons working with graduate assistants. The second type of activity will involve the analysis of information obtained during the field seasons and the estimation of the economic relationships to be used in the general system. In this task F. Lee Brown will be assisted by Shaul Ben-David.

F. L. Brown combines economic experience, also in the area of water resources research, with an extensive mathematical and economic background in the estimation and testing of econometric models. He holds advanced degrees in Mathematics and Econometric Statistics combined with sampling theory. S. Ben-David has dealt extensively with large-scale public water projects under contracts with various federal and state agencies. Nathaniel Wollman, an economist with long established credentials in the are of Natural Resources Economics, will serve as a consultant to the Economics subproject.

REFERENCES

[1] Ad Hoc Water Resources Council, Evaluation Standards for Primary Outdoor Recreation Benefits, Supplement No. 1 to Senate Doc. 97, June 4, 1964.

[2] Ben-David, S., et al., "Reexamination of the Value of Glen Canyon Dam Under the Proposed Water Resources Council Guidelines," University of New Mexico Working Papers Series, 1971.

[3] Center for Business and Economic Research, Brigham Young University, Four Corners Regional Commission Development Plan (draft), Provo, Utah, October 1971.

[4] Clawson, M., Methods of Measuring the Demand for and Value of Outdoor Recreation, Reprint 10 (Washington: Resources for the Future, Inc., 1959).

[5] Clawson, M., and J.S. Knetsch, Economics of Outdoor Recreation (Baltimore: The Johns Hopkins Press), 1966.

[6] Crane, D.A., "A Discussion of Estimating Water Oriented Recreation Use and Benefits," Paper presented at the Ninth Annual Environmental and Water Resources Engineering Conference, Vanderbilt University, June 1970.

[7] Eckstein, O., Water Resource Development: The Economics of Project Evaluation (Cambridge: Harvard University Press), 1958.

[8] Hasting, V.S., "Quality of the Recreation Experience - Estimation of Its Benefits," in Estimation of First Round and Selected Subsequent Income Effects of Water Resource Investment, Institute for Water Resources Report 70-1, Dept. of the Army, Corps of Engineers, Feb. 1970, pp. 10-28.

[9] Isard, W., "Regional and Interregional Input-Output Analysis: A Model of a Space Economy," Review of Economics and Statistics, Nov. 1951.

[10] Kalter, R.J., et al., Federal Evaluation of Resource Investments: A Case Study, Tech. Report No. 24, Cornell University Water Resources and Marine Sciences Center (Ithaca, N.Y.: February 1970).

[11] Kalter, R.J., and L.E. Gosse, Outdoor Recreation: Projection for 1970-1985 (Ithaca, N.Y.: Cornell University Special Series No. 5, 1969).

[12] Kalter, R.J. and L.E. Gosse, "Recreation Demand Functions and the Identification Problem," J. Leisure Research, Vol. 2, No. 1, Winter 1970, pp. 43-53.

[13] Knetsch, J.L., and R.K. Davis, "Comparison of Methods for Recreation Evaluation," in Kneese, A.V. and S.C. Smith (eds.) Water Research (Baltimore: Johns Hopkins Press, 1966) pp. 125-142.

[14] Lansford, R.R., W.P. Gotsch, J. McArthur, and W. Waneka, "Water Resources in the Four Corners Economic Development Region," in Four Corners Agriculture and Forestry Development Study, Special Report No. 2, New Mexico State University Agricultural Experiment Station, May 1971.

[15] Leven, C., ed., Development Benefits of Water Resources Investments, Corps of Engineers, Institute for Water Resources, 1970.

[16] Mishan, E.J., "A Survey of Welfare Economics, 1939-1959," The Economic Journal, Vol. 70, No. 278, 1960, pp. 197-256.

[17] Rugg, R., "Demands of Multiple-Purpose Travellers and Route Diverters for Reservoir Recreation," in Estimation of First Round and Selected Subsequent Income Effects of Water Resources Investment, Institute for Water Resources Report 70-1, Dept. of the Army, Corps of Engineers, February 1970., pp. 29-60.

[18] Subcommittee on Evaluation Standards, "Proposed Practices for Economic Analysis of River Basin Projects," Report to the Inter-Agency Committee on Water Resources, revised May 1958.

[19] U.S. Congress, Policies, Standards and Procedures in the Formulation, Evaluation and Review of Plans for Use and Development of Water and Related Land Resources, Senate Document 97, 87th Congress, 2nd Session, approved May 29, 1962.

[20] U.S. Dept. of the Interior, Bureau of Reclamation, Colorado River Storage Project and Participating Projects, Upper Colorado River Basin, Project Planning Report No. 4-8a.81-1, December 1950.

[21] U.S. Dept of the Interior, Bureau of Reclamation, Environmental Statement Draft - Navajo Project, National Technical Information Service, Springfield, Va., September 1971.

[22] U.S. Water Resources Council, Principles for Planning Water and Land Resources, Report by a Special Task Force (Washington) July 1970.

[23] U.S. Water Resources Council, Standards for Planning Water and Land Resources, Report by a Special Task Force (Washington) July 1970.

[24] U.S. Water Resources Council, A Summary Analysis of Nineteen Tests of Proposed Evaluation Procedures on Selected Water and Land Resource Projects, Report by a Special Task Force (Washington) July 1970.

[25] Wantrup, S.V., Resource Conservation Economics and Policies (University of California Press, 1952).

Subproject Number 14

Epidemiology

A Base-line Survey of the Distribution of Respiratory and Other Disease Categories in the Lake Powell Region

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF

MAN'S ACTIVITIES IN THE LAKE POWELL REGION

Amount Requested $27,596 Proposed Duration 2 years

Requested Starting Date May 15, 1972

Principal Investigator: Stephen J. Kunitz
Social Security # : 103-30-6673
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Preventive Medicine & Community Health and Sociology	Preventive Medicine & Community Health	Research and Project Administration
February 8, 1972	February 8, 1972	February 9, 1972

INTRODUCTION

The creation of Lake Powell and its attendant developments is but one example, albeit a massive one, of the changes that are occurring in the Southwest as American Indians are increasingly influenced by developments in the larger society and as non-Indians in increasing numbers move into areas previously uninhabited. The changes being wrought by developments such as increasing industrialization, recreation, shifting populations, and so on, are not well understood in this region. This is as true for those interested in problems of health and disease as it is for those interested in social organization, economics, atmospheric sciences, and limnology, and makes planning for the future more difficult than it needs to be. All over the reservation and in adjacent areas disease patterns seem to be changing; as some problems decline in importance, others increase. For instance, the infant death rate seems to have declined over the past decade for Indians in this region as well throughout the nation. Concurrently, new problems will emerge, such as chronic diseases and accidents, whose magnitude we cannot predict and for which it thus becomes difficult to plan appropriately. It is the purpose of the epidemiology component of the Lake Powell Project to gather comparative and base-line data from facilities in northern Arizona and northwestern New Mexico that will allow for some predictions to be made as to the likely course of events in the Lake Powell region and to then follow trends over time to monitor such changes as will take place and thus, refine whatever predictions are made on the basis of comparative studies.

Background

Epidemiology as a discipline represents an interface between the social sciences on the one hand and natural sciences on the other. Disease may be seen as an outcome of the interplay of a variety of different factors, social and environmental; as circumstances change, disease patterns change. Thus, incidence and prevalence studies of a variety of disease may be one useful indicator of change (Moriyama, 1968; Bryant, 1969). The change in our own century, for instance, from acute infectious disease to chronic diseases is a reflection of major changes in standard of living (as well as medical advances) in Western nations.

In our own nation, American Indians are still subjected to those diseases that are characteristic of poverty-stricken, non-industrial societies throughout the world, with some unique features, of course. Average age at time of death has increased among American Indians over the past several decades,

and this is primarily a reflection of decreasing mortality rates in the youngest age groups (Hill, 1970). Among Indians in 1964, accidents of all types were the single leading cause of death (18.8% of all deaths). In the general population, accidents accounted for only 5.8% of all deaths. Diseases of the heart and vascular lesions of the central nervous system were far and away major causes of death in the non-Indian population, along with neoplasms. Indians died proportionately less often from these diseases and more often from infectious diseases (USPHS, 1966;17). One might well expect on the basis of work already done among Indians and elsewhere that the patterns of disease usually discovered in the past will change with increasing rapidity in coming years. It is also likely that such changes will occur differentially on different parts of the Navajo Reservation as economic, social, and environmental changes take place.

Indeed, it is clear from previous studies that there are differences in disease distribution on different parts of the reservation. Van Duzen, et.al. (1969) have suggested that malnutrition is less common on the eastern side of the reservation than the western side because of better economic conditions in the former area. Kunitz, et.al. (1969, 1971) found alcoholic cirrhosis distributed unevenly on the reservation depending on access to border towns and presumed level of white contact.

The importance of comparing areas of the reservation is that one needs to gather data from areas that can act as controls for the specific region under consideration. For instance, as we pointed out above, changes are occurring all over the reservation, and it is important to be able to sort out those that are specific to a region and, presumably, related to specific features there, such as power plant construction and respiratory disease, and those that are non-specific and found over many different areas, such as, perhaps, infant mortality rates. For our purposes, the reservation has already been divided into regions which are useful units with which to at least begin an analysis. The Indian Health Service has divided the Navajo Reservation into a number of service units, each with either a hospital or field clinic. Though people do use facilities other than those within the area where they live, it is possible to characterize patients on the basis of the service unit where they live (this will be described in more detail under Methods). The advantage of using service units as beginning units of analysis is that something is known of their populations in terms of size and predominant mode of life, (Kunitz, et.al. 1969).

Specific Aims

It is our goal to collect data from Indian Health Service and other medical facilities serving the Navajo Reservation and selected border towns in order to:

1. gather data by which comparisons can be made between different areas on the Reservation in order to project what changing disease patterns may develop in areas undergoing marked change, especially the Lake Powell region.

2. establish base-line data for the Lake Powell region by which to assess changing health status over time.

3. attempt a comparison between two non-Indian, off-reservation communities (Page, Arizona and Farmington, New Mexico) in order to assess the impact on patterns of respiratory disease in the non-Indian population of the introduction of coal-fired electrical generating plants.

Methods

The disease categories in which we are particularly interested are respiratory diseases, malnutrition and certain diseases of early infancy, and accidents. As we review hospital and clinic records, other problems may emerge as worthy of investigation, but these are the ones in which we at present are most interested. We will discuss them in more detail after describing the procedures for gathering data.

Epidemiological studies may be carried out in a variety of ways, depending on resources, the problem to be studied, and so on. Mortality studies are most commonly done by reviewing death certificates and correlating demographic variables with diagnostic categories. The pitfalls of such a study primarily involve the accuracy and comparability of diagnoses from one physician or osteopath or justice of the peace to another. Though these problems are indeed serious, many valuable studies of changing death patterns have been carried out, and we ourselves have used such data for preliminary studies of mortality from respiratory disease in the Southwest (to be described in more detail below).

In small populations mortality studies may not provide large enough numbers to be meaningful. Instead morbidity studies may be more adequate and preferred for a number of reasons. As Ipsen has pointed out in regard to studies of respiratory disease, morbidity studies may be more attractive than mortality studies:

> First because frequencies per population is higher and secondly, because disease would be expected to react to more environmental changes and in a manner that might

be diagnostically specific. However, the sources of morbidity data are scarce, lack uniformity and are highly circumstantial. Among sources are: (A) number of visits to out-patient clinics, by cause, (B) absenteeism in working populations, by specific cause, (C) self registration of symptom severity, for certain allergies and bronchial asthma, (D) regular home visits to a selected population group. (Ipsen, 1969; 139).

Of the methods of gathering morbidity data mentioned above, B,C and D are either inappropriate (B), impractical (C), or so expensive as to outweigh their usefulness at this early stage of the work (D), though it is recognized that at a later stage such procedures may turn out to be both appropriate and valuable. We are left with (A), reviewing medical records, as the method of choice for a number of reasons:

1. for Indians, medical care is provided free of charge in Indian Service Hospitals and clinics and thus there is no fee barrier to utilization.

2. the method of reporting is uniform from one facility to another;

3. the caliber and training of the physicians is about the same from one facility to another, and assignment is on what appears to be an almost random basis;

4. the use of these same kinds of records has been shown to be valuable in a variety of previous studies (Brown, et.al. 1970; Van Duzen, et.al. 1969; Kunitz, et.al.1969, 1971; Rubenstein, et.al.1969);

5. as a preliminary method of gathering information from a wide area, it is the only economical means available.

The records available for analysis which will probably provide the richest and best data are those from Indian Health Service hospitals and clinics. These data are available from July 1, 1970. Reasons of space necessitate that older records be discarded periodically. The Indian Health Service tabulates clinic visits by diagnostic category (ICDA code) and facility where the patient was seen. No demographic data are presented in these print-outs, which are done on a monthly basis. From these one can only get a rough idea of the magnitude of particular disease categories as they came to the attention of physicians in a number of hospitals and clinics. More detailed information is available on those patients admitted to the hospital. Upon discharge, a Clinical Record Brief (see appended sheet) is sent to the Navajo Area Office in Window Rock, Arizona. It is these sheets that are available from July

1, 1970. They contain a wealth of information, all of which can be easily coded and then tabulated while still assuring that there will be no invasion of privacy (by not recording name or social security number). In addition to diagnoses, age, sex, tribe, community of residence, length of hospitalization, and information on type and place of accident (when appropriate) are listed. These variable can all be analyzed in terms of area of residence, a procedure that has been usefully employed in the past (Levy, et.al.1969; Kunitz, et.al.1969, 1971), and one which will allow us to make a beginning assessment of different morbidity patterns on various part of the reservation, relating these to both social and environmental differences.

There are obvious pitfalls using this type of material. First, it cannot be assumed that hospital and clinic utilization is the same from one area to another. A considerable amount of work has been done with Navajos on the factors that influence hospital utilization (Levy, 1962a, 1962b; Adair and Deuschle, 1970). In general, young men tend to be under-represented in the hospital and clinic populations, as they are in other ethnic groups. Second, accessability of the facility is often a limiting factor when distances are long, roads poor, and transportation expensive. At the same time, however, there is no fee for service barrier to utilization as exists in other portions of the general U.S. population. Third, aside from giving some very gross information on disease distributions, the clinic records will not be of much value in telling anything about the people seen. Thus, we will only have detailed information on those people sick enough to be admitted to the hospital. In general, however, as care is free, those people who, in the judgement of the physician, are sick enough to require hospitalization usually get it. We will, therefore, be missing many minor, but epidemiologically important, illnesses and picking up only those serious enough for hospitalization. Despite these pitfalls, the hospital discharge data represents a rich source of information which can be obtained and analyzed very economically. It is therefore planned that we will do this in the summer of 1972.

While the Indian Health Service records are probably the best available, they are by no means the only records of where people seek care. Scattered on and around the reservation are many other hospitals which provide care to Indians and non-Indians alike. Some of these are local county hospitals, some are mission hospitals, and one is administered by Project HOPE. The record keeping systems in these different facilities vary from abysmal to excellent. In many instances it may be impossible to retrieve the data which would be comparable to that provided by the Indian Health Service. For very serious problems requiring long-term hospitalization, this does not

represent too much of a problem as such patients are transferred to Indian Health Service Hospitals. For more routine problems, however, patients may never be seen at an IHS facility. Even when their care has been paid for out of contract funds by the Indian Health Service, the record keeping system is such that it is not comparable to IHS records, nor sometimes is it even retrievable.

Nevertheless, because these facilities do provide so much service to Indians and non-Indians living in the study area, we will have to make an attempt to get permission to review the records that do exist. We are particularly interested in reviewing records from Page, Arizona and Farmington, New Mexico because Farmington has been influenced by the construction of coal-fired electrical generating plants in much the same way as Page may be influenced in 1974. Thus, we will be particularly interested in comparing the patterns of respiratory disease in the two areas.

The same pitfalls which apply to the use of IHS records also apply here, only more so. We don't know whether the medical care in the two areas is comparable, whether hospital beds are equally available, whether hospital costs are a barrier to utilization in one place and not another, and many other questions. To assess the comparability of whatever figures we might gather from the two areas, we will have to spend some time interviewing physicians, administrators and health officers in the two areas. We will plan to do this in the summers of 1972 and 1973.

As we pointed out above, the problems in which we are particularly interested are those related to: A. Respiratory disease; B. Malnutrition and certain diseases of infancy and childhood; and C. Accidents. In the following paragraphs, we will describe some of the work already done in these areas and the reasons for wanting to investigate them further.

A. Respiratory Disease: There has been a considerable amount of concern expressed over the presumed increase in morbidity and, presumably, mortality from respiratory disease in the Four Corners area as a result of the operation of coal-fired electrical generating plants beginning in 1965. Geer (1971) has documented an increase in hospital admissions for respiratory disease in the Durango, Colorado area from the period 1961-65 to 1966-70. Similar concern has been voiced over developments in the Lake Powell region, where the Navajo Generating Plant is due to begin operation in 1974 and where another plant is under consideration on Kaiparowitz Plateau.

There is no doubt that degradation of air quality is correlated with both increased mortality from respiratory disease

(Winkelstein, et.al.1967, 1968) as well as increased morbidity (Holland and Reid, 1965), although the precise mechanism is as yet not fully understood. In the summer of 1971, we reviewed all the death certificates from Coconino, Navajo, and Apache Counties, Arizona, and San Juan and McKinley Counties, New Mexico as a background for morbidity studies to be undertaken in 1972-74. The data were available from 1960-69 in Arizona and 1960-70 in New Mexico. Unfortunately, air quality data are not available uniformly from these regions. In addition, the relatively small size of the population as well as its scattered distribution make correlations between deaths from respiratory disease and air quality measures highly unreliable. Nonetheless, the patterns that emerged from a preliminary analysis revealed the effects of poverty and crowding more than the effects of degraded air quality. For instance, San Juan County, where the Four Corners Power Plant is located and where what data we have indicate poorer air quality than elsewhere, had lower rates of death from respiratory disease than did any other county. Indians in general had higher death rates (except for emphysema) than did other ethnic groups. Among non-Indians, those counties with the highest death rates were those with the highest percent of whites with Spanish surname (Spearman's r=.9). This is evidently related to economic status (Schmidt, 1970). Deaths among Indian children below the age of one year are decreasing in all areas so they are now only slightly higher than non-Indian death rates in the same counties. It should be pointed out that whereas San Juan County seems to have poorer air quality than the other four counties, it is also (according to preliminary 1970 census data) a wealthier county than the others. Thus, the effects of poor air quality may be more than offset by the effects of better economic conditions, at least for the present. Whether, and how, the balance will change in the future is an empirical question which we hope to be able to help answer.

Because of these somewhat unexpected findings, it is important to review the official mortality reporting system in these five counties to be sure that reporting artifacts and biases haven't distorted the picture. We will plan to do that in conjunction with the work described previously interviewing physicians, health officers, and administrators about hospital utilization.

With these mortality data as a background, we will plan to examine hospital admissions and clinic utilization patterns for the same ICDA codes using both IHS and other hospital data. It may well be, for instance, in the Shiprock-Farmington area that people get sick as often as or more than, people elsewhere but have a lower mortality rate because of their better housing conditions and, perhaps, better accessability to medical care. Whiel we recognize that the effects of chronic

low levels of air pollution may best be detected by doing field studies using pulmonary function tests (Ferris, 1969), such studies at this time are premature.

B. Malnutrition and certain disease of infancy and childhood: Previous work by Van Duzen, et.al. (1969) suggests that severe malnutrition (marasmus and kwashiorkor) occurs primarily on the western end of the Navajo Reservation although less severe forms are seen on the eastern end as well. They suggest further that this is due to the somewhat better economic circumstances of people living on the eastern end. Impressionistically, it appears that infant health and nutritional status have begun to improve rather markedly on the western end of the reservation in the past year or two. As both infant health in general and nutritional status in particular are rather good indicators of socio-economic status, we will want to look at this category to: a. see if patterns do indeed vary in a demonstrable fashion from one part of the reservation to another; b. establish base-lines for the northwestern part of the Reservation adjacent to Lake Powell to see if changes there over time are in any way related to the growth of economic activities; and c. if, as is likely, the morbidity and mortality experience of infants in the Lake Powell region do improve, is it more rapid improvement that is occurring in other areas of the reservation? Given the realtively small number of children, it may not be easy to demonstrate point c. even if it is true. At the same time, as the data can be gathered so cheaply and easily it is well worth making the effort as it would then be possible to say whether the effects of the developments around the lake had been the same as or more than developments on other parts of the reservation in terms of the health benefits accruing to the population.

C. Accidents: As we pointed out above, accidents are a major cause of death and disability among American Indians. Navajos are no exception (Brown, et al.1970). The major cause of accidents among Navajos is automobiles, the greatest number of deaths (48.2%) being a pedestrian hit by a motor vehicle. Navajos are probably more at risk for this type of accident because, compared to the rest of the population, they must do a great deal of driving. In addition, however, faulty vehicles, poor roads, and a great deal of drunkeness probably account for the high number. We will be interested especially to see if the incidence of accidents varies from one place on the reservation to another. Brown, et.al. did not describe this kind of pattern. However, we will only be able to analyze carefully people admitted to the hospital as a result of accidental injury, not those treated as out-patients and released, which was what Brown and his colleagues studied. We would expect that as settlement patterns and occupational structure change, the type of accident seen would change also.

We are particularly interested in examing number of days that people are hospitalized as a result of accidents (and also as a result of respiratory diseases). We pointed out previously that diseases could be seen as dependent variables, the results of numerous interacting forces both environmental and social. But diseases also are costly in their own right, and it may well be that we will be able to calculate how much disease costs, in terms of days in the hospital, from one part of the reservation to another. Beyond that, of course, is the attempt that some medical economists have made to measure that amount of income lost by people dying before they would have been expected to. This has been attempted with American Indians (Reinhard, et.al.1970) as well as with other populations.

Such calculations are difficult to do, and may have limited significance in a society where employment and income are very low. A more appropriate kind of measure may be some estimate of "social utility," such as life-years saved (Feldstein, 1970; Fanshel and Bush, 1970; Nat. R.M.P., in press). This in turn is dependent on the construction of life tables, which may be possible using 1970 census data, data from the National Health Survey (some of which was done on the Navajo Reservation), as well as data we collect ourselves (Johnston, 1966).

Users

We would expect that the Health Committee of the Navajo Tribal Council, the Indian Health Service, the Environmental Protection Agency and local and state health departments will have some interest in the results of the proposed epidemiology project, and efforts would be made to disseminate the results to all of them. We would also, of course, be available for personal and continuing discussions with all of them should they request them.

Relations with other components of the Lake Powell Project

It is clear that we will be working closely with economics and anthropology on the one hand as their results on changing settlement, job, and income patterns over time. We will also be concerned with the results of the atmospheric studies and will depend heavily for data and interpretations on Drs. Walther and Williams.

In addition, we will collaborate with the biological limnologists on a study of the fecal contamination of the lake. For details of that study, see the biology proposal.

CLINICAL RECORD BRIEF - IHS INPATIENT SERVICES

RECORD CODE 15

1. HISTORY NUMBER	2. SOCIAL SECURITY NO	10. CLASSIFICATION CODE	11. FACILITY NAME	12. FACILITY CODE
3. LAST NAME (Capitalized) FIRST, MIDDLE		13. AGE	14. RELIGION	15. HR. ADMITTED / 16. ADMISSION CODE
4. BIRTHDATE (Mo. Day Yr.) / 5. SEX / 6. TRIBE / 7. OPTIONAL		17. CLINICAL SERVICE ADMITTED TO	18. Clinical Serv Code	19. DATE ADMITTED (Mo., Day, Yr.)
8. COMMUNITY, COUNTY, STATE CODE				20. DISPOSITION DATE (Mo., Day, Yr.)
9. PRESENT ADDRESS		21. ADMITTING CLERK		22. NO. DAYS IN HOSPITAL

23. NEXT OF KIN — RELATIONSHIP — ADDRESS

24. PERSON TO NOTIFY (If not next of kin) — RELATIONSHIP — ADDRESS

25. ADDITIONAL INFORMATION - INCLUDE POSTAL ADDRESS IF NOT ABOVE.

26. ICDA DIAG. CODE	27. HOSP. ACQ. INFEC. OR ACCIDENT	28. ESTABLISHED DIAGNOSES (Including complications). USE STANDARD TERMINOLOGY ONLY. Show Reason for Admission as First Diagnosis
		(1)
		(2)
		(3)
		(4)
		(5)
		(6) (Continue on Reverse)

29. ICDA OPERATION CODE	30. FOR DIAG. (Enter (1), (2) or (3) from 28 above)	31. OPERATIVE AND SELECTED PROCEDURES	32. POST-OP INFECTION YES	NO	33. DATE
		(Continue on Reverse)			

34. DISPOSITION (Check one)

1. DISCHARGED	DIED WITHIN 48 HOURS	4 - WITH AUTOPSY
2. TRANSFERRED		5 - WITHOUT AUTOPSY
	DIED AFTER 48 HOURS	6 - WITH AUTOPSY
3. IRREGULAR DISCHARGE		7 - WITHOUT AUTOPSY

35. NAME OF FACILITY TRANSFERRED TO: — 36. FACILITY CODE

37. CLINICAL SERVICE DISCHARGED FROM — 38. CLINICAL SERV. CODE

39. CONSULTATIONS (Number)

40. DATE OF INJURY	41. ALLEGED CAUSE OF INJURY (Include hospital accidents)	42. ICDA E-CODE	43. PLACE OF INJURY	44. PLACE CODE

45. CAUSE OF DEATH (Immediate)	46. DUE TO	47. DUE TO (Underlying cause)	48. UNDERLYING CAUSE OF DEATH CODE

49. DATE	50. ATTENDING PHYSICIAN'S SIGNATURE	51. REVIEWED BY

HSM-441
REV 7-71

Consultants:

Robert L. Berg, M.D., Professor and Chairman, Department of Preventive Medicine and Community Health, University of Rochester School of Medicine, Rochester, New York.

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Taylor McKenzie, M.D., Service Unit Director, Indian Health Service Hospital, Shiprock, New Mexico.

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Warren Winkelstein, M.D., Professor of Epidemiology, University of California School of Public Health, Berkeley, California.

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
HEALTH SERVICES AND MENTAL HEALTH ADMINISTRATION

NAVAJO AREA
INDIAN HEALTH SERVICE
P. O. BOX G
WINDOW ROCK, ARIZONA 86515

January 14, 1972

Stephen J. Kunitz, M.D., Ph.D.
Assistant Professor of Preventive
Medicine & Community Health and
of Sociology
The University of Rochester
School of Medicine & Dentistry
Rochester, New York 14642

Dear Dr. Kunitz:

The Navajo Area Research & Publications Committee met on January 13, 1972 and discussed your research proposal.

We are pleased to grant approval of the project as outlined in your letter of December 20, 1971. If you plan to develop a formal protocol on the project, we would, of course, appreciate receiving copies for study.

We shall assume that, on completion of the project, you will seek clearance prior to any and all publications, as a courtesy to the Navajo people.

We wish to encourage you in your efforts in this needed line of endeavor.

Sincerely yours,

John E. Butts

John E. Butts, D.M.D., Chairman
Area Research & Publications Committee
Navajo Area Indian Health Service

JEB:pmb
cc: AR&P Committee Members

THE UNIVERSITY OF ROCHESTER
SCHOOL OF MEDICINE AND DENTISTRY
260 Crittenden Boulevard
Rochester, New York 14642

January 14, 1972

TO: Stephen J. Kunitz, M.D.

FROM: Clinical Investigation Committee
University of Rochester School of Medicine

RE: Research Proposal to National Science Foundation for work on Navajo Indian Reservation

This Committee has reviewed the information you submitted pertaining to the above application for evaluation of your judgment in determining (1) the rights and welfare of the individual(s) under investigation, (2) appropriate methods to secure informed consent, and (3) the risks and potential medical benefits of the investigation.

DECISION:

APPROVED

REMARKS:

Any modifications in the proposal as submitted to this Committee which involve major changes in the subjects of study, in the means for obtaining informed consent, or in risk to the subjects should be considered with your Departmental Chairman or his delegate (Division or Unit Head) to determine the necessity for reevaluation by this Committee.

A. J. Gillies

Dr. Alastair J. Gillies, Chairman
Dr. John M. Bennett
Dr. Robert G. Campbell
Dr. Jules Cohen
Dr. J. Raymond Hinshaw
Dr. Marshall Lichtman
Dr. Klaus J. Roghmann
Rev. Nathaniel T. Whitcomb

Original to Investigator for Office of Research Administration
Copy for Investigator
Copy for Clinical Investigation Committee File

REFERENCES

1. Adair, J. and K.W. Deuschle; 1970, The People's Health, New York: Appleton-Century-Crofts, Inc.

2. Brown, R.C., B.S. Gurunanjappa, R.J. Hawk, and D. Bitsuie; 1970, "The epidemiology of accidents among the Navajo Indians," Public Health Reports, 85; 881-888.

3. Bryant, J.H.; 1969, "The gap between biomedical technology and health needs in developing countries," in C. Nader and A.B. Zahlan, eds., Science and Technology in Developing Countries, New York: Cambridge University Press.

4. Fanshel, S. and J.W. Bush; 1970, "A health status index and its application to health-services outcomes," Operations Research, 18; 1021-1066.

5. Feldstein, M.D.; 1970, "Health sector planning in developing countries," Economica, May, pp. 139-163.

6. Ferris, B.G.; 1969, "Chronic low-level air pollution; use of general mortality and chronic disease morbidity and mortality to estimate effects," Enviornmental Research, 2; 79-87.

7. Geer, R.; 1971, Testimony before the Committee on Interior and Insular Affairs, United States Senate, 92 Congress; (Enviornmental Problems Associated with the Production of Electrical Power by Coal Fired Plants in the Four Corners Region of the Southwest U.S.). Hearings held in Durango, Colorado, 27, May.

8. Hill, C.A., Jr.; 1970, "Measures of longevity of American Indians," Public Health Reports, 85; 233-239.

9. Holland, W.W., and D.D. Reid; 1965, "The urban factor in chronic bronchitis," The Lancet, 27 February, pp. 445-448.

10. Ipsen, J.; 1969, "Episodic morbidity and mortality in relation to air pollution," Environmental Research, 2; 137-141.

11. Johnston, D.F.; 1966, An Analysis of Sources of Information on the Population of the Navaho, Bureau of American Ethnology, Bull. 197, Washington, D.C.: U.S. Government Printing Office.

11. Kunitz, S.J., J.E. Levy, and M.Everett; 1969, "Alcoholic cirrhosis among the Navaho," Quarterly Journal of Studies on Alcohol, 30; 672-685.

12. Kunitz, S.J., J.E. Levy, C.L. Odoroff, and J. Bollinger; 1971, "The epidemiology of alcoholic cirrhosis in two Southwestern Indian tribes," Quarterly Journal of Studies on Alcohol, 32; 706-720.

13. Levy, J.E., 1962a, "Some trends in Navajo health behavior," Ethnologist's report, U.S. Public Health Service, Division of Indian Health, ms. on file in Navajo Area Office, Window Rock, Arizona.

14. Levy, J.E.; 1962b, "The influence of social organization on behavioral response to a health activity," Ethnologist's report, U.S. Public Health Service, Division of Indian Health, ms. on file in Navajo Area Office, Window Rock, Arizona.

15. Levy, J.E., S.J. Kunitz, and M.Everett; 1969, "Navajo criminal homicide," Southwestern Journal of Anthropology, 25; 124-152.

16. Moriyama, I.M.; 1968, "Problems in the measurement of health status," in E.B. Sheldon and W.E. Moore, eds., Indicators of Social Change, New York: Russell Sage Foundation.

17. National Regional Medical Program; in press, Proceedings of National Regional Medical Program Conference and Workshop on Evaluation, Chicago, Ill., Sept. 28-30, 1970. Washington D.C.: U.S. Government Printing Office.

18. Reinhard, K.R., F.W. Felsman, and L.F. Moody; 1970, "Time loss and indirect economic costs caused by disease among Indians and Alaska Natives," Public Health Reports, 85; 397-411.

19. Rubenstein, A., J. Boyle, C.L. Odoroff, and S.J. Kunitz; 1969, "Effect of improved sanitary facilities on infant diarrhea in a Hopi village," Public Health Reports, 84; 1093-1097.

20. Schmidt, F.H.; 1970, Spanish surnamed American employment in the Southwest, Washington, D.C.: U.S. Government Printing Office.

21. U.S. Public Health Service; 1966, Indian Health Highlights, Washington, D.C.: U.S. Department of Health, Education, and Welfare, Public Health Service, Bureau of Medical Services, Division of Indian Health, Office of Program Planning and Evaluation, Program Analysis and Statistics Branch.

22. Van Duzen, J., J.P. Carter, J. Secondi, and C. Federspiel; 1969, "Protein and calorie malnutrition among pre-school Navajo Indian children," The American Journal of Clinical Nutrition, 22; 1362-1370.

23. Winkelstein, W., S. Kantor, E.W. Davis, C.S. Maneri, and W.E. Mosher; 1967, "The relationship of air pollution and economic status to total mortality and selected respiratory system mortality in men, I. Suspended particulates," Archives of Enviornmental Health, 14; 162-171.
1968,"II. Oxidesof sulfur," Archives of Enviornmental Health, 16; 401-405.

Subproject Number 15

Anthropology

AN ANALYSIS OF THE SOCIOECONOMIC IMPACT OF LAKE POWELL AND RELATED INDUSTRIAL DEVELOPMENTS ON THE NAVAJO INDIANS

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

Principal Investigator: Jerrold E. Levy
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Senior Investigator: Lynn A. Robbins
Senior Investigator: Roland M. Wagner

Department of Anthropology
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Tucson, Arizona

Endorsements

Principal Investigator	Department Head	Approving Administrative Official
Jerrold E. Levy Professor	Raymond H. Thompson Head, Department of Anthropology (602) 884-1304	Edward N. Wise Coordinator of Research

Ed. note: For comments on format see p. 370. (O.L.A.)

ABSTRACT

This is a proposal for a study of the social and economic impact of the creation of Lake Powell and its attendant power, mining, and tourist industries on the Navajo Indians of north-central Arizona.

The analyses will be conducted on three levels: the family level, local community level, and the tribal level. The investigators will proceed in the following manner:

(A) Family Level

During the first year a detailed micro-analysis of the social and economic status of Navajos in three areas will be conducted, as well as a similar analysis of white families in the Page community. Data collecting method will be by face-to-face formal interviews of family heads. Data-gathering at this level will be completed by the end of year one.

(B) The Local Community Level

A study of the local political institutions in the three Navajo study areas and the Anglo Page community by the use of informal interviews of (a) individuals in formal leadership positions such as Chapter officers and local delegates to the Navajo Tribal Council, city councilmen and mayor in Page; (b) individuals in informal leadership positions in these communities. This level of the investigation will concentrate on the analysis of the mediating position of the local institutions between the decision-making institutions at the Tribal and state level and the local populace, as well as a determination of the attitudes towards and the degree of understanding of the changes currently occurring in the Lake Powell area.

(C) Tribal Level

This level of investigation will concentrate on Tribal governing institutions and, using the methods of informal interviews and review of documents, will seek to determine the Tribe's perception of the implications of the Lake Powell impoundment and their role in future decision making processes as well as the manner in which the Tribe executes or makes known its decisions to the local communities in the impact area, and conducts planning aimed at effecting major social and economic change. This aspect of the research will be completed during year two.

At all three levels of analysis the research will attempt to examine the interaction between Whites and Navajos and the

feedback effect of this interaction upon the decision-making and planning activities of the Tribe.

The family-level socio-economic analysis in the White community will provide the economic proposal with a micro-study of the type of population whose economic changes that project will be studying at a more general level. The local community-level study of Page will provide a detailed description of the type of White community affected by state and federal decision-making as investigated by the law proposal.

The Tribal level of analysis will provide a study of a major decision-making institution at a level comparable to that of the surrounding states in a manner which will provide information to the law project in its wider study of the legal-institutional framework of the decisions pertaining to the Lake Powell area. Findings are considered to be important sources of information and guidelines by both the Tribe and the Bureau of Indian Affairs.

General Statement of the Problem

The Navajo reservation encompasses 25,000 square miles and extends into the Four Corners area of the states of Arizona, Utah, and New Mexico. Most of the reservation is arid, or semi-arid. A population of 120,000 lives widely scattered over this land engaged primarily in sheep-raising and in seasonal or temporary wage-labor off the reservation. In the far western portion of the area there are several small towns either close to the border or within commuting distance on weekends which afford a variety of employment. These towns include, principally, Page, Kanab, Fredonia, and Tuba City (the latter located on reservation land).

The northwestern portion of the Navajo reservation is generally regarded by Navajo specialists as one of the more traditional areas of the reservation. The land is arid, and the people rely heavily on stock-raising for a livelihood. Until as late as the 1950's there was but one main road extending from Tuba City eastwards across the Hopi mesas to connect the western parts of the reservation with the eastern capital of the tribal government at Window Rock. In 1960 this road became paved. It was not until 1962 that the road connecting Tuba City with Monument Valley became paved, and thus opened up the region along the eastern edge of the Kaibeto Plateau and the western portion of Black Mesa to extensive Anglo contacts. This area was so isolated that the ancestors of many Navajo families there today never did go to Fort Sumner.

Kit Carson's troopers did not penetrate very successfully into the convoluted canyons and arid terrain of the region.

Extensive involvement with the Anglo world did not take place for the Navajo people as a whole until World War II. Since these years Navajo reliance on wage labor has been continually growing. This trend holds true for the far western area as well. Coincident with this increasing emphasis on wage labor has been a progressive skyrocketing of the Navajo population and steady over-grazing of reservation land. The population surplus must of necessity seek employment off reservation; the land is not capable of supporting 120,000 people by livestock alone. The western region had some of the largest herds on the reservation as far back as records extending (Range Management Report, 1937), and our own data indicate that extremely large herds still exist in this area today (in one particular case, the herd tops 1000 head).

In 1957, several interrelated developments took place which ultimately had a tremendous impact on the Navajo people in this area. Construction began on Glen Canyon dam; unrelated Navajo families moved into the area to obtain employment, some of whom eventually stayed on as permanent residents; the city of Page grew up to house employees, and at the end of the project in 1966 an artificially impounded body of water, Lake Powell, existed along approximately 75 miles of their northern border. A new highway connected Page with Flagstaff, and the bridge across Glen Canyon afforded easy access to towns in Utah. In 1970 ground was broken for a new electrical generating plant directly east of Page. A railroad line was constructed across the Kaibeto Plateau to Black Mesa, where extensive coal deposits were being mined as a source of fuel for the operation of the plant.

Essentially, then, within a space of fifteen years one of the most isolated and traditional areas of the Navajo reservation has been exposed to intensive contacts with urban-industrial American society. At the same time the Tribe has emerged as an important decision-maker in all future developments in the Lake Powell area.

How have the Navajo people reacted to these developments? We are in a position to answer this question and to assess the impact of Anglo contact in a fairly controlled fashion in this region at the family and local community levels of analysis.

How is the Navajo Tribe affected by the impoundment of Lake Powell and related developments, economically and politically. And how will the Tribe be functioning within the larger framework of decision-making in this area. We

will be able to address ourselves to such questions at the tribal level of analysis as outlined in this posposal.

Research Methodology

(A) Family Level

Samples of households in three areas adjacent to Lake Powell and the Black Mesa strip mine will be selected for study.

1. Impact area 1. The Page-Lechee area. This is the primary impact area adjacent to Lake Powell and the Glen Canyon Dam. It is comprised of the city of Page and the Lechee Grazing District #3 on the Navajo Indian Reservation. The human population is comprised of the White and Navajo Indian residents of Page and of more pastorally-based Navajos who have been moving close to the town-site. A wide range of socio-economic adaptation is embraced by this heterogeneous population drawn to the area almost solely because of the creation of the lake. The households to be interviewed will include a random sample of 30 non-Indian families and all the estimated eighty Navajo households in Page and the Lechee area. This sample will yield baseline data for measuring social and economic change resulting from the impoundment of the lake.

2. Impact area 2. Black Mesa. The strip-mining operations at Black Mesa are having an effect through displacement of a number of Navajo families and the interjection of a foreign, non-Indian population as well as the opportunity for new jobs. Approximately 50 households immediately surrounding the strip-mining activities will be studied in order to establish a baseline for this kind of change.

3. Control Area - Kaibeto-Red Lake Community

This area lies between the two impact areas described above. Because there are no activities immediately related to the Lake or power production other than the laying of a narrow-gauge railway track from the mine to the Navajo Power Plant, this area will yield data which will distinguish the extent of socio-economic change already underway which is not due to the creation of Lake Powell. We wish to be able to make conclusions regarding the impact of Lake Powell as a change-producing event especially pertaining to the question of whether these changes are qualitatively different from the types of change occurring generally on the Navajo reservation. A typically extended kin group composed of 15 families will be studied. This group has been studied from 1959 to 1969 by Levy and Kunitz, and provides a study in depth of changing socio-economic adaptation of the western Navajo prior to the impoundment of the Lake.

For all the areas sampled, as well as for Page and the Navajo reservation generally, studies and statistics describing the pre-lake period will be utilized to establish a general baseline. Studies of Page have been done by Nancy Wagner and Willis Sibley and associates, Studies of the Black Mesa area have been conducted since the 1950's by David Aberle, and of other western Navajo communities by Shepardson, Levy, J. and R. Wagner.

Local Community Level

General interviewing and a review of statistics will be conducted in the above mentioned communities to obtain information concerning (a) general demographic and economic changes at the local level, (b) the extent of involvement of local political and other institutions in the process of planning for change, and (c) the nature of the perceptions and resulting reactions to change at this level.

Tribal Level

The investigation of the relationships between the governing institutions of the tribe and the local communities as well as external agencies (i.e. state and federal) will involve the following types of activities:

a) Informal interviews with present and past Navajo leaders and federal officials which will attempt to gather information necessary for an assessment of the understandings of these Navajos of the position of the Navajo Tribe in the general decision-making processes involving the Upper Colorado River Basin.

b) A review of tribal and, where appropriate, Bureau of Indian Affairs records pertaining to decision-making regarding the developments at Lake Powell and the Colorado River and the planning for the consequent social, economic, and political changes. The Navajo Tribe has expressed its interest and offered its cooperation in conducting this aspect of the study.

c) A review of extant federal and tribal statistics pertaining to the overall demographic and economic status of the Navajo Tribe. This information will not only provide an overall perspective for the present investigation, but will also provide the data for the economic and legal investigations.

In summation, our methodology will include both quantitative analyses of specifically selected samples as well as a descriptive handling of a variety of forms of pertinent information.

Procedures -- Year 1

(A) Family Level

One graduate student will be assigned to conduct interviews in each of the three areas sampled. These formal interviews will obtain the following types of information:

a) Household composition, age, education, and English ability of household head and spouse(s).

b) Plotting seasonal household residence shifts with the sheep herds, if this is still done.

c) Basic genealogical data to link together families in the sample.

d) Major contacts of families in the sample with any other community families in selected cooperation variables (sheep shearing, pooling herds, giving rides, loaning pickup, etc.).

e) Overall number of sheep and cattle owned by each family. Estimated contribution of stock to total family income.

f) The Navajo families will be asked additional questions on the following points: who is working in the household, how long employed, how many jobs in the past year, what kind, pay, location, and difficulties in finding employment.

This material will be coded in such a way that it is amenable to statistical analysis.

(B) Local Community Level

The interviews and review of statistical data at this level will be performed by two principal investigators during year one.

(C) Tribal Level

During year one the senior principal investigator will lay the groundwork for the proposed investigations for the Navajo Tribe by conducting conferences with the appropriate tribal and federal officials. A procedure for data gathering will be mutually agreed upon.

Procedures -- Year 2

(A) Family Level

The analysis of the community surveys will be conducted during the summer and fall of year two.

(B) Local Community Level

A preliminary analysis of the findings at the local community level will be undertaken during the fall of year two and the determination made as to whether further specific investigations have to be carried out at this level by the principal investigators.

(C) Tribal Level

The first nine months of year two will be devoted to the tribal level of investigation on a full-time basis by one graduate student and on a part-time basis by one of the principal investigators.

Analysis and interpretation of all stages of the research will begin December 1 of year two, leading to the final reports by the end of year two.

PERSONNEL

The principal investigators have had a broad range of acquaintance with the Navajo.

Dr. Jerrold Levy of the University of Arizona has had more than a decade of anthropological research among the Navajos throughout the impact area under consideration.

Roland M. Wagner, currently at the University of Santa Clara, did anthropological work in the area in the summers of 1966, 1968, and from December 1969 through November 1970. He is currently working on his Ph.D. dissertation based on the results of this research.

Dr. Lynn Robbins of Huxley College of Environmental Studies did fieldwork among the Navajos of the Chaco Canyon region in 1970 and has also had experience with the Blackfeet in Montana.

Dr. Joseph G. Jorgensen of the University of Michigan will serve as one consultant to the project. He has had field experience with the Shoshone and Ute and will serve as an advisor on methodology and general theoretical orientation.

Another consultant will be Dr. Leroy Johnson of the University of Oregon. Dr. Johnson has had broad experience with quantitative techniques and problems involved in anthropological fieldwork. He will be our principal statistical and methodological consultant.

Dr. Robert Euler, Prescott College, will serve as consultant to the project concerning the investigation on Black Mesa. Dr. Euler has conducted archaeological and anthropological studies of the Black Mesa area since the initiation of mining activities.

Dr. Ross Tocher, University of Michigan, has kindly offered his consultant services gratis both to the project and to the graduate student working in Page, Dr. Tocher's expertise is in the area of natural resource management.

Four graduate students will be selected from a broad range of graduate departments for their skills in anthropology, economics, and political science.

It will be necessary to use interpreters in doing the interviewing. We will hire three Navajos full-time to do this work.

Ed. note: This typed version of the anthropology component could not be adequately edited because the final typescript was not received on schedule due to faulty mail service. The staff was obliged to do its best with handwritten instructions on arrangement of paragraphs from previous versions. If a new version of this component, typed in the format of this proposal,is received from the Principal Investigator, it will be forwarded to NSF for distribution to the reviewers.
Also, the bibliography has not been received at this time and therefore could not be included. (O.L.A.)

BIBLIOGRAPHY

Aberle, David F.

1961 "Navaho", in Matrilineal Kinship, David M. Schneider and Kathleen Gough, eds. Berkeley and Los Angeles: Univ. of California Press.

1963 Some Sources of Flexibility in Navaho Social Organization. Southwestern Journal of Anthropology, 19:1-18.

1966 The Peyote Religion Among the Navaho. Chicago: Aldine.

Aberle, David F., and Omer C. Stewart

1957 Navaho and Ute Peyotism: A chronological and distribution study. University of Colorado Studies, Series in Anthropology no. 6. Boulder: University of Colorado Press.

Adair, John

1944 The Navajo and Pueblo Silversmiths. Norman: University of Oklahoma Press.

Adams, William Y.

1963 Shonto: A Study of the Role of the Trader in a Modern Navaho Community. Bureau of American Ethnology, Bulletin 188. Washington, D.C.: U.S. Government Printing Office.

Bailey, Flora L.

1950 Some sex beliefs and practices in a Navaho community, with comparative material from other Navaho areas. Reports of the Ramah Project, no. 2. Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University, vol. 40, no. 2. Cambridge, Mass.: Peabody Museum.

Bellah, Robert N.

1952 Apache Kinship Systems. Cambridge, Mass.: Harvard University Press.

Carr, Malcolm, Katherine Spencer, and Doriane Woolley

1939 Navaho clans and marriage at Pueblo Alto. American Anthropologist, 41:245-257.

Collier, Malcolm Carr

1946 Leadership at Navaho Mountain and Klagetoh. American Anthropologist, 48:137-138.

1951 Local organization among the Navaho. (unpublished ms.).

Downs, James F.

1964 Animal Husbandry in Navajo Society and Culture. University of California Publications in Anthropology, Vol. 1 Berkeley: Univ. of California Press.

Dyk, Walter
1938 Son of Old Man Hat, a Navajo Autobiography. Recorded by Walter Dyk. New York: Harcourt, Brace and Co.

1947 A Navaho Autobiography. Viking Fund Publications in Anthropology, no. 8.

Franciscan Fathers
1910 An Ethnologic Dictionary of the Navaho Language. St. Michaels, Ariz.: The Franciscan Fathers.

Goldfrank, Esther S.
1945 Irrigation agriculture and Navaho community leadership: case material on environment and culture. American Anthropologist, 47:262-277.

1946 More on irrigation agriculture and Navaho community leadership. American Anthropologist, 48:473-476.

Goodwin, Grenville
1942 The Social Organization of the Western Apache. Chicago: University of Chicago Press.

Haile, Berard (Fr. Berard)
1954 Property concepts of the Navaho Indians. The Catholic University of America Anthropological Series, no. 17. Washington, D.C.: The Catholic University of America Press.

Hill, W.W.
1936 Navaho warfare. Yale University Publications in Anthropology, 5.

1938 The agricultural and hunting methods of the Navaho Indians. Yale University Publications in Anthropology, 18.

1940a. Some Navaho culture changes during two centuries (with a translation of the early eighteenth-century Rabal manuscript). Essays in historical anthropology of North America published in honor of John R. Swanton. Smithsonian Miscellaneous Collections, 100:395-416.

1940b. Some aspects of Navaho political structure. Plateau, 13:23-28.

Hoijer, Harry
1938 The Southern Athapaskan languages. American Anthropologist, 40:75-87.

1956 The chronology of the Athapaskan languages. International Journal of American Linguistics, 22:219-232.

Kaut, Charles R.
1957 The Western Apache clan system: its origins and development. University of New Mexico Publications in Anthropology, no. 9. Albuquerque: University of New Mexico Press.

Kimball, Solon T.
1950 Future problems in Navajo administration. Human Organization, 9:21-24.

Kimball, Solon T., and John H. Provinse
1942 Navajo social organization in land use planning. Applied Anthropology, 1:18-30.

Kluckhohn, Clyde
1939 Some personal and social aspects of Navaho ceremonial practice. The Harvard Theological Review, 32:57-81.

1944 Navaho witchcraft. Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University, vol. 22, no. 2. Cambridge, Mass.: Peabody Museum.

1945 A Navaho personal document with a brief Paretian analysis. Southwestern Journal of Anthropology, 1:260-281.

1956 Aspects of the demographic history of a small population. In: Estudios Antropologicos, Publicados en Homenaje al Doctor Manuel Gamio. Mexico, D.F.: Direccion General de Publicaciones.

Kluckhohn, Clyde, and Dorothea Leighton
1946 The Navaho. Cambridge, Mass.: Harvard University Press.

Ladd, John
1957 The Structure of a Moral Code. Cambridge: Harvard University Press.

Leighton, Dorothea, and Clyde Kluckhohn
1947 Children of the People. Cambridge, Mass.: Harvard University Press.

Leighton, Alexander
1949 Gregorio, the hand-trembler: a psychobiological personality study of a Navaho Indian. Reports of the Ramah Project. Report No. 1. Papers of the Peabody Museum of American ARchaeology and Ethnology, Harvard University, vol. 40, no. 1. Cambridge, Mass.: Peabody Museum.

Levy, Jerrold E.
1962 Community organizaiton of the Western Navajo. American Anthropologist: 64:781-801.

1965 Navajo Suicide. Human Organization: 24:308-318.

1969 (with S.J. Kunitz and M. Everett) Navajo Criminal Homicide. Southwestern Journal of Anthropology: 25:124-152.

1971 (with S.J. Kunitz) Indian Reservations, Anomie and Social Pathologies. Southwestern Journal of Anthropology: 27:97-128.

The Navaho Yearbook
1954 The Navajo Yearbook of Planning in Action. Report No. 4, Compiled by Robert W. Young. Pub. 1955. Window Rock, Arizona: Navajo Agency.

1957 The Navajo Yearbook. Report No. 6. Compiled and Edited, with articles by Robert W. Young. Pub. 1957. Window Rock, Arizona: Navajo Agency.

1958 (same as above), Report No. 7, Pub. 1958.

1961 (same as above), Report No. 8, Pub. 1961

Rapoport, RobertN.
1954 Changing Navaho religious values: a study of Christian missions to the Rimrock Navahos. Reports of the Rimrock Project Values Series, no. 2. Papers of teh Peabody Museum of American Archaeology and Ethnology, Harvard University, vol. 41, no. 2. Cambridge, Mass.:Peabody Museum.

Riechard, Gladys
1928 Social life of the Navaho Indians, with some attention to minor ceremonies. Columbia University Contributions to Anthropology 7.

1939 Dezba:Woman of the Desert. New York:J.J. Augustin.

Roessel, Robert A., Jr.
1951 Sheep in Navaho culture. M.A. thesis, Washington University, Department of Sociology and Anthropology. (Mimeo.).

Shepardson, Mary and Blodwen Hammond
1970 The Navajo Mountain Community. Social organization and kinship terminology. Berkeley and L.A.: University of California Press.

Spuhler, James N., and Clyde Kluckhohn
1953 Inbreeding coefficients of the Ramah Navaho population. Human Biology, 25:295-317.

Underhill, Ruth
1956 The Navajos. Norman, Okla.: University of Oklahoma Press.

Van Valkenburgh, Richard
1936 Navaho common law. Museum Notes, Museum of Northern Arizona, 9:18-22.

Vogt, Evon Z.
1949 Navaho Veterans: a study of changing values. Reports of the Rimrock Project Values Series, no. 1. Papers of the Peabody Museum of American Archaeology and Ethnology, Harvard University, vol. 41, no. 1. Cambridge Mass.: Peabody Museum.

Subproject Number 16

Law and Political Science

THE LEGAL-INSTITUTIONAL ASPECTS OF THE IMPACT OF 20TH CENTURY MAN'S ACTIVITIES ON THE UPPER COLORADO RIVER BASIN

a component of

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

Amount Requested: $74,995 Proposed Duration: 2 Years

Requested Starting Date: May 15, 1972

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ABSTRACT

The management of the water resources of the Upper Colorado River Basin reflects a vector of political forces and mix of social values which have become institutionalized through a long series of court decisions, statutes, compacts and administrative actions. Water allocation policies and priorities affecting the economic development, the Upper Basin environment, and American Indian have been incorporated in both substantive and procedural laws. This sub-project will analyze those political forces and values and the laws and the lawmaking processes deriving from them:

1. To determine the relative extent to which policies promoting preservation of the environment and American Indian water rights were expressed, represented and protected in public decision-making for the period 1920-1972.
2. To analyze current legal and policy issues posed by Lake Powell and the five Upper Basin steam-power plants, and propose legal and political mechanisms to optimize the equitable representation of competing interests in future river basin developments, and to provide alternative institutional arrangements designed to achieve a given mix of social goals.

The disciplines of law and political science will be combined to conduct the investigation.

INTRODUCTION AND PURPOSE

Man's impact on the Upper Colorado River Basin cannot be understood apart from the legal and political institutions within which policy decisions have been made concerning the allocation and use of the Basin's water resources. Judicial, legislative and administrative decisions and the incentives provided by them to the general public, particular groups and public agencies continue to change the face of the Upper Basin.

Almost every scientifically measurable "impact" which the Lake Powell Project will investigate has its antecedent in one or more policy decisions made within a legal-institutional matrix. Yet it is unclear whether, and to what extent, the physical, biological, and social sciences informed and influenced the long series of policy decisions that created Lake Powell and related developments in the Upper Basin.

Any scientific study of the impact of past human decisions which seeks to provide base-line data for application to

society's needs, on the one hand, while neglecting to investigate the available and potential means by which that data can inform policy decisions, on the other, risks paraplegia. If, for example, political constraints have operated to limit the contribution of science to past policy-making, to the detriment of legitimate social values, those constraints must be identified and understood if science is to gain more relevancy in future decision-making. Moreover, any scientific effort must explore the range of public values and preferences as a means of identifying its goals toward which these policy-making processes may contribute.

The legal-institutional study herein proposed intends, first, to review critically how we made the decisions which have resulted in various impacts in the Upper Basin; second, to analyze the current legal and policy problems; and, finally, to propose improved legal and political mechanisms for intelligent and equitable river basin planning. The first objective would be achieved in year one, the second and third in year two.

OBJECTIVES

A. YEAR ONE: PUBLIC DECISION-MAKING IN THE EVOLUTION OF UPPER BASIN WATER DEVELOPMENT

I. Outline of Objectives

a. To prepare legal and political science bibliographies of published material relative to public decision-making underlying Upper Basin Water Resource Development, covering the period, 1920 to date;

b. To develop a legal-political model for evaluating public policy-making in river basin development as it relates to the distribution of economic benefits, environmental protection, and American Indian water rights;

c. To describe the structure, jurisdiction, legal authority and procedures of the principal decision-making institutions of the period;

d. To identify the principal legal and political decisions which determined the allocation of water resources in the Upper Basin during the period;

e. Recognizing the competing values involved, to analyze those decisions, and attendant procedures, to determine, *inter alia*:

1) How, and to what extent, the structure, constitution and procedures of the

decision-making body favored one or more competing interest

2) What competing interests were represented, and in what manner, before the decision-making body
3) What affected interests were not represented, and why not, before the decision-making body
4) What policies and legal precedents were invoked by the decision-making body in reaching its decision
5) Whether, and to what extent, those policies or precedents were development-oriented, environmentally-oriented or Indian-oriented
6) Whether, and to what extent, scientific data and evidence was presented to and considered by the decision-making body
7) How interests were compromised or denied protection in the decision-making process
8) What conflicts of interest were involved; how they were perceived; and how they were treated
9) Whether the decision-making body was aware of, and made provision for accomodations to, possible future changes in policies and priorities
10) The principal results of the decision-making, including new alignments of interest, new institutional arrangements, and new problems created
11) What changes in policies, precedents or priorities are reflected in the decisions covering the period

f. To determine and describe generally the critical factors in any failure of the legal and political institutions to protect environmental values and American Indian water rights during the period.

2. Discussion

Lake Powell and its environmental effects are descendants of forces set in motion during the 19th Century, when a law of prior possession and prior appropriation, aptly expressed by the maxim, "First in time, first in right," became universally accepted among the Basin states and territories. The early genesis of developmental priorities will be only summarized in the study. In-depth treatment will begin with a later historical period.

a. The Compact and Boulder Canyon Project. In the

first quarter of the 20th Century, the Upper Basin states, whose development of Colorado River water for irrigated agriculture lagged far behind that of California in the Lower Basin, feared the preemption of the Colorado River by these Lower Basin uses. An effort was undertaken to bind all of the basin states to an interstate compact that would allocate the water of the Colorado River between the Upper and Lower Basin states.

The apprehensions of Upper Basin states materialized while final compact negotiations were taking place in Santa Fe, New Mexico, in 1922. The United States Supreme Court unequivocally gave interstate effect to the prior appropriation doctrine in its ruling in Wyoming v. Colorado, 259 U.S. 419 (1922).

From the negotiations came the unratified Colorado River Compact. The compact did not take effect until after 1929. Article VII of the Compact recited: "Nothing in this compact shall be construed as affecting the obligations of the United States of America to Indian tribes."

Development priorities favoring the agricultural culture and developing urban centers of the white man obviously dominated these early decisions allocating water in the Basin. These decisions tended to be made in terms of the values of water for irrigation and power development. Other values may not have been regarded, such as the consequences of these decisions for environmental values and values peculiar to the American Indians in the area. American Indian water rights and Federal water rights, which were exercisable for the benefit of other interests, such as environmental protection, were also extant. Although those rights had a very low profile during the course of compact negotiations, their identification and analysis would be critical to any comprehensive study of how we got where we are in the Upper Basin.

1) Navigational Servitude. For all the activity of the Basin states and the accomodation of the federal government during this period, there existed the federal dominant servitude in the flow of a navigable stream, rooted in the Commerce Clause of the U.S. Constitution.

2) Non-Indian Reserved Water Rights. There also existed in a somnolent state in 1920 the right of the United States to unappropriated water flowing across reserved public lands, that is, federally-owned lands withdrawn from entry and settlement under the public land laws of the United States. This right went largely unarticulated until 1955, Federal Power Commission v. Oregon, 349 U.S. 435. Non-navigable streams necessary for recreational development and environmental

protection, among other things, could and do come within its reach. Given the vast acreage of the National Forest Reserve and the reserved land under the management of the Bureau of Land Management, the amount of water in the Basin which has been subject to this right is enormous.

3) Indian Reserved Water Rights. In the case of Winters v. United States, 207 U.S. 574 (1908), the U.S.Supreme Court ruled that the United States reserved water for the Indians of the Fort Belknap Reservation in the treaty of 1888 which created the Reservation: "The power of the Government to reserve the waters and exempt them from appropriation under the state laws is not denied, and could not be." Supra, at 577. The full import of this ruling and its rationale was not to be recognized in the Lower Basin until the 1963 decision in Arizona vs. California, discussed infra; nonetheless, it constituted legal precedent during the post-1921 period when major decisions were being made concerning the allocation and apportionment of the waters of the Colorado River.

b. Initial Upper Basin Development

1) Upper Colorado River Basin Compact. In October of 1948, representatives of the states of Wyoming, Utah, New Mexico, Colorado and Arizona executed the Upper Colorado River Basin Compact. Congress ratified the Compact on April 6, 1949 (63 Stat. 31). The Compact apportioned "in perpetuity" the Upper Division water. Arizona was apportioned 50,000 acre-feet per annum, with the balance divisible on the following percentages: Colorado, 51.75%; New Mexico, 11.25%; Utah, 23%; and Wyoming, 14%.

The Compact created the Upper Colorado River Commission. Specific attention will be paid to the structure of the Commission, the representation of interests on it, before it and the alternatives considered.

2) Colorado River Storage Project Act (1956). Congress, in order "to initiate the comprehensive development of the water resources of the Upper Colorado River Basin," enacted the CRSPA on April 11, 1956 (70 Stat. 105). It authorized the Secretary of the Interior to construct, operate and maintain dams, reservoirs and power plants for the following initial units: Curecanti, Flaming Gorge, Navajo and Glen Canyon. Lake Powell was thus authorized.

Considerable controversy surrounded the enactment of CRSPA. The legislative history was extensive and the political maneuvering complex. A comprehensive review of this legislative history will permit a political-legal analysis of how Lake Powell was born. It will reveal the extent to which

environmental consequences were foreseen and articulated and how the environmental factors in general fared in the face of other priorities.

c. 1963 Arizona v. California Decision and Reserved Rights.

1) Non-Indian Reserved Water Rights. The Supreme Court ruled in 1963, 373 U.S. 546, that, in the Boulder Canyon Project Act, Congress intended "to reserve water sufficient for the future requirements" of national forests, wildlife areas and recreational areas. Supra, at 51.

2) Indian Reserved Water Rights. In cases following Winters (1908), courts have struggled with the problem of reconciling the changing Indian need for water with the non-Indian need for a definite allocation to permit development of the off-reservation lands sharing the same watershed with the Indians. The Reserved Rights doctrine has been interpreted in distinct ways with important differences in implication. As enunciated in the Winters case, the doctrine stands for the proposition that, on making a treaty with the United States Government, the Indians themselves reserved for their own use sufficient water to make their reservations productive.

The second interpretation of the Reserved Rights doctrine arises from Arizona v. California, 373 U.S. 546 (1963), and holds that when the United States created the various Indian reservations, the United States reserved the necessary water from the adjacent rivers and streams for those reservations.

Regardless of which construction is placed upon the Reserved Rights doctrine, however, it is clear that Indian reservations--no matter how created--have the right to use sufficient water from included and adjacent streams and rivers to make those reservations productive, and that that right is superior to all subsequently-created state water rights.

What are the implications of the competing definitions of Winters rights? How have the definitions of rights affected federal policy and Indian economic institutional development in the Upper Basin?

d. Later Upper Basin Development. In addition to the hydroelectric production at Glen Canyon Dam, there was established a plan for a series of coal-burning, steam-generated power plants on the Upper Basin. The defeat of legislative proposals involving one or more additional dams on the lower Colorado River gave birth to a major steam power proposal advanced by a combine of 23 power companies and agencies,

dubbed Western Energy Supply and Transmission Associates (hereinafter, the WEST system). Of the six plants proposed, five are or will be operating in the Upper Basin: Four Corners (2,075 megawatts, already operating in the San Juan Valley near Fruitland, New Mexico); Navajo (2,310 megawatts, under construction at Page near Lake Powell); Kaiparowitz (5,000 megawatts ultimately, located across Lake Powell from Navajo); San Juan (330 megawatts ultimately, located a few miles north of Four Corners); and Huntington Canyon (430 megawatts, located approximately 30 miles southwest of Price, Utah).

Land, coal, water and air is being dedicated to these plants under the aegis of contracts, statutory law and administrative decisions. How did these contracts, laws and decisions come about? Were environmental and American Indian interests represented in the decision-making process?

d. National Environmental Policy Act (1969).

This federal legislation took effect on January 1, 1970, after the creation of Lake Powell and the construction of the Four Corners steam-power plant. It requires the submission of an "environmental impact statement" as a prior condition to project development. What effect has it had on other Upper Basin development?

B. YEAR TWO: CURRENT LEGAL AND POLICY ISSUES POSED BY UPPER BASIN WATER AND POWER DEVELOPMENT

1. Outline of Objectives

a. To define and analyze the current and impending legal and policy issues associated with Lake Powell, related development, and the steam-power plants, including the
   1) Legal and policy aspects of the growing bank storage of water in the Navajo sandstone;
   2) Legal and policy aspects of water and air pollution in the area;
   3) Legal and policy aspects of the non-Indian use of Navajo land and groundwater underlying American Indian land; and
   4) Legal and policy aspects of enviornmental impact statements made for the area.

b. To develop and propose legal and policital mechanisms to optimize the equitable representation of competing

interests in future river basin development within the context of variable assumptions about the mix of social goals sought by the nation, the region, and specific groups such as the American Indians.

2. Discussion

Given the present status of Upper Basin water and power development, what are the current legal issues which relate to the protection and improvement of the environment and of the interests of the American Indian? Year two of the study would identify and define those issues, and discuss the legal precedents and theories applicable to their resolution, and propose procedural guidelines for future decision-making.

The following are only some of the legal issues which warrant analysis. To whom belongs the growing bank storage of water resulting from the creation of Lake Powell? What effect is it having upon the Upper Basin's obligation to refrain from causing the flow of the River at Lee Ferry to fall below 75,000,000 acre-feet for any ten-consecutive-year period?

What legal controls are available or needed to combat present or expectant water pollution in Lake Powell?

What rights or claims do American Indians have in the River and its tributaries in the Upper Basin? Must these rights be satisfied within a Compact apportionment formulae, or can they be exercised apart from those formulae?

It has been estimated that American Indian claims to Colorado River, if perfected, could alter substantial water projects in the Upper and Lower Colorado Basin. For example, Congressman Wayne Aspinall indicated that the Congress would not appropriate funds for the vast Central Arizona Project unless the Navajos agreed to limit future rights to Colorado River water. In 1969, the Associate Solicitor for Indian Affairs urged the Navajo Tribal Council to limit their rights in part to no more than 50,000 acre feet per year of which 34,100 was to be used at a coal-fuel power plant at Page, Arizona. Subsequently, other incentives were offered to encourage tribal action, including the promise that the power plants involved would hire Navajo employees and that a $125,000 gift would be made to the Navajo Community College. What is the legal effect of the "waiver" of water rights entered into by the Navajos?

The five coal-burning power plants of the WEST system, previously described, raise numerous legal issues which would be studied in the second stage of the project. What legal controls are available or needed to prevent or abate the air pollution caused by the WEST power plants in the Upper Basin?

Are the contractual arrangements underlying these power developments flexible enough to accomodate changes found to be necessary for environmental protection? Are the legal institutions responsive enough to accomplish these changes? How are the rights of American Indians affected by these power developments? What substantive and procedural changes in the law are needed to promote environmental protection and the cultural integrity and aspirations of American Indians? To the extent that environmental and American Indian interests may conflict, how is that conflict to be resolved?

How is the National Environmental Policy Act operating in practice in the Upper Basin? The Lake Powell area provides excellent subject matter for a case study of the strengths and weaknesses of this recent federal legislation.

METHOD

The principal investigator, consultants and research assistants will employ recognized methods of legal and political science research in collecting and analyzing the following categories of data:

1. Judicial decisions;
2. Legislation;
3. Legislative histories (debates, reports, hearings);
4. Journal Articles;
5. Administrative rulings and executive orders;
6. Compacts and Compact Commission actions;
7. Contracts (water, mineral, power development, land use);
8. Texts and periodicals; and
9. Interviews of public officials (legislators and administrators) and knowledgeable informants.

The legal-institutional study project will proceed in a co-ordinated manner with the other components of the greater Lake Powell project, including Systems Analysis, in order to promote the maximum integration of base-line data.

PRODUCTS AND USERS

The legal-institutional study will produce the following results for the following users.

A. Products

1. A publishable legal and political science bibliography of source materials pertaining to public decision-making in river basin planning and development, in general, and the Upper Colorado River Basin, in particular;
2. A legal and political science model for

evaluating decision-making related to river basin planning and development;

3. An overall historical and analytical study of how water resources in the Upper Basin have been allocated by judicial decisions, interstate agreements, legislative enactments, administrative actions, and contractual arrangements, from 1920 to 1973;
4. Base-line data concerning how competing interests are and can be represented and recognized in public decision-making;
5. A case study of the relative role played by scientific inquiry and findings in the planning and development of a river basin;
6. A case study of the practical problems confronting the application and enforcement of the "environmental impact statement" procedure of the National Environmental Policy Act;
7. A proposal for new legal and political mechanisms to achieve the equitable representation of competing interests in river basin planning and development.

B. Users

1. Federal Government: Bureau of Reclamation; Army Corps of Engineers; Environmental Protection Agency; Federal Power Commission; Water Resources Council; Bureau of Indian Affairs; Office of Indian Water Rights, U.S. Department of the Interior; Congressional Committees.
2. State Governments and Regional Interests: Legislative committees and state planning organizations of Upper Basin states.
3. American Indians: Navajo and Hopi Tribes; national American Indian associations.
4. Universities and Research Centers.

BIBLIOGRAPHY

"Adjudication of Federal Reserved Water Rights," 42 U. Colo.L. Rev. 161 (August, 1970).

Air and Water News (1970 -).

Arizona v. California, 373 U.S. 546 (1963).

Bechtel Corporation. Status Report, Environmental Planning for the Navajo Generating Station (September, 1970).

Braybrooke, David, and Lindblom, Charles E. A Strategy of Decision: Policy Evaluation as a Social Process (New York: The Free Press, 1963).

Bureau of Reclamation, Draft of Environmental Statement, Huntington Canyon Generating Station and Transmission Line (March, 1971).

Bureau of Reclamation, Draft of Environmental Statement, Navajo Project (January, 1971).

Chambers, Reid Peyton. "Discharge of the Federal Trust Responsibility to Enforce Claims of Indian Tribes: Case Studies of Bureaucratic Conflict of Interest, "Subcomm. on Ad. Practice and Proc., Comm. on the Judiciary, 91st Cong., 2d Sess.

"Cold Facts on Hot Water: Legal Aspects of Thermal Pollution," Wis.L.Rev. 253 (1969).

Colorado River Basin Compact.

Colorado River Storage Project Act, April 11, 1956, 70 Stat. 105.

Colorado, Upper Colorado River Commission. Annual Reports and Official Records of Proceedings (1950 -).

Contract between Secretary of the Interior and Salt River Project, No. 14-06-400-5033, January 17, 1969.

Corker, "Water Rights and Federalism - The Western Water Rights Settlement Bill of 1957," 45 Calif. L. Rev. 604 (1957).

D'Amato, Anthony A. "Environmental Degradation and Legal Action," 26 Bulletin of the Atomic Scientists 24 (May, 1967).

Dellwo, R.D. "Indian Water Rights -- the Winter's Doctrine Updated," 6 Gonzaga L.Rev. 215 (Spring, 1971).

Dept. of the Interior, Bureau of Reclamation Project Feasibilities And Authorizations (Washington, 1957) 1046 p.

Dept. of the Interior. Federal Indian Law (U.S. Government Printing Office, 1958).

"Ecosystem as a Criterion for Public Land Policy," 10 Nat'l Res. J. 204 (April, 1970).

Edwards, "Legal Control of Thermal Pollution," 2 Nat Resources J 1 (1969).

Federal Water Pollution Control Administration, The Practice of Water Pollution Biology. Washington, D.C.: U.S. Government Printing Office. 1969. Paperback.

"Federal Water Rights Legislation and the Reserved Lands Controversy." 53 Georgetown L.J. 750 (1965).

Folz, William E. "The Economic Dynamics of River Basin Development," 22 Law & Contemp. Problems 205 (Spring, 1957).

Gindler & Holburt,"Water Salinity Problems: Approaches to Legal and Engineering Solutions," 9 Nat Resources J 329 (1969).

Hamill, Louis. "The Process of Making Good Decisions About the Use of the Environment of Man," 8 Nat'l Res. J. 279 (April 1968).

Hart, Henry. "Crisis, Community and Consent in Water Politics," 22 Law and Contemp. Problems 510 (Spring, 1957).

Hasler, "Man-Induced Eutrophication of Lakes," in Singer, ed., Global Effects of Environmental Pollution. New York: Springer-Verlag. 1970. Hardbound.

Herfindahl & Kneese, Quality of the Environment (Washington, D.C.: Resources for the Future, Inc. 1965).

Holden, Matthew, Jr. "Pollution Control as a Bargaining Process: An Essay on Regulatory Decision-Making" (Cornell Univ. Water Resources Center, 1966).

Ingram, Helen M. "Patterns of Politics in Water Resource Development: A Case Study of New Mexico's Role in the Colorado River Basin Bill" (Univ. of N. Mexico, 1969).

Kraenzel, Carl F. "The Social Consequences of River Basin Development," 22 Law & Contemp. Problems 221 (Spring, 1957).

Krier, James. "The Pollution Problem and Legal Institutions: A Conceptual Overview," 18 U.C.L.A. Law Rev. 429 (1971).

Mann, Dean E. "Human Dimensions of the Atmosphere from the Perspective of a Political Scientist," chapter in report, Human Dimensions of the Atmosphere (Nat'l Science Foundation, 1968).

Mann, Dean E. "Political Implications of Migration to the Arid Regions of the United States," National Res. J. (April, 1969).

Mann, Dean E. "Proposals for Federal Control of Weather Modification Activities," chapter in Weather Modification and the Law (Oceana Publications, 1968).

Mann, Dean E. "The Political and Social Institutions of the Arid Region," chapter in Aridity and Man (Amer. Assn. for Advancement of Science, 1963).

Mann, Dean E. The Politics of Water in Arizona (U. of Arizona Press, 1963).

Marshall, Herbert. "Politics and Efficiency in Water Development," Water Research, ed. by Allen Kneese and Stephen Smith (Resources for the Future: John Hopkins Press, 1965).

Meyers and Tarlock. Legal and Economic Aspects of Environmental Protection (The Foundation Press, 1971).

Meyers, Charles J. "The Colorado River," 19 Stan.L.Rev. 1 (November, 1966).

Meyers and Tarlock. Water Resource Management (The Foundation Press, 1970).

Miller, "Indians, Water, and the Arid Western States - A Prelude to the Pelton Decision," 5 Utah L. Rev. 495 (1957).

Murphey, E.F. "Prolegomena to a Reform of Man's Behavior Toward Nature," 4 Ind. Legal F. 425 (Spring, 1971).

National Environmental Policy Act, 42 USC §§4321-4347 (1969).

Navajo Tribal Council. Resolutions: February 18, 1966; July 28, 1966; December 11, 1968; June 3, 1969; June 27, 1969.

Ohrenschall and Imhoff, "Water Law's Double Environment: How Water Law Doctrines Impede the Attainment of Environmental Enhancement Goals," 5 Land & Water L.Rev. 259 (1970).

Price, Monroe. Fettered Sovereignty, Cases and Materials on American Indian Legal Problems (Bobbs Merrill, ____).

Price, Monroe. Native American Law Manual (1970).

Public Land Law Review Commission. Final Report (U.S. Government Printing Office, 1970).

Sax, J.L. "Public Trust Doctrine in Natural Resource Law: Effective Judicial Intervention," 68 Mich. L. Rev. 473 (January, 1970).

Sentry Royalty Company and Navajo Tribe, Mining Lease Contract No. 14-20-0603-8580, February 1, 1964.

Sentry Royalty Company and Navajo Tribe, Mining Lease Contract No. 14-20-0603-9910, June 6, 1966.

Sondheim & Alexander, "Federal Indian Water Rights: A Retrogression to Quasi-Riparianism?" 34 So. Calif. L. Rev. 1 (1960).

Stinson, "Western Interstate Water Compacts," 45 Calif. L. Rev. 655 (1957).

Tippy, Roger. "Preservation Values In River Basin Planning," 8 Nat'l Res. J. 259 (April, 1968).

Treaty with the Navajo Indians (1868).

Trelease, Frank J. "A Model State Water Code for River Basin Development" 22 Law & Contemp. Problems 301 (Spring, 1957).

United States v. Ahtanum Irrigation District, 236 F. 321 (9th Cir., 1956).

United States v. Powers, 305 U.S. 527 (1939).

United States v. Walker River Irrigation District, 104 F.2d 334 (9th Cir. 1939).

Upper Colorado River Basin Compact, 63 Stat. 31.

Veeder, Federal Encroachment on Indian Water Rights and the Impairment of Reservation Development, printed in TOWARD ECONOMIC DEVELOPMENT FOR NATIVE AMERICAN COMMUNITIES: A COMPENDIUM OF PAPERS (Joint Economic Comm., Subcomm. on Economy in Government, 91st Cong., 1st Sess., 1969) Vol. 2, at p. 460.

Veeder, "The Pelton Decision: A Symbol - A Guaranty that the Development and Conservation of our Nation's Resources Will Keep Pace with our National Demands," 27 Montana L. Rev. 27 (1965).

Veeder, "Winters Doctrine Rights - Keystone of National Programs for Western Land and Water Conservation and Utilization," 26 Montana L. Rev. 149 (1965).

Warner, David. "Federal Reserved Water Rights and their Relationship to Appropriative Rights in the Western States," 15 Rocky Mt. Min. Law Instit. 399 (_____).

Water Resources Council, Western U.S. Water Plan, Plan for Study (Draft, February 5, 1971).

"Water Resources on the Public Lands -- PLLRC's Solution to the Reservation Doctrine," 6 Land & Water L. Rev. 89 (1970).

Weatherford, G.D. "Legal Aspects of Interregional Water Diversion," 15 U.C.L.A. Law Rev. 1299 (September, 1968).

Wengert, Norman. "The Politics of River Basin Development," 22 Law & Contemp. Problems 258 (Spring, 1957).

Western Agricultural Economics Research Council Committee on the Economics of Water Resources Development, "Upper Colorado River Development" (Denver, 1958), 116 p.

"Western Water and the Reservation Theory - The Need for a Water Rights Settlement Act," 26 Montana L. Rev. 199 (1965).

White, Gilbert F. "A Perspective of River Basin Development," 22 Law & Contemp. Problems 157 (Spring, 1957).

Wilbur and Ely. Hoover Dam Documents (U.S. Government Printing Office, 1948).

Wildavsky, Aaron. "The Political Economy of Efficiency: Cost Benefit Analysis, Systems Analysis, and Program Budgeting," Political Science and Public Policy, ed. by Austin Ranney (Chicago: Markham Pub. Co., 1968).

Winters v. United States, 207 U.S. 564 (1908).

represent too much of a problem as such patients are transferred to Indian Health Service Hospitals. For more routine problems, however, patients may never be seen at an IHS facility. Even when their care has been paid for out of contract funds by the Indian Health Service, the record keeping system is such that it is not comparable to IHS records, nor sometimes is it even retrievable.

Nevertheless, because these facilities do provide so much service to Indians and non-Indians living in the study area, we will have to make an attempt to get permission to review the records that do exist. We are particularly interested in reviewing records from Page, Arizona and Farmington, New Mexico because Farmington has been influenced by the construction of coal-fired electrical generating plants in much the same way as Page may be influenced in 1974. Thus, we will be particularly interested in comparing the patterns of respiratory disease in the two areas.

The same pitfalls which apply to the use of IHS records also apply here, only more so. We don't know whether the medical care in the two areas is comparable, whether hospital beds are equally available, whether hospital costs are a barrier to utilization in one place and not another, and many other questions. To assess the comparability of whatever figures we might gather from the two areas, we will have to spend some time interviewing physicians, administrators and health officers in the two areas. We will plan to do this in the summers of 1972 and 1973.

As we pointed out above, the problems in which we are particularly interested are those related to: A. Respiratory disease; B. Malnutrition and certain diseases of infancy and childhood; and C. Accidents. In the following paragraphs, we will describe some of the work already done in these areas and the reasons for wanting to investigate them further.

A. Respiratory Disease: There has been a considerable amount of concern expressed over the presumed increase in morbidity and, presumably, mortality from respiratory disease in the Four Corners area as a result of the operation of coal-fired electrical generating plants beginning in 1965. Geer (1971) has documented an increase in hospital admissions for respiratory disease in the Durango, Colorado area from the period 1961-65 to 1966-70. Similar concern has been voiced over developments in the Lake Powell region, where the Navajo Generating Plant is due to begin operation in 1974 and where another plant is under consideration on Kaiparowitz Plateau.

There is no doubt that degradation of air quality is correlated with both increased mortality from respiratory disease

CLINICAL RECORD BRIEF - IHS INPATIENT SERVICES

RECORD CODE 15

1. IHS USER NUMBER	2. SOCIAL SECURITY NO	10. CLASSIF. CODE	11. FACILITY NAME	12. FACILITY CO
3. LAST NAME (Capitalized) FIRST, MIDDLE		13. AGE	14. RELIGION	15. HR. ADMITTED / 16. ADMISSION CODE
4. BIRTHDATE (Mo. Day. Yr.) / 5. SEX / 6. TRIBE / 7. OPTIONAL		17. CLINICAL SERVICE ADMITTED TO	18. Clinical Serv Code	19. DATE ADMITTED (Mo., Day, Yr.)
8. COMMUNITY, COUNTY, STATE CODE				20. DISPOSITION DATE (Mo., Day, Yr.)
9. PRESENT ADDRESS		21. ADMITTING CLERK		22. NO. DAYS IN HOSPITAL

23. NEXT OF KIN RELATIONSHIP ADDRESS

24. PERSON TO NOTIFY (If not next of kin) RELATIONSHIP ADDRESS

25. ADDITIONAL INFORMATION - INCLUDE POSTAL ADDRESS IF NOT ABOVE.

26. ICDA DIAG. CO	27. HOSP. ACQ. INFEC. OR ACCIDENT	28. ESTABLISHED DIAGNOSES (Including complications). USE STANDARD TERMINOLOGY ONLY. Show Reason for Admission as First Diagnosis
		(1)
		(2)
		(3)
		(4)
		(5)
		(6) (Continue on Reverse)

29. ICDA OPERATION CODE	30. FOR DIAG. (Enter (1), (2) or (3) from 28 above)	31. OPERATIVE AND SELECTED PROCEDURES	32. POST-OP INFECTION YES	NO	33. DATE
		(Continue on Reverse)			

34. DISPOSITION (Check one)

1. DISCHARGED	DIED WITHIN 48 HOURS	4 - WITH AUTOPSY
		5 - WITHOUT AUTOPSY
2. TRANSFERRED	DIED AFTER 48 HOURS	6 - WITH AUTOPSY
3. IRREGULAR DISCHARGE		7 - WITHOUT AUTOPSY

35. NAME OF FACILITY TRANSFERRED TO: 36. FACILITY CODE

37. CLINICAL SERVICE DISCHARGED FROM 38. CLINICAL SERV. CODE

39. CONSULTATIONS (Number)

40. DATE OF INJURY	41. ALLEGED CAUSE OF INJURY (Include hospital accidents)	42. ICDA E-CODE	43. PLACE OF INJURY	44. PLACE CODE

45. CAUSE OF DEATH (Immediate)	46. DUE TO	47. DUE TO (Underlying cause)	48. UNDERLYING CAUSE OF DEATH CODE

49. DATE	50. ATTENDING PHYSICIAN'S SIGNATURE	51. REVIEWED BY

HSM 43-1
REV 7-71