SECOND PROGRESS REPORT

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

National Science Foundation - Research Applied to National Needs

CONTENTS

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March 15, 1973

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INTRODUCTION

In the 1972 proposal of the Lake Powell Research Project, specific tasks were outlined for the completion of the Project objectives. Progress toward completing these tasks has been made during the year 1972-1973. Achievements in the partial completion of the tasks are described below.

Due to the fact that the natural and physical science subprojects began research before the present year, reports of these subprojects are centered around problems concerning specific changes in management decisions. Subprojects in the social sciences began work in the summer of 1972, and are still largely concerned with assessing the impact of the creation of Lake Powell itself.

Additional discussion of research results is provided in the individual subproject reports which follow this section.

Progress Toward Completion of Project Tasks

Task 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.

The method chosen to project the amount of runoff of the Upper Colorado River Basin (UCRB) over time is tree-ring analysis. In order to pursue this method of predicting future runoff trends in the Basin, it was necessary first to demonstrate the capability of tree-ring data for estimation of long-term runoff in major runoff producing subregions of the UCRB. Progress to date is the demostration of this correlation for an area in the Uinta Mountains and the reconstruction of the annual runoff in that area for the past 225 years. This progress has resulted in increasing the level of confidence that runoff for the entire UCRB can be reconstructed during the work period 1973-1974 in which methods for predicting future runoff can be further established.

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

To accomplish this task, the equipment for refining the measurement of lake evaporation was purchased and installed following a plan jointly agreed upon with the Bureau of Reclamation and the Lake Powell Research Project (LPRP). The equipment is being calibrated on site. Data collection is to begin April 1, 1973.

The sites for drilling test holes for bank storage investigations have been selected and agreed upon jointly with the Bureau of Relamation. Drilling is scheduled to begin in the late spring of 1973, and the contract for drilling is being processed by the Bureau of Reclamation. A model has been constructed as a first approximation to describe the percolation of water into the reservoir banks. An estimate of the quantity of water to be expected in bank storage at full reservoir capacity has been obtained using this model.

Task 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.

Biological changes in Lake Powell are measured by developing indexes of eutrophication, using phytoplankton and zooplankton counts. Preliminary measurements have been made at a number of stations on the lake. The bulk of the data so far suggests that fecal coliform counts in Lake Powell are acceptable for recreational body contact with the water. Stations are being sampled monthly during the winter and weekly during the summer. In view of public interest in this topic, careful monitoring will be continued. Conclusions cannot be made until data for a full year have been collected.

A computer model of the chemistry of the lake has been completed and tested in the laboratory. This model provides values for the calcium carbonate saturation index. An additional computer program has been developed which evaluates the contribution of each tributary to the chemistry of the lake. The model will allow prediction of the effect on the lake of changes in water regime in the Colorado, Green and San Juan river basins; it will also be used to provide part of the data necessary for estimates of salt flux through Lake Powell and to isolate changes in water quality caused by the impoundment.

A layer of oxygen-deficient water develops during the summer at mid-depth within the lake. This oxygen minimum layer has important effects on the chemistry and biology of the lake at depth.

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

Fluctuation in lake level has attracted the attention of scientists working on the shoreline. Vegetation has been flooded, biomass increased, and waters enriched; as a consequence, some adverse effects have been observed, and predictions are available on the quality of campsites and swimming areas. Efforts are being made to determine the carrying capacity of shoreline areas for natural campsites and for recreational activities.

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

Baseline data for the concentration of heavy metals in the lake and in the natural food chain are being collected, in preparation for the assessment of the future impact of coal-fired electric power plants constructed in the vicinity of Lake Powell.

d. Effect of siltation upon lifetime.

During the past year, echo sounding profiles of the old channels of the San Juan and Colorado were made and cores of the sediments were obtained. As anticipated, most of the sediments are transported by the two major tributaries and deposited primarily in deltas near the upper ends of Lake Powell. Downstream distribution of these sediments is inhibited by underwater dams caused by slumping in areas of Chinle outcrop.

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

a. Effects on recreational availability.

The effect of the impoundment was the creation of 1500 miles of shoreline with several marinas and a variable number of campsites. Subsequent to the creation of the lake, the fluctuating water level has led to corresponding changes in the number and quality of campsites from year to year. In some cases, a fluctuation in the lake level has led to a decrease in the number and quality of usable campsites.

Coliform counts, increasing enrichment of the lake, the decomposition of submerged shoreline vegetation, and changing textural quality of campsites must all be assessed to predict the future effects on recreational availability.

b. Economic effects on the Indian Nations.

During the research year 1972-1973, efforts to assess the economic effects of the creation of Lake Powell on the Navajo Nation have concentrated on these effects within the local Navajo communities adjacent to the lake. New job opportunities have become available for Navajos at the Navajo Power Plant, the Peabody Coal Mine at Black Mesa, and in various business establishments in the town of Page. Earlier job opportunities were afforded by the construction of Glen Canyon Dam itself.

In addition to evaluation of the total number of new jobs available, attempts to assess the effect of new developments on local social organizations have been made. A tendency has been observed for a large number of skilled Navajo workers to migrate to the Lake Powell area to take advantage of job openings, with the result that the local community receives less benefits than it had anticipated. A considerable amount of job competition among Navajos has been created. These demographic shifts will have implications for the future composition of communities in the area. Assessment of the total benefit to the Navajo Tribe has not yet been completed by LPRP investigators.

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

A regional accounts system has been constructed in which the financial interactions of important economic sectors in the region (recreation, power production, irrigation) are linked with economic units outside the Lake Powell region. This system is being developed in order to estimate the effects of changes in water management policies on the economy of the region. The data from which the accounts model is being constructed are drawn to a large extent from the detailed expenditure and receipt records of the individual operating accounts in the area, such as the National Park Service and the Bureau of Reclamation.

Task 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.

Data have been collected from the Indian Health Service and from private and mission hospitals serving the Navajo people. The 1972-1973 research work has allowed the estimation of the reliability and completeness of the Indian Health Service data, although specific disease patterns have not yet been examined. Having determined the reliability of the data, investigators are now ready to proceed with substantive analysis.

The impact of the creation of Lake Powell is an example of the effect of modernization on a variety of populations in a previously isolated rural area. The impact includes effects on health, disease and fertility patterns, and demographic population changes.

b. Effects upon the social structure of Indian nations in the region.

All previous studies of Navajo social organization for the entire Reservation have been assessed. Special attention was paid to those studies conducted in the impact area in the years immediately prior to the creation of Lake Powell. These studies form the baseline against which changing social organization may be documented, as it is revealed by studies now in progress in the impact area.

The anticipated transition from an essentially kin-based social organization and a subsistence economy to the isolated nuclear family and wage work economy has already been observed in work so far accomplished.

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.

The baseline data already gathered for air contaminants documents the excellent regional air quality, especially compared with the lesser air quality of Page, Arizona. The programs for statistical analysis of all input data have been devised. The importance of the baseline data will be fully realized when coal-fired power plants begin operation in the impact area.

Task 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 management structure.

The Legal-Institutional subproject has devoted its first year to the study of the legislative history of the Colorado River Storage Project Act of 1956, examining in particular detail the manner in which conservation values and Native American water rights were treated in the legislative process. The subproject has accumulated and analyzed legal and political information which will facilitate informed responses to questions concerning implications of changes in water management of the region. This analysis has enabled the subproject to confirm a model which explains the coalition of interest groups that resolved their internal differences by forming a political bloc strong enough to obtain sufficient benefits to satisfy what would otherwise be competing needs.

A case study of Navajo water rights has been made because these rights are among the most dynamic variables in the water management system of the UCRB. The subproject has studied methods which exist for quanitification of Indian water rights, all of which have been used in the Upper Basin: litigation, legislation and contract. The functioning of the Navajo Tribe as an emerging decision-maker in the area has been examined by analysis of the history of the Navajo Indian Irrigation Project.

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

A collection of environmental impact statements for the UCRB has been made, and evaluation of the impact statements initiated. The most important finding to date has been that most existing impact statements have only concerned local or near-site effects, and that no single agency seems to have developed a method to evaluate regional or downstream consequences of particular projects.

An attempt is being made to investigate the connection between impact statements and water management policy in the Upper Basin.

Task 6. The Development of a Methodology for Correlating All Research Components Essential to Achievement of Objectives

During the 1972-1973 research year, efforts have been concentrated on the development of a simulation model for the Lake Powell region. This work has been carried out in close cooperation with the Principal Investigators of all subprojects. The principal components of the simulation model have been specified and preliminary computer programs for some of the submodels have been developed. When full specification of the relationships has been achieved and the coefficients estimated, it will be possible to estimate the total impact of alternative water management policies on the economy and environment of the region.

SUBPROJECT PROGRESS REPORTS

Each of the above tasks has been partially accomplished by one or more LPRP subprojects. Table 1 shows the assignment of tasks to specific subprojects (those with primary responsibility for a given task are underlined). It will be noted that the numbering of subprojects has been changed from the LPRP proposal and First Progress Report. In view of the integrative function for the overall Project of the Systems Analysis subproject, Systems Analysis has been allocated number "1" and the other subprojects have been renumbered accordingly, following the same order in which they were originally presented.

Submitted by

Orson L. Anderson
Natural Sciences Coordinator

March 15, 1973

Table 1. Task Assignments

SUBPROJECT	TITLE
1	Systems Analysis
2	Biological Limnology
3	Shoreline Ecology
4	Heavy Metals
5	Streamflow Trends
6	Lake Evaporation
7	Bank Storage
8	Physical Limnology
9	Lake Geochemistry
10	Sedimentation
11	Background Air Quality
12	Impact Analysis
13	Economics
14	Epidemiology
15	Anthropology
16	Law and Political Science
17	Social Sciences Coordinator
18	Natural Sciences Coordinator

TASK*	SUBPROJECTS ASSIGNED
1a.	5
1b.	6,7,9
2a.	2,3,4,6,7,8,9,10
2b.	3
2c.	4
2d.	10
3a.	2,3,11,13
3b.	15
3c.	11,13
4a.	12,14,15
4b.	15
4c.	11,14
5a.	16
5b.	15,16
5c.	12
6.	1

*For statement of tasks, see pp. 1-6.

SYSTEMS ANALYSIS: Shaul Ben-David and F. Lee Brown

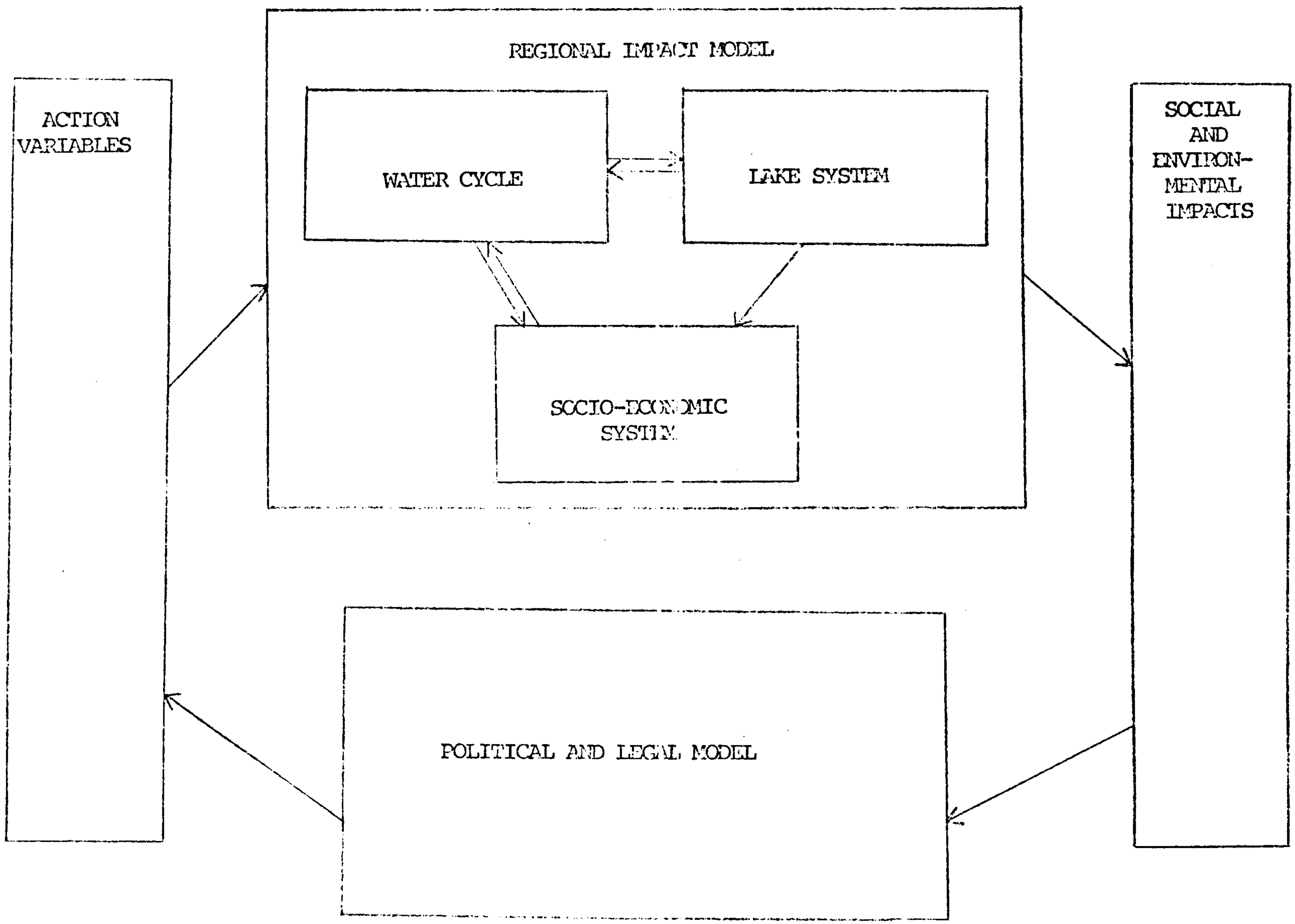
During the phase of research summarized here, the Systems group has concentrated its efforts on developing a simulation model for the Lake Powell region. This work has been done in close cooperation with principal investigators from each of the subprojects of the Lake Powell Project. Through discussions carried out in Flagstaff, Page, Arizona, Albuquerque, and Washington, D.C., it has been possible to specify the principal components of the simulation model as well as the relationships between these components. When full mathematical specification of each of the relationships has been achieved, it will be possible to determine the effects of changes in the magnitude of the variables selected for inclusion in the inputs vector and variables in the output, or impact vector.

One feature of the simulation model being developed for the Lake Powell Project is believed to be unique. That is, each relationship contained in the model is to be empirically estimated, either by individual subprojects, subprojects in cooperation with one another, or by the Systems group using data supplied by the subprojects. This is in contrast with other models of this scope in which many relationships must be either ignored or "guestimated." The empirical nature of this model should result in a high degree of model reliability, and as a consequence, high utility to users of the model.

Since the development of the regional impact model is a cooperative effort, involving all the subprojects, the pace of model development is constrained by opportunities for the subproject personnel to interact with the Systems group, as well as by the rate of progress of the subprojects themselves. Thus, the model can not achieve full mathematical specification until the empirical work of the individual subprojects has been completed. These constraints have dictated an approach which calls for the initial use of functions in which parameter values are only approximate. Using these approximate values, trial runs of the model can be made, which allow preliminary work, such as the de-bugging of computer programs and identifying critical or sensitive relationships between variables, to be completed before all the final data become available. Thus, the model can be made to "work" although the output values it generates at this stage are unreliable. It then remains only to insert the empirical estimates of the model parameters to make the model useable.

As can be seen in Figure 1, the regional impact model is divided into three main sub-models: water cycle, lake system, and socio-economic system. The water cycle portion of the model is the most fully developed at this point. Based on preliminary data supplied by the hydrology sub-project, a computer program has been developed which simulates the hydrological behavior of Lake Powell. The model treats water inflows and releases at Glen Canyon Dam as inputs and calculates resulting lake level, surface area,

Figure 1. Simulation Model.



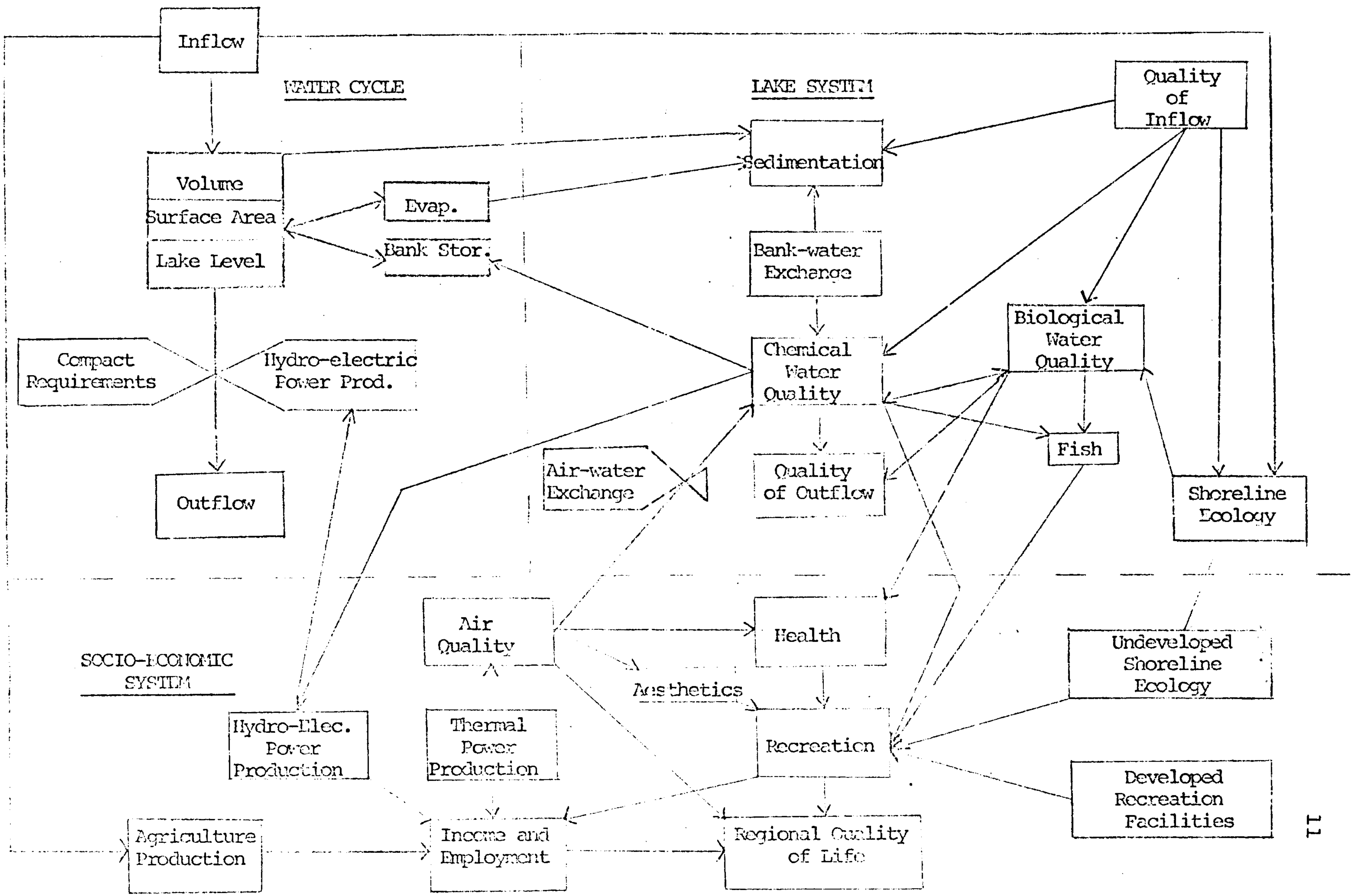
and volume. Evaporation is then calculated as a function of surface area and season, and bank storage is calculated as a function of lake level. Finally, volume, surface area, and lake level are adjusted to account for losses to evaporation and bank storage. A new iteration is then begun for the next month in the cycle. Considering the fact that the evaporation and bank storage functions are only approximations at this point, lake behavior as simulated by the model conforms well with actual lake behavior during the 1965-1970 period (the period for which data on actual behavior were available).

One of the potential uses of the model can now be examined. The timing of releases from Glen Canyon Dam is subject to discretion, given the constraints imposed by the Colorado River Compact and hydro-electric power production requirements. Alternative release policies can be simulated and their effects on lake volume, surface area, and level determined. While the values of these variables may be of some interest in themselves, of far greater significance is the fact that, as indicated in Figure 2 , volume, area, and elevation affect variables in the lake system and the socio-economic system. These relationships will now be explained.

Shoreline ecology is conducting, as part of its research effort, an inventory of campsite availability and quality along the entire shoreline at various lake levels. Campsite availability and quality affect (as supply factors) the amount of recreation which takes place in the region. The amount of recreation, more explicitly recreation expenditures, in turn affects regional income and employment. Part of the task of the economics project is to evaluate this connection between campsites and employment and income. The result of this cooperative effort between subprojects will be a functional relationship between lake level and regional employment and income. Thus, although several alternative release policies may be acceptable from the standpoint of meeting commitments to the lower basin and hydro-power requirements, they will not all have the same impact on employment and income. One purpose of the model is to identify such impacts.

Shoreline ecology is identifying a second impact of alternative release policies. The amount of organic matter entering the water from the shoreline is a function of the level, and changes in the level of the lake. The organic matter input in turn becomes one of the factors affecting biological water quality. Biological water quality is also affected by the quality of water flowing into the lake - both directly and indirectly through chemical water quality. The lake geochemistry subproject is developing a model which predicts the chemical composition of lake water as a function of chemical inflow into the lake, both in inflow waters and from the air, and as a result of water contact with sediments and banks. The various water quality parameters can then be connected to recreation demand, through impacts on fish populations, health (coliform bacteria), and aesthetics (anaerobic conditions). From recreation there is once again a connection to regional income and

Figure 2. Regional Impact Model.



employment. Chemical and biological water quality also affect the quality of water released to downstream users. Finally, chemical water quality affects the rate of corrosion of hydro-power equipment, and, thus, regional income and employment.

This complex of interactions ultimately connects elements of the input vector to those of the output vector. The inputs in this example, all subject to some degree of control, are air quality, a function of the level of thermal power production and levels of emission control, quality of inflow, a function of upstream release and irrigation practices, and lake level, a function of release policy. The outputs, or impacts, are regional employment and income and quality of water released from the lake. Thus, the model allows an evaluation of the impact of alternative policy combinations on a variety of variables of interest.

Several other input-output links are being developed. Rates of inflow and evaporation affect rates of sedimentation, and, therefore, the useful life of the lake. The chemical composition of the water affects the rate of loss to bank storage by either causing "cementing" of the banks or increasing bank porosity. The ultimate impact of flows into bank storage depends on the location and recoverability, both physical and legal, of the water lost from the lake. Development of recreational facilities, private as well as public, affects recreation, and ultimately, employment and income. In each case, the emphasis is on developing the connection between a variable which is subject to control, action variables in Figure 1, and other variables which reflect the benefit of a particular action, social and environmental impacts in Figure 2.

An important adjunct to the regional impact model is the political and legal model shown in Figure 1. The term "model" is used here in a sense which is somewhat different than its use in "regional impact model." That is, the latter contains functional relationships which are amenable to computer programming for purposes of simulation. The political and legal model, on the other hand, can be viewed as a set of guidelines for interpreting the impacts generated by the simulation and for specifying likely values for the action variables. Essentially, the political and legal model provides the constraints or bounds on the simulation. In one sense this can be viewed as nothing more than a means of preventing model users from asking the model to simulate answers to stupid questions. More important, however, is the feedback capability that is provided. For example, it is possible that some combination of policies (values of action variables), each of them plausible on their own, result, after simulating the passing of a few years, in an impact or combination of impacts that is highly unlikely to develop in actuality (draining the lake, say). While it is not possible to build safeguards against all such possibilities into a simulation model, it is possible to monitor the impacts as they develop over time, and when pressures begin to appear, to intervene with educated guesses about the effects such developments would have on policy. This provides new values for the action variables and the simulation can continue. The presence of the political and legal model, then, allows model users to simulate events much farther in the future, with some confidence that the results are sensible, than use of the simulation model alone would permit.

BIOLOGICAL LIMNOLOGY: David Kidd

Introduction

The general purpose of this project is to develop indexes of eutrophication for Lake Powell. Diversity indexes are being generated from phytoplankton and zooplankton counts. Lower diversity values indicate less optimal water quality conditions. Primary productivity measurements are being monitored in order to establish baseline indexes of the rate of carbon-12 fixation. The assumption is that more nutrient enriched waters cause higher fixation rates. In addition, coliform bacteria levels are being monitored in order to establish baseline levels for this reservoir.

Progress

Field work was delayed until August 1, 1972 because of the late arrival of the houseboat. Nine stations have been established along a gradient from the dam to the inlet of the Colorado River. Stations have been selected in order to monitor major inputs from tributaries such as the San Juan River and inputs from potential population growth centers along the impoundment. Sampling intervals are every fourth week during the winter and every week during the summer. Sampling depths have been selected so as to characterize the photic zone which becomes less deep as one proceeds up river. The houseboat is now fully equipped as a floating laboratory for water sampling, titrations, turbidometer measurements, vacuum filtration, photometer readings, and incubation of bacterial samples.

Work is on schedule and the data is being processed as rapidly as it should be in these kinds of investigations. Gaps in the data chart are due to either bad weather or mechanical failure of the boat. Sampling did not start at station three until October. At that time a buoy was made available in front of the dam.

Inferences

All data is of a preliminary nature and conclusions should not be drawn until the end of the sampling program. Table 2 displays primary productivity information. Higher values so far appear at Station 5, the Rainbow Marina sewage buoy and at Station 9, the inlet. Table 3 displays $\bar{D}$ values. There is not enough information to make statements at this time. Table 4 provides coliform counts. Higher counts occurred early in August at Stations 4 (Warm Creek Bay) and Station 5 (Rainbow Marina sewage buoy. Station 1 (Wahweap Swimming Beach) does not display unusually high values. Levels are about what one expects for recreational waters and seem safe for direct body contact. Levels are high enough to indicate probable occurrence of <u>Salmonella</u>, a dysentery causing bacterium. Figure 3 shows a

PRELIMINARY INFORMATION NOT FOR PUBLICATION

Table 2. Primary productivity data for nine stations at Lake Powell. Units are mg C^{12}/m^2/day.

Station	8/1-4/72	8/7-10/72	8/14-17/72	9/11/72	10/9-12/72	11/6-9/72	12/4-7/72
1	637.6	623.3	754.2	559.9	145.1	470.4	47.9
2	730.8	489.0	578.9	646.7	264.3	582.9	
3					287.0	295.8	
4	262.9	821.3	605.6	543.1	417.4	403.4	
5	852.9	616.3	1037.3		255.1	194.3	
6	558.4	199.8	690.3		397.5	177.7	
7	618.3	716.1	546.3		495.6	167.5	157.8
8	661.7	718.6	643.1		449.2	198.6	89.7
9	572.9	1616.8	965.5		1155.7	662.8	92.2

PRELIMINARY INFORMATION NOT FOR PUBLICATION

Table 3. $\bar{D}$ station average values for Phytoplankton (P) and Zooplankton (Z).

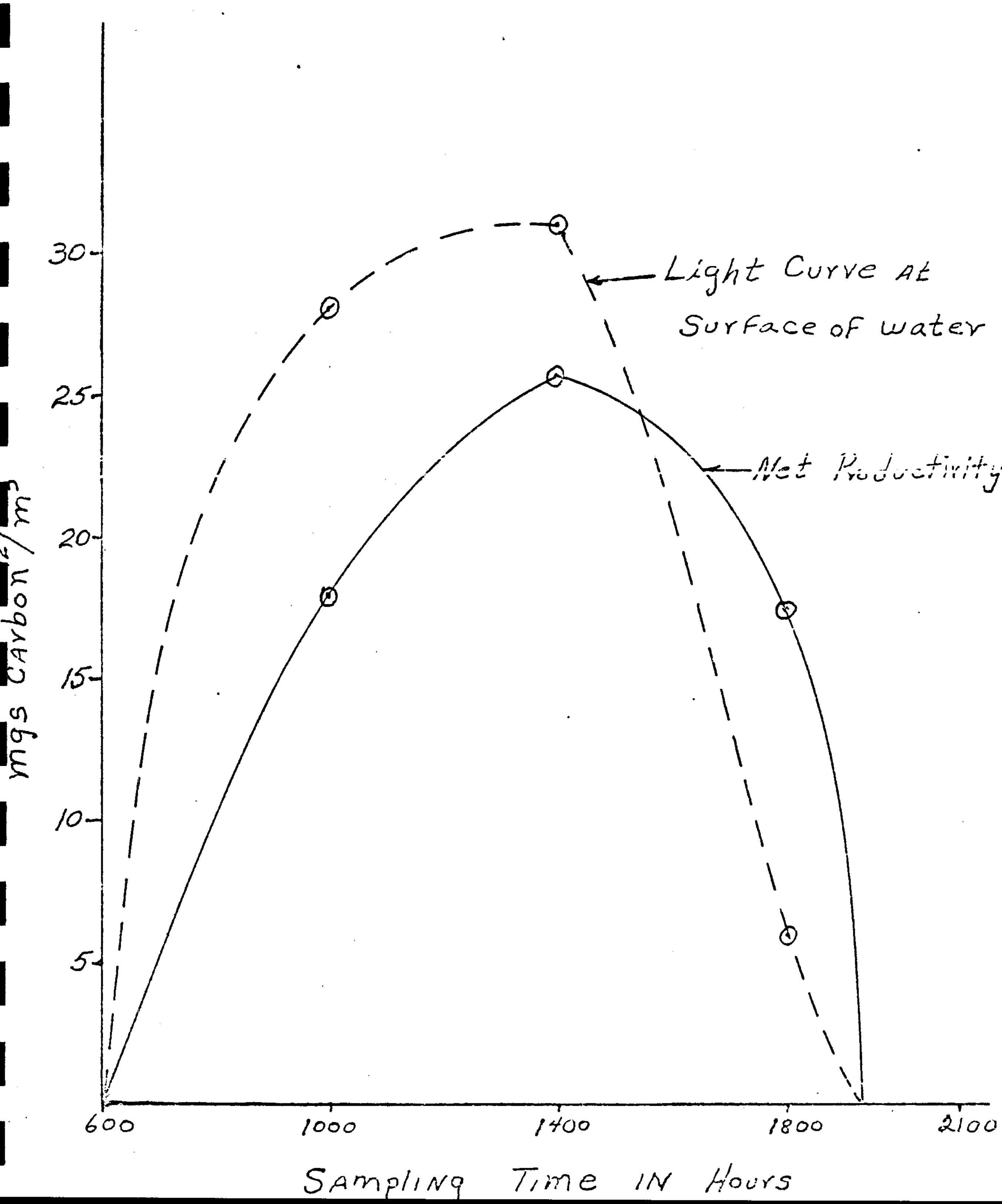
Date	8/1-4/72		8/7-10/72		8/14-17/72		9/11/72		10/9-12/72	
Station	P	Z	P	Z	P	Z	P	Z	P	Z
1	2.058	1.764	2.769	0.750	2.819	2.536	2.690	2.434	3.697	3.089
2	0.767	1.949	2.084	0.685	2.463	2.496	2.917	2.661	3.607	3.098
3									3.729	3.243
4	1.896	2.304	1.465	1.245	2.136	1.809	2.015	2.640	3.711	3.145
5	3.182	2.913	2.570	2.462	2.291	1.880			3.333	3.145
6	3.540	3.324	2.908	2.883	3.006	1.800			3.958	2.906
7	1.941	2.802	2.442	0.702	2.173	1.275			3.996	3.002
8	1.167	2.369	1.511	2.890	2.031	1.239			4.321	2.754
9	3.438	2.827	2.422	2.304	1.403	2.735			3.896	2.269

Table 4. Surface coliform counts per 100 cc of sample.

Station	8/1-4/72	8/7-10/72	8/14-17/72	9/11/72	10/9-12/72	11/6-9/72	12/4-7/72
1	16	542	790	452	520	590	740
2	80	1184	428	554	862	754	
3					280	1222	
4	3292	712	130	366	244	578	646
5	5640	632	352		400	400	
6	88	664	380		290	400	
7	210	440	584		444	512	190
8	204	774	332		320	322	360
9	524	124	924		546	472	410

PRELIMINARY INFORMATION NOT FOR PUBLICATION

Figure 3. Diurnal Light and Carbon Fixation Curves.



diurnal light and carbon-12 fixation curve. This experiment was run in September. Higher fixation occurs during the 9:00 AM to 3:00 PM period. In general, primary productivity experiments are conducted during this same period.

Relation to Overall LPRP Objectives and Other Subprojects

A centraltheme of the LPRP is water quality. This project relates directly to this major goal by assessing the trophic status of Lake Powell. Other projects are assessing physical and chemical parameters of water quality. Bacterial measurements provide a link to the epidemiology project. The fact that some stations indicate differing water quality conditions relates to the hydrology projects in that drainage patterns may be producing differences in water quality at certain lake locations.

In general, assessment of water quality is of direct or indirect relationship to all other projects.

SHORELINE ECOLOGY: Loren Potter

Introduction

For the first time in recent years, the maximum seasonal water level did not reach that of the previous year, resulting in a 2-foot elevational zone (3620'-3622') of one-year old successional vegetation unflooded. The 1970-71 drawdown was 3602' to 3597'; the 1971-72 drawdown was from 3622' to 3607'; the 1972-73 drawdown was from 3620' to 3603'.

Transects

The permanently established belt transects of representative vegetational types were remeasured in July. The vegetation was more productive in 1972 due to more than average amount of rainfall in the fall and winter of 1971 and in spite of the severe drought of January to June, 1972. The greatest change was in a band above the maximum water level due to capillary rise of moisture, especially in sandy soils. With repeated flooding to a particular level, this fringe zone would show definite increases in coverage and vigor of native species, e.g., Indian ricegrass, blackbrush, saltbush, and sand sage. To obtain better measures of biomass, a series of clip plots were established in native vegetation and in drawdown areas of sandy soils.

Shoreline Mapping

During 1972 the balance of the approximately 1500 miles of shoreline surface materials were mapped. Area of each type will be calculated this spring.

Campsite Carrying Capacity

After consultation with Mr. Carlock Johnson, Superintendent of Glen Canyon National Recreational Area, as to the greatest need for campsite data, several areas were selected: Iceberg, Slickrock, Rock Creek, and the Escalante River and its tributary canyons. The campsites were designated as single or multiple and as sand or rock. These were indexed on detailed topographic maps at a scale of 1 inch:400 feet and with 10-foot contour lines. In addition, campsites on Face and West Canyons and much of the main channel and tributaries from Rainbow Bridge to Wahweap have been located at the 3620 foot contour level. Enlargements of some aerial photos have been obtained and the investigators are currently attempting to establish proper signatures on the photos to identify campsites from the stereo pairs as well as a method to superimpose contour lines on the photos.

For this study, there is need of aerial photography at a scale of 1:12,000 or at least 1:20,000 and preferably color rather than black and white. The resolution to establish the necessary signatures to identify types of campsites is extremely difficult and inconclusive from existing photos.

Biomass Studies

Measurements of standing biomass of the principal shoreline types of surface materials were completed in May and June, 1972. In each $1m^2$ clip plot total foliage cover,relative foliage cover of each species, frequency, total oven-dry weight, and relative weight by species was determined. Analyses of domed and shelfy terraces was based on 500 plots, dune sand and sandy drawdown zones on 250 plots, and talus slopes on 50. Below is given a brief summary from the total data to be submitted later. See Table 5.

Maximum biomass is attained on the dune sand followed by talus slopes because of the prevalence of woody growth on the latter. The sandy drawdown zones which have been exposed from the previous August through May have a foliage cover nearly equalling the unflooded zone and a rapid seasonal recovery in total biomass. It is this biomass which will yearly be flooded and subject to decomposition - leading to enrichment of the lake. It is also a major factor in recreational use of the favorite sandy shoreline sites. The one-year growth, dominated by tamarisk, may be up to 6 feet tall. If not flooded for two years, it will be 10-12 feet tall. When flooded, a submerged woody vegetation will be left offshore which will result in serious objections by boaters and swimmers.

To determine the effect of flooding and decomposition on tamarisk, 65 3-foot tamarisk plants were transplanted under water in December, 1972. Some of these are being recovered by encasing in plastic bags under water. In one month's time they are enveloped by a layer of gelatinous material of algae, diatoms, and silt. Loss of weight of the tamarisk, weight of the periphyton, and concentration of total nitrogen and phosphate of tamarisk and periphyton are being determined at monthly intervals. The experiment will be repeated starting in June to determine the effect of flooding initiated in the summer. These studies are being supplemented by diving observations of decomposition of several dominant species at increasing depths and times of submergence. Mr. Carlock Johnson, Superintendent, has expressed genuine interest in these studies because of the importance to shoreline recreational use.

Table 5. Summary of Vegetational Analysis of Biomass and Cover

Zone	Oven-Dry Total Biomass g/m^2	Total Foliage Cover, %
Domed Terrace	13.8	1.5
Shelfy Terrace	11.7	1.4
Dune Sand	86.5	5.0
Sandy Drawdown	13.3	4.5
Talus	45.2	5.0

Species (over 10% biomass)	D. Terrace Rel Wt	D. Terrace Rel Cover	S. Terrace Rel Wt	S. Terrace Rel Cover	D. Sand Rel Wt	D. Sand Rel Cover	S. Drawdown Rel Wt	S. Drawdown Rel Cover	Talus Rel Wt	Talus Rel Cover
Coleogyne ramosissima	29.2	13.0	40.0	17.0	35.4	19.7			19.5	11.7
Gutierrezia microcephala	15.7	28.8	16.9	20.3						
Ephedra torreyana	11.9	4.8	8.8	12.7						
Oryzopsis hymenoides					13.7	24.6				
Ephedra viridis					11.0	11.7				
Tamarix pentandra							66.0	55.5		
Oenothera pallida							24.0	19.8		
Haplopappus drummondii									30.2	30.9
Atriplex confertifolia									27.4	22.4

Shoreline Textural Changes

Attention has been given to shoreline changes resulting from flooding and exposure with drawdown. Sandstone cliff walls have an increasing intensity of white carbonate material forming a sharply defined "bathtub ring". Domed terrace shorelines are little changed but with a slight increase of silt in the occasional sandy pockets. Shelfy terraces are softened in contour by thin protruding ledges of sandstone breaking off. Talus slopes lose much of their sand, silt, and clay content and have a resulting bouldery shoreline. Similarly, areas of old Pleistocene alluvial terraces become bouldery shorelines. Rock slides are least affected, though their formation is usually caused by a weakening of the underlying, soft Chinle formation. Sandy shorelines, if steep, are suspect to slumping, as are talus slopes. On gentler sandy shorelines a terracing effect develops with the stages of retreating waterline.

Though these textural changes are not of great significance during the normal filling of the reservoir where each summer season the water level exceeds the previous year, it is a forecast of the lessening of desirable shoreline which will result with each drawdown period even when the reservoir is at its final operational levels. As with the decomposing vegetation, the character of the shoreline is a prime factor in recreational management of the Powell Recreational Area.

HEAVY METALS: David Kidd and Loren Potter

Introduction

The Colorado River system has a rich natural source of a variety of heavy metal cations that have been a part of the downstream movement of materials which are now partly trapped in the physical and biological components of the ecosystem of the Lake Powell reservoir. Analysis of heavy metal cations to establish baselines prior to additional influences because of recreational use of the Lake and other developments, such as coal-burning power plants in the area, require sampling of a variety of kinds of materials - water, soils, sediments, plants and fish.

Discussion

Before starting a regular sampling program throughout the drainage system and of trophic levels, it was deemed necessary to establish reliable accuracy and precision in the treatment of samples and in the atomic absorption analysis. To this end, concentrated effort has been given to the elements: mercury, lead, cadmium, zinc, iron, and copper. Samples collected in 1971 and 1972 of sediments, soils, and fish have been used.

The work on mercury which has been conducted by Mr. Donald Standiford on the shoreline ecology subproject since 1971 has been completed as a thesis problem and will soon be published. A summary of some aspects of fish analyses are given in Table 6 for seven species of fish and eleven organs or tissues. Between species of fish there is no correlation of size to mercury concentration. However, in the analysis of size groups within some species of larger predators, there is an increase in mercury with increased size. The mercury concentration of muscle of trout is low but the concentrations in the vital organs of liver, heart, kidney, spleen, stomach, brain, gonads, and gills are higher than in other species. Of the various tissues, the mercury concentration of muscle when averaged for all species is the highest, followed by that of liver.

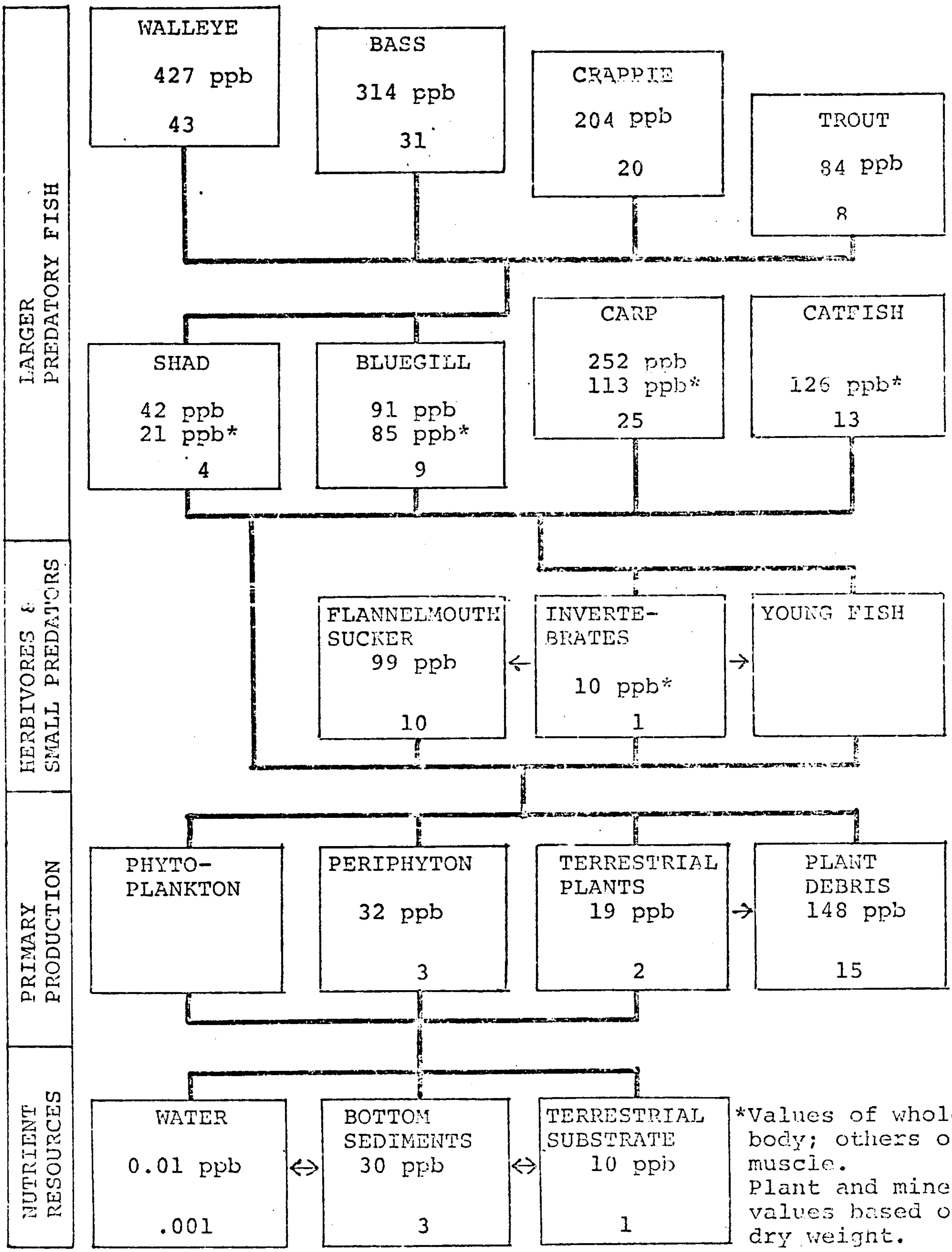
Fig. 4 provides a summary of the biological magnification of mercury in progressive trophic levels. It clearly exemplifies the concentration through the paths of the food chain and the maximum accumulation in the large predatory carnivores, especially walleye and bass. Some of the former had concentrations above the safe allowable amount of 500 ppb.

Table 7 includes some preliminary analyses of five metallic cations. Analyses for copper have also been done but data have not yet been corrected for percentage recovery. Sediment samples are arranged from the San Juan River downstream to the dam. These results are preliminary and interpretive discussion is not appropriate at this time. Many of the techniques

Table 6. Mercury concentrations of several species of fish of Lake Powell (ppb)

	WALLEYE	LARGE-MOUTH BASS	TROUT	BLACK CRAPPIE	BLUEGILL	CARP	FLANNEL-MOUTH SUCKER	$\bar{X}$ ALL SAMPLES	COEFF. OF VARIATION
No.	8	7	3	7	8	5	3	41	
$\bar{X}$ Wt.	1597	1098	1125	441	193	574	653	812	
Range	(300-3350)	(350-2225)	(140-2015)	(300-600)	(151-230)	(513-638)	(650-660)	(140-3350)	
Muscle	427 (209-763)	314 (192-688)	84.5 (73-101)	204 (157-294)	91.0 (57-127)	252 (181-339)	98.8 (48-186)	232 (48-763)	12
Liver	149 (42-362)	163 (53-587)	186 (27-384)	62.2 (38-88)	86.6 (62-96)	152 (55-217)	36.2 (9-33)	122 (9-587)	14
Heart	135 (63-320)	102 (19-421)	228 (137-404)	22.4 (11-37)	129 (87-158)	66.7 (51-84)	14.6 (11-25)	97.8 (11-421)	12
Kidney	86.2 (40-136)	144 (44-498)	253 (93-326)	26.9 (10-43)	28.6 -	180 (95-251)	33.9 (19-56)	107 (10-498)	13
Spleen	77.7 (28-160)	168 (26-673)	257 (192-346)	25.6 (9-50)	-	-	29.0 (28-30)	101 (9-673)	10
Stomach	87.3 (30-158)	79.2 (26-280)	89.3 (78-107)	27.2 (18-47)	35.9 (28-47)	32.0 (21-43)	11.6 (3-25)	56.1 (3-280)	17
Brain	17.2 (4-31)	41.0 (4-74)	98.2 (67-152)	5.5 (0-10)	29.5 (23-36)	86.5 (60-120)	10.9 (6-14)	35.1 (0-152)	-
Gonads	42.2 (16-91)	34.0 (11-107)	68.7 -	11.1 (4-16)	23.6 -	60.4 -	9.9 (4-19)	29.6 (4-107)	12
Skin & Scales	22.5 (12-37)	17.4 (4-27)	13.1 (12-15)	5.5 (-1-9)	40.3 (29-68)	23.7 (16-36)	11.6 (3-21)	18.7 (-1-68)	17
Gills	51.1 (29-78)	42.7 (14-100)	94.4 (55-128)	11.6 (5-20)	15.7 (9-22)	28.1 (19-39)	10.0 (8-11)	36.6 (5-128)	13
Bone	15.7 (7-29)	18.8 (3-37)	16.4 (2-33)	5.5 (1-11)	10.4 (0-24)	25.2 (16-31)	8.1 (3-11)	14.0 (1-37)	28

Fig. 4. Relation of Lake Powell trophic levels to mean ppb Hg concentration and magnification factor relative to shoreline substrate.



*Values of whole body; others of muscle.
Plant and mineral values based on dry weight.

PRELIMINARY DATA NOT TO BE PUBLISHED

Table 7. Preliminary Results of Some Heavy Metal Concentrations in Lake Powell Ecosystem

NO.	SAMPLE LOCATION	DEPTH M	LEAD ppm	LEAD SE	CADMIUM ppb	CADMIUM SE	MERCURY ppb	MERCURY SE	ZINC ppm*	ZINC SE	IRON ppm*	IRON SE
SEDIMENTS:												
9	Colo R above SJR	105	25.7	-	144	36	30	1.9	88	-	22,584	-
13	Piute Farms SJR	1	13.9	0.0	128	16	40	1.2	54	2	11,542	989
27	"	2	22.0*	1.3	174	4	41	4.8	97	2	25,532	2,273
24	"	2	51.5*	10.0	164	14	40	0.9	105	4	24,062	354
36	L. Powell SJR	5	22.4*	1.6	223	18	38	2.0	106	6	24,960	1,832
23	"	9	19.3	1.3	151	8	17	1.5	68	5	12,732	1,190
45	"	9	89.7*	2.9	643	57	53	3.4	288	15	21,916	1,880
12	Copper C SJR	13	37.3*	2.6	109	19	27	0.2	97	13	25,040	5,541
15	SJR	45	34.2*	8.6	99	8	33	0.6	98	15	23,390	1,163
2	Piute Mesa SJR	22	35.8*	-	-	-	33	0.7	129	-	27,662	-
16	"	22	38.5*	10.0	133	6	-	-	112	7	16,455	770
46	"	29	16.1*	1.0	151	9	21	1.3	62	4	13,971	1,379
29	"	15	12.8*	1.2	61	13	17	0.7	29	2	7,305	599
38	Piute Cr SJR	49	22.7*	0.7	214	11	35	1.3	78	3	18,050	1,148
37	Wilson Cr SJR	78	22.8*	1.8	260	36	28	1.0	78	6	18,901	3,474
33	Bald Rock C SJR	99	24.7*	1.0	209	7	28	0.8	104	3	26,638	2,365
31	Mouth SJR	106	14.8*	1.6	164	14	16	1.1	67	5	18,129	1,731
32	"	36	5.6	0.6	78	10	5	0.6	29	1	6,566	139
39	Buoy 53 Colo R	103	18.5*	-	215	-	46	3.6	108	-	25,453	995
30	Reflection C	1	1.9	-	63	12	3	0.5	7	<1	1,108	197
41	Rainbow Br Mar	81	3.8	0.9	150	7	13	0.6	33	2	4,357	394
5	"	81	13.0	-	181	28	-	-	33	5	5,744	1,091
26	Rainbow Sew Buoy	87	24.1*	5.1	384	56	25	0.3	319	-	5,969	1,252
22	Below Rock Cr C	5	3.4	0.6	62	9	12	2.8	24	1	4,702	400
18	Padre Bay Channel	132	31.9*	3.8	157	43	28	2.5	89	7	24,029	3,586
1	Padre Weather Sta	61	12.5	1.3	403	89	21	0.8	54	1	10,902	785
28	"	58	3.4	0.1	64	4	6	0.3	24	<1	5,662	112
19	"	55	2.9	-	128	30	17	0.4	42	11	6,469	2,097
20	Mouth Navajo C	130	11.3	1.0	42	-	18	0.8	48	3	10,935	1,208
4	Head Wahweap B	9	4.8	0.8	207	84	13	0.4	53	5	12,036	1,762
34	Wahweap Swim Beach	13	4.8	0.4	90	5	9	1.9	23	2	4,396	286
10	N end Wahweap Mar	16	24.9*	2.7	99	11	13	0.5	27	1	4,564	-
6	S end Wahweap Mar	25	15.2	-	121	61	5	0.5	16	1	2,184	566

Column heading "ELEMENTS#" spans the element columns.

Table 7 continued

NO.	LOCATION	DEPTH	LEAD		CADMIUM		MERCURY		ZINC		IRON	
		M	ppm	SE	ppb	SE	ppb	SE	ppm*	SE	ppm*	SE
SEDIMENTS - Continued												
21	1971 Sta 4	60	54.5*	10.9	224	7	50	5.1	74	1	17,136	373
14	"	56	44.7*	5.0	178	15	32	0.9	61	2	12,414	742
17	Glen Canyon Dam	120	11.2	0.6	196	32	51	0.9	103	-	15,862	558
47	"	120	19.3*	1.1	323	6	48	1.2	97	5	19,213	1,787
SHORELINE:												
25	Piute Farms SJR	0	9.0	1.2	274	11	5	0.5	36	5	4,547	545
7	Alcove C SJR	0	4.6	-	68	14	1	0.1	15	2	2,771	600
35	Mouth SJR	0	2.7	0.4	115	18	3	0.4	27	1	13,534	1,356
8	Reflection C	0	7.8	-	140	45	5	0.8	23	-	1,563	-
SEEP:												
40	Mouth SJR	-	1.4	0.3	114	5	30	1.8	15	1	2,999	106
FISH: (from Padre Bay, 3/29/72)			ppb	SE	ppb	SE	ppb	SE	ppm	SE	ppm	SE
53	Crappie muscle, 560 g		207	45	<5	-	204	23.1	24	<1	28	10
52	" 600 g		90	-	<5	-	141	8.5	22	4	10	-
51	Bass muscle, 910 g		278	-	54	5	199	10.9	14	<1	5	-
55	" 2225 g		268	68	<5	-	620	17.2	-	-	7	1
54	Walleye muscle, 1110 g		280	28	53	-	-	-	-	-	15	1
50	" 3350 g		972	115	113	27	686	43.2	19	2	12	2

\# Concentrations corrected for percentage recovery for all samples and elements. Lower limits of detection were: lead .003 ppm, cadmium 0.1 ppb, mercury 1 ppb, zinc 1 ppb, and iron 20 ppb.

* Values obtained by flame atomic absorption spectroscopy Perkin-Elmer 306; all others by graphite rod HGA70, or mercury by flameless atomic absorption.

refined for these cations will be applicable to the others to be included in the study. The results are also valuable in indicating some of the variations and peculiar problems, such as high concentrations of zinc associated with sewage disposal areas and apparently derived from zinc in the chemical, portable toilets used on boats. Thus, metallic ion analysis relates to sanitation programs, recreational use, and gasoline consumption, as well as to natural resources.

SECULAR RUNOFF TRENDS IN THE MAJOR SOURCE AREAS OF THE UPPER COLORADO RIVER BASIN: G. C. Jacoby, Jr., and C. W. Stockton

Much progress has been made toward fulfilling the objectives of this subproject during this, the first year.

Field collecting of tree-ring samples was accomplished during two weeks in August, 1972. These collections, which were made in the major runoff-producing areas of the Upper Basin, will supplement the existing tree-ring samples. At each of 12 sites at least 10 trees were cored, two cores being taken from each tree. The total number of cores collected is more than 225. Fortunately, most of these cores have proved to be satisfactory for use. In only one site, Uinta D, did several of the cores prove to be undatable. This was not totally unexpected because most of the trees sampled were so old that they tended to be rotten toward the center. However, the four trees (eight cores) that did prove to be datable are of good climate-sensitive quality and of superior length. Table 8 gives the current status of the necessary initial analysis of the samples, the final step of which is computer processing to reduce the measured ring widths to a stationary time series (see Fritts [1] for further detail).

Concurrent with the processing of the tree-ring data, workers have been collecting, evaluating, and placing on computer punch cards the total monthly runoff data from 15 stations within the Upper Basin. These data, averaging 40 years in length, have been collected mostly by John K. Yu, a hydrology graduate student hired by this project, and are now ready for calibration with the tree-ring data. Thus, the investigators are now prepared to reconstruct annual runoff records from the five major runoff-producing areas. The first area chosen for detailed study is the Whiterocks River drainage in the Uinta Mountains, north-central Utah. A detailed explanation of the reconstruction for this area follows. It is felt that this reconstruction gives a good estimation of the long-term runoff trends for the Uinta Mountain region. This, then, is a major step in fulfilling the primary objective of determining the long-term runoff trends in the major runoff-producing areas that supply Lake Powell.

Tentative Reconstruction of Annual Runoff Series for Whiterocks River near Whiterocks, Utah

Dendrochronology.--Four tree-ring sites (A, B, C, D) were sampled within this basin during the summer of 1972. These sites were chosen parallel to the long axis of the watershed so that the change in elevation and inherent climatic difference could be incorporated into future runoff reconstructions. Relative site positions and elevations are shown in Figure 5 . Some of the pertinent statistics relating to these sites are listed in Table 9.

Of interest in the location of these sites is the distribution of tree species within the basin. There are very few Ponderosa pine here, the zones being (from upper to lower) Engelmann spruce,

Table 8 . Status of Analysis of the Eleven Tree-Ring Chronologies Collected in the Upper Colorado River Basin During the Summer of 1972

Series name	Species	Cores/Trees		Chron. length	Dated	Checked	Measured	Processed
Uinta Mtns. A	E. spruce	20	10	1433-1971	x	x	x	x
Uinta Mtns. B	D. fir	20	10	1730-1971	x	x	x	x
Uinta Mtns. C	D. fir	18	9	1640-1971	x	x	x	x
Uinta Mtns. D	P. pine	8	4	1423-1971	x	x	x	x
Uinta Mtns. north	E. spruce	31	15	1605-1972	x	x	x	x
Windriver Mtns. A	L. pine	22	10	1676-1972	x	x	x	
Windriver Mtns. B	D. fir	24	12	1567-1972	x	x	x	x
Windriver Mtns. C	D. fir	39	18	1542-1972	x	x		
Windriver Mtns. D	L. pine	28	13	1491-1972	x	x		
Dolores, Colo.	D. fir	22	11	1793-1972	x	x	x	
LaSal Mtns.	E. spruce	22	11	1494-1972	x	x		
LaSal Mtns. A	P. pine	22	11	1506-1972	x	x		

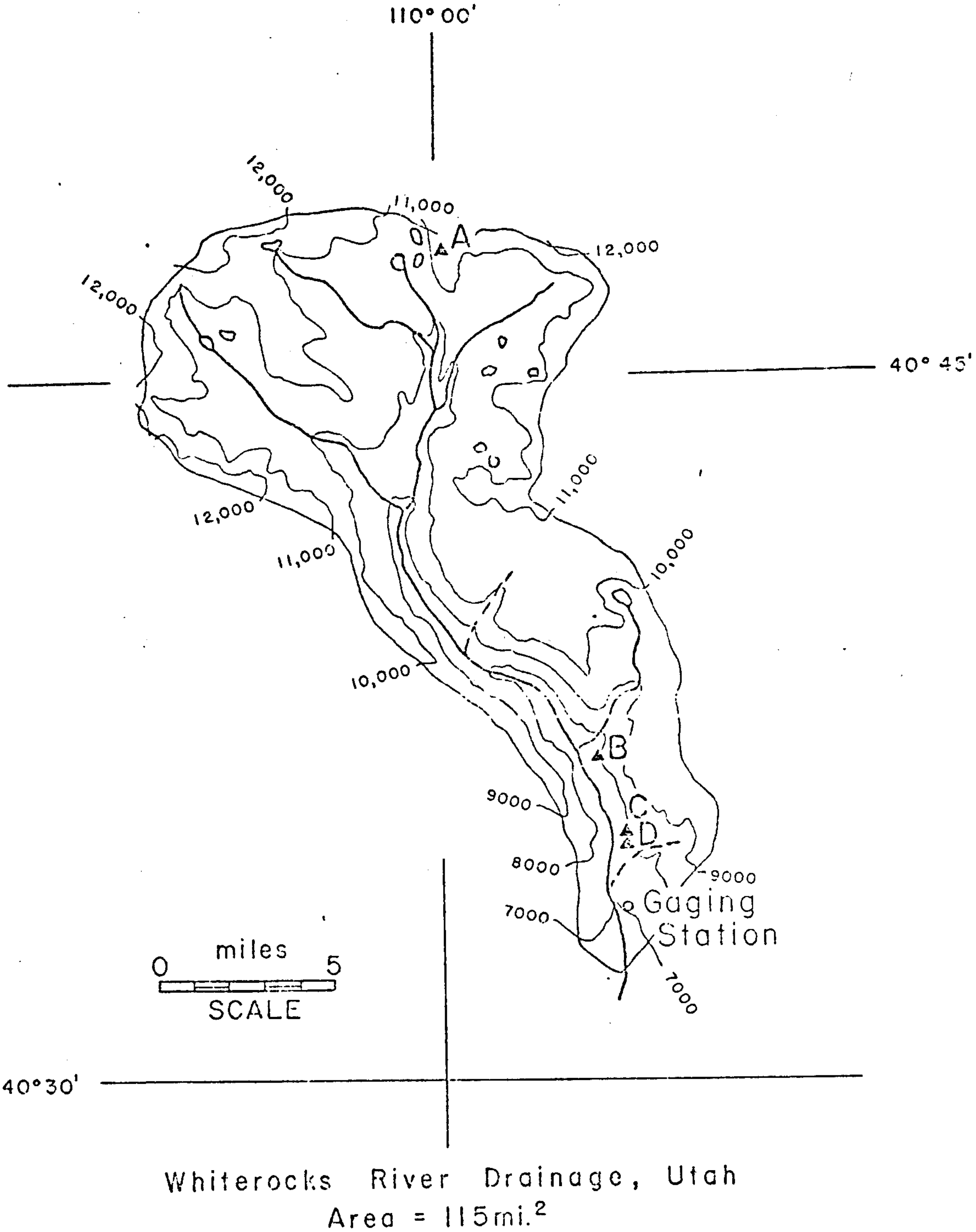


Fig. 5 . Map of Whiterocks River drainage, showing locations of gaging station and tree-ring sites.

Table 9. Pertinent Statistics for Tree-Ring Sites in Whiterocks River Basin

Site	Species	Serial R	Mean sensitivity	Standard deviation	Average ring width (mm)
A	Engelmann spruce	0.7056	0.1135	0.1836	0.5996
B	Douglas fir	0.4662	0.3037	0.3567	1.3177
C	Douglas fir	0.5486	0.3354	0.4025	1.0532
D	Pinyon pine	0.4654	0.3080	0.3329	0.4648

Douglas fir, and pinyon pine. Fritts [1] has shown that maximum climatic information is contained in tree-ring sites at forest borders rather than in interiors. In the case of the Whiterocks Basin, most of the basin (approximately the upper three fourths) is covered by a dense stand of Engelmann spruce. Site A was selected as a representative upper forest border site for this species. This site is at an elevation of 10,600 feet, near timberline. Past experience at the Laboratory of Tree-Ring Research has shown that such high-elevation sites are most reflective of temperature changes, rather than of precipitation changes as in lower elevation sites. Thus, the predominant stress-creating climatic factor, which is reflected in the annual ring widths, is seasonal distribution of temperature. Trees growing under such stress conditions tend to be long-lived and produce comparatively small ring widths. In addition, since the controlling climatic factor is temperature and temperature does not fluctuate widely from year to year, these types of sites tend to have relatively low mean sensitivity (high frequency variance) and are most useful in exhibiting temperature trends. From Table 9 , it is apparent that site A typifies such a timberline site. That is, the mean ring width is small (.599 mm), the mean sensitivity is low (.1135), and the serial correlation is high (.7056).

Site B is located at the upper forest border of Douglas fir and site C is at the lower border of Douglas fir. Site D is an upper border pinyon pine site and is a sensitive, long-duration series. The dating and measuring of this site have only recently been completed; consequently it was not available for the following reconstruction analysis, but it will be utilized in future analyses.

As can be seen in Table 9 , the tree-ring series from sites B and C are quite similar, with site C being somewhat more sensitive to climate than site B. This is indicated by the mean sensitivity values, .3354 versus .3037, and standard deviation, .4025 versus .3567. Also, the fact that average growth (ring width) at site C is less than at site B suggests greater climatic sensitivity. Overall, the series statistics from both sites are indicative of good climatic information content.

The first step in data processing was to compute a principal component analysis. This was done in order to (1) evaluate the spatial coherence among the three sites, A, B, and C, (2) do away with the necessity for selecting key sites, and (3) obtain independence for the variables to be included in the least squares prediction equation. However, before this analysis was made--and on the basis of earlier modeling work for tree-ring series (see Stockton [2])--the individual series were lagged upon themselves so that the final matrix of the series contained 12 variables rather than four. These 12 variables are interpreted to represent not only the spatial but also the temporal coherence of the series. The principal component analysis indicated four prominent patterns within the series for the three sites. Eigenvector 1, which accounted for 36% of the total variance, illustrated that, in both time and space, site A is grossly different from sites B and C. Eigenvector 2, representing 22% of the variance, also stressed the difference between site A and sites B and C, but indicated that in terms of time patterns they tend to become similar as frequency increases. Eigenvector 3 demonstrated that there is a two-year period in all the series. Eigenvector 4 suggested a pattern of wide (or narrow) in all three series, followed by two years of opposite and then a return to the first condition. The conclusion from this analysis is that site A is substantially different from sites B and C and consequently represents an additional source of information. To determine the effect of including site A in the analysis, the same type of analysis was run only on sites B and C. In this case eigenvector 1 accounted for 53% of the variance, showing the great similarity between sites B and C. In fact, in eigenvectors 1 through 4, sites B and C maintain a constant pattern. Only in the time frequency domain is there any contrast between the two sites, and then it is subtle.

Hydrology.--The runoff record for this basin suggests a typical snowmelt runoff situation, with the peak occurring in May and June but sometimes carrying over into July. The recession limb of a typical hydrograph appears to extend to November. However, the basin is small enough that carryover from one year to the next appears to be negligible. In some years (e.g., 1909, 1914, 1917, 1952) there appears to have been a substantial amount of runoff in August, at which time the trees were in the middle of, or just ceasing, growth for that year. In such cases, the next year's ring width is affected, resulting in a too-high value for the reconstructed runoff data for that year. These problems can be better evaluated after completion of a more careful analysis of the rainfall-runoff regime, which is currently being undertaken.

The runoff record for this basin extends from 1900-1971, but there are two periods of missing data, 1904-1908 and 1911-1913. For this reason, the analysis that follows is based on the continuous part of the record, 1914-1971, and the earlier parts of the record will be used to check the reconstructed values.

Dendrohydrology.--Utilizing the results from the dendrochronology analysis and the record of runoff for the period 1914-1970, we reconstructed the annual runoff record for the Whiterocks River for the period 1750-1969 (Figure 6). The reconstructed record is based on the tree-ring series from sites A, B, and C, as it was found that the temperature information in site A is useful in the prediction efforts. If site A is excluded, 56.6% of the variance in the recorded record can be accounted for using tree-ring data, whereas if site A is included, 57.5% of the variance is accounted for. As the study progresses, site D will be included and will probably increase the predictability, as it represents a different species on a different site; as shown by Fritts [1] , it will probably contain a different degree and amount of climatic data.

The first six principal components (i.e., the 12-variable tree-ring value matrix for the period 1750-1971 weighted according

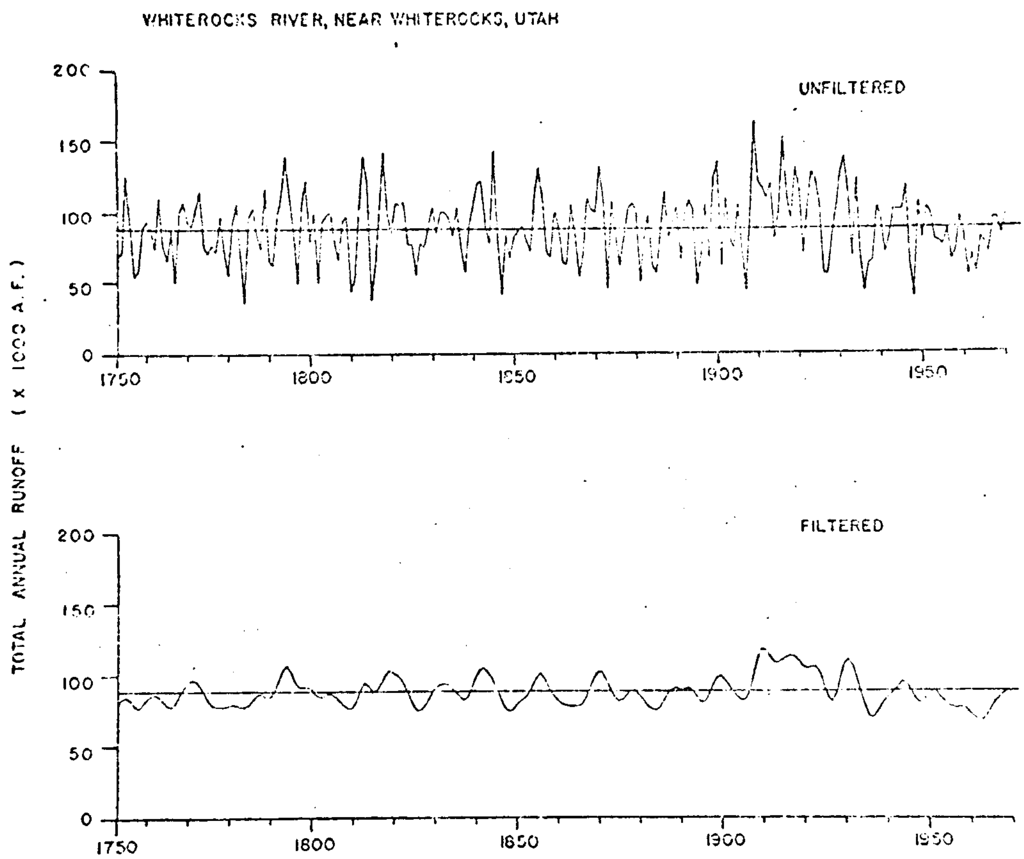


Fig. 6. Tentative 200-year reconstruction of annual runoff for the Whiterocks River, near Whiterocks, Utah, in the Uinta Mountains. The reconstruction utilizes only three of the four sites shown in Fig. 5 because the Uinta D site had not been processed at the time this analysis was made.

Lower graph is the same series after filtering with a digital filter that separates out the variance with a frequency greater than 10 years. This permits the low-frequency tendencies to be studied.

to the eigenvector weights) were used as independent variables in a least squares (stepwise multiple linear regression) analysis to obtain the relationship between the runoff record and the tree-ring series. To evaluate the difference in persistence between the runoff series and the tree-ring series (in addition to allowing for modeling the autoregressive tendencies that might be in the runoff series due to baseflow), seven different mathematical models were tried. The criterion used for evaluation was the percentage of variance accounted for in the original 54-year runoff record. (As the study progresses, additional criteria such as comparison of frequency spectra will also be used.) Table 10 shows the outcome of the model test. Because model 6 accounted for the most variance, it was used for the reconstruction. This model is a mixed moving average-autoregressive model, which seems appropriate in this case. Apparently, the baseflow component is not significant on an annual basis, as the variables pertinent to the baseflow component did not significantly influence the equations (Table 10).

The equation that represents model 6 is

$$f_t = 88.73 - 5.89E_1 - 4.03E_2 - 4.97E_3 - 17.38E_4 - 7.59E_5 + \text{error},$$

where

f_t = runoff at time t

E_n = principal component composed of tree-ring values x at time x_{t+2}, x_{t+1}, x_t, x_{t-1}.

Figure 7 is a plot of the reconstructed versus actual values, where the reconstructed values were obtained from the above equation. The standard error is also shown. Using the above equation the correlation coefficient of the reconstructed with the actual values is .76, 57.5% of the variance in the 54-year actual record is accounted for in the reconstructed values, and the standard error is 21.15.

The reconstructed record (1751-1969) shows a mean annual runoff of 88,710 acre-feet (standard deviation is 23,955 acre-feet). This mean is very close to that for the period 1917-1970, which is 88,710 acre-feet. Consequently, it appears that the average annual runoff for the period of gaged runoff is not grossly different from the average of the long-term runoff.

However, inspection of the hydrograph of the reconstructed series for the period 1751-1969 does reveal some interesting aspects of the period 1900-1969. First, this period contains the most pronounced trend (from high to low) of any period in the 220-year series. Second, it appears that the period of the gaged record contains the most extensive and pronounced wet period (1907-1932) of any period in the 220-year reconstructed record. These two phenomena seem to correspond with similar ones in the tentative

Table 10. Comparison of Various Models for Predicting Annual Runoff for Whiterocks River from Tree-Ring Series. Each model allows compensation for differences in persistence--moving average and autoregressive--between the two series. In addition, models 1, 2, and 3 allow for persistence in runoff due to baseflow. Criteria for inclusion of variables in the least squares prediction is $F \geq 3.75$.

Model	% variance accounted for
1. Runoff (f_t) | tree-ring series x_t, x_{t-1}, x_{t-2}, x_{t-3} with $f_{t-1} + f_{t-2} + f_{t-3}$	51.5
2. Runoff (f_t) | tree-ring series x_t, x_{t-1}, x_{t-2}, x_{t-3} with $f_{t-1} + f_{t-2}$	51.5
3. Runoff (f_t) | tree-ring series x_t, x_{t-1}, x_{t-2}, x_{t-3} with f_{t-1}	51.5
4. Runoff (f_t) | tree-ring series x_t, x_{t-1}, x_{t-2}, x_{t-3}	51.5
5. Runoff (f_t) | tree-ring series x_{t+1}, x_t, x_{t-1}, x_{t-2}	44.5
6. Runoff (f_t) | tree-ring series x_{t+2}, x_{t+1}, x_t, x_{t-1}	57.5
7. Runoff (f_t) | tree-ring series x_{t+3}, x_{t+2}, x_{t+1}, x_t	48.1

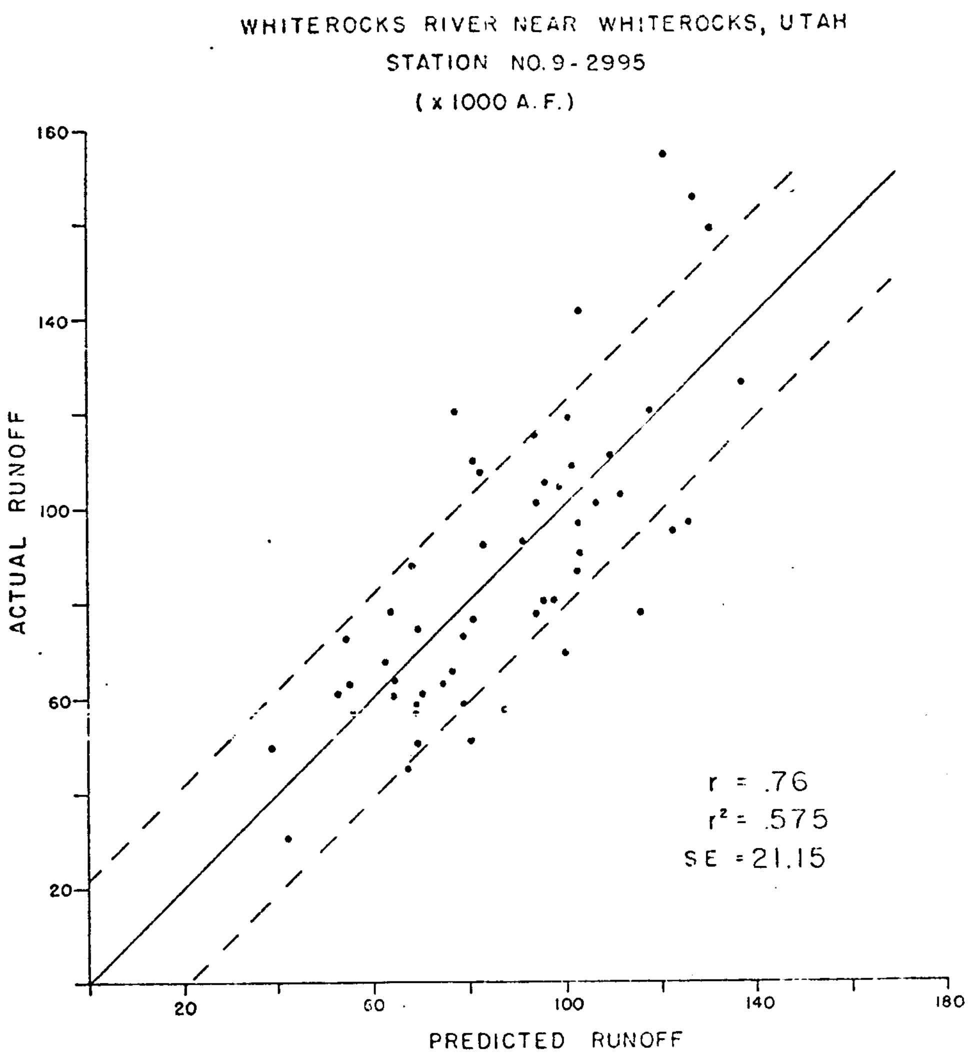


Fig. 7 . Gaged annual runoff values versus values reconstructed from tree rings using the equation given in the text. The solid line represents the locus along which the points would fall if the relationship were perfect. The standard error band (i.e., that band within which at least 68% of the values fall) is shown by the dashed line. Correlation coefficient (r) is .76, and coefficient of determination is .575.

400-year reconstruction for the entire Upper Colorado River basin (Figure 8) based on 14 widely disseminated tree-ring records. It is interesting to note that the pronounced drought of 1852-1890, which is so conspicuous in Figure 8 , does not appear in the Whiterocks reconstruction. Third, the present downward trend (1907-1970) is the longest and most pronounced in the reconstructed record. This seems to correspond with that in Figure 8 . However, note that a similar trend occurs during the period 1605-1630 in Figure 8 ; when data from site D is incorporated, it will probably be possible to push the reconstructed Whiterock River series back in time to include this 1600-1650 period. Figure 9 illustrates nicely the duplication of the trend in the gaged record by the reconstructed Whiterocks record, suggesting that the trend is due to climatic causes and not to man-made watershed modifications.

Conclusions

This preliminary reconstruction illustrates the capability of tree-ring data for estimating long-term changes in the annual runoff series. After the subproject has completed several such reconstructions and has analyzed the differences among the five major runoff producing areas, it will be possible to make a better estimate of the effects of overall watershed modifications on the annual runoff inflow into Lake Powell.

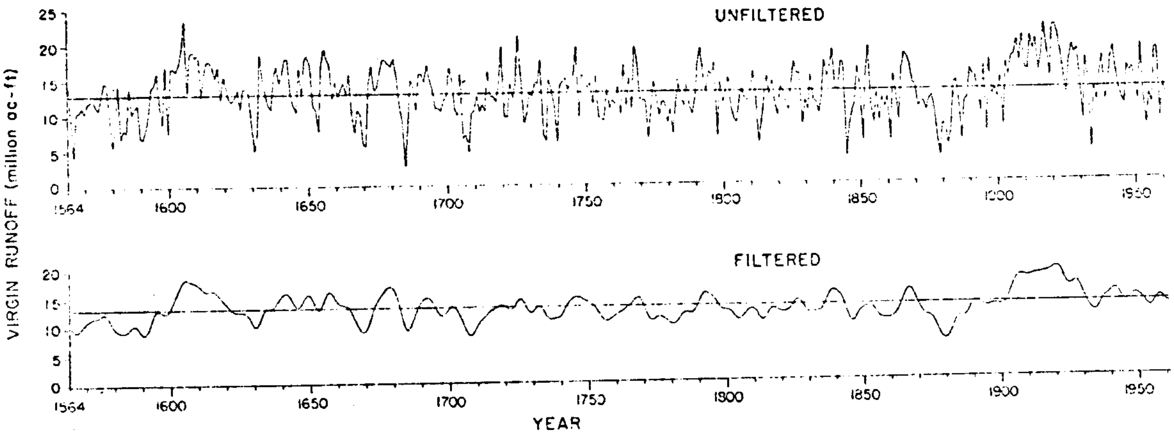


Fig. 8 . Tentative 400-year reconstruction of annual runoff at Lees Ferry, Arizona. This reconstruction is based on 14 chronologies within the Upper Colorado River Basin that were in the files of the Laboratory of Tree-Ring Research prior to initiation of the Lake Powell Project. A future similar reconstruction will include nine additional chronologies sampled in the summer of 1972 under the Lake Powell Project.

Lower graph is the same series after filtering with a digital filter that separates out the variance with a frequency greater than 10 years. This permits the low-frequency tendencies to be studied.

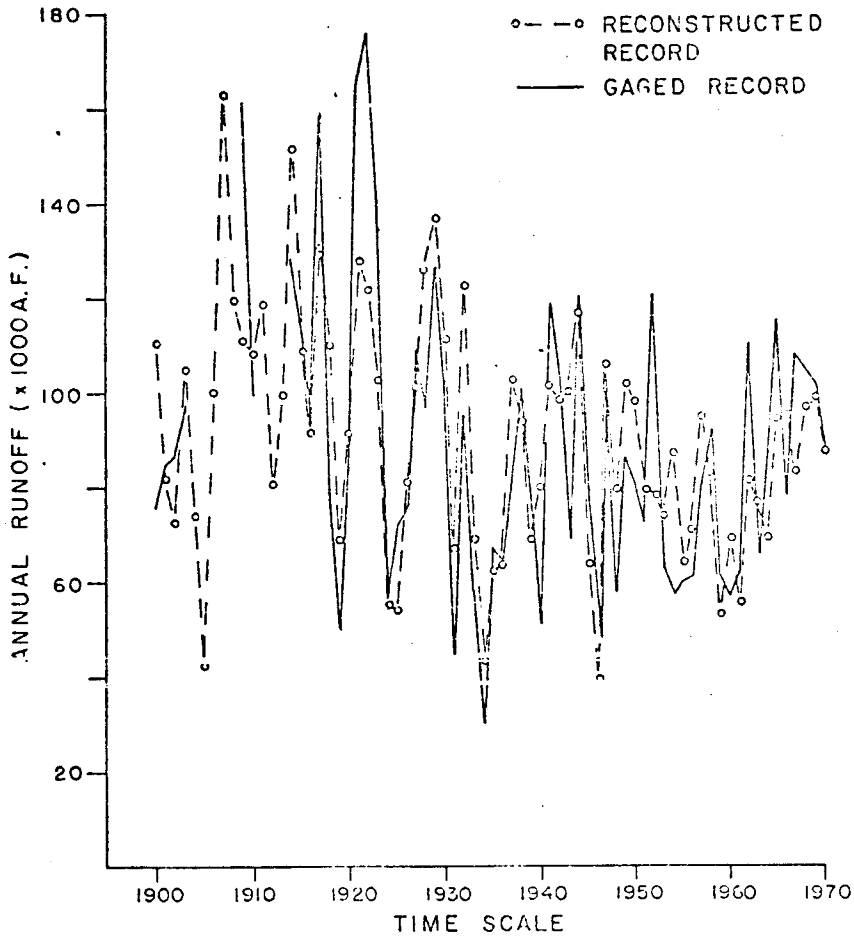


Fig. 9 . Graph of gaged annual runoff series superimposed upon the tree-ring reconstructed series. This figure illustrates the duplication of long-term trend in the actual series by the reconstructed series.

LAKE EVAPORATION: Gordon Jacoby

The Evaporation Subproject is still in an instrument evaluation and installation phase. The comprehensive data collection phase is scheduled to begin April 1, 1973, and to continue for 18 months. Also, a data-reduction system is being set up at Lowell Observatory in Flagstaff, Arizona. This system is in a design-and-procurement stage with an operational target date of late April 1973, when the first data tapes will be produced from the raft recording stations.

The various parameters to be recorded at the Lake are outlined below:

Temperature

There are four thermistor probes per raft. One measures surface water temperature and one measures mean air temperature between the 2- and 4-meter elevations. The other two probes will be used for additional air or water temperature measurements as needed.

From reviews of other evaporation studies, it is apparent that measurement of actual surface temperature requires more than the standard approach to immersing a temperature probe to a shallow depth. The actual "skin" temperature cannot be measured this way. Under consideration by LPRP personnel for determination of "skin" temperature are two narrow-bank, infra-red radiometers, one from Barnes Engineering Company in Stamford, Connecticut. This type of radiometer will be used to measure the temperature of the upper millimeter or so of the water. The other radiometer being considered is from Radiometrics, Inc., in Tucson, Arizona.

The relative humidity measurement devices tested so far may may have technical problems. Therefore, use of two of the thermistors as wet "bulb" and dry "bulb" thermometers, is being attempted for relative humidity or vapor pressure determination.

Relative Humidity

The R.H. sensing devices have had mechanical problems and have been returned for readjustment by the manufacturers.

Wind Speed

A Weather Measure Corp. Model W103 6L anemometer with high-frequency tachometer is being tested and barring unforeseen difficulties will be installed on all rafts. This anemometer has a threshold velocity of 0.6 mph and a distance constant of 7.3 feet. It is one of the most sensitive instruments available.

Solar Radiation

A Swissteco S-1 Radiation Balance Meter is now being tested at the lake and initial functioning seems to be acceptable for net radiation measurements.

Recorder Systems

There are two Sierra Corporation Model 700 Digital Recorders on hand and two on order. These recorders were tested and approved for installation by the Engineering and Research Center of the Bureau of Reclamation.

Fourth Raft

This raft, to be located near Hite, has been delivered to Page and will be placed in position by the Bureau of Reclamation personnel.

Current Installations

Both recorders and instruments are being operated in the Page area for testing purposes.

Lake Evaporation Data Reduction System (LEDARS)

The evaporation project has two components: the data acquisition system (DAS) and the lake evaporation data reduction system (LEDARS). The DAS is the set of instrumented rafts on the Lake. The LEDARS is at Flagstaff at Lowell Observatory.

The lake stations record data on cassette tape. The system described herein is to provide for digital computer reduction of these data. A block diagram of the data reduction system (DARS) is given in Figure 10. Primary data reduction is to be done on a DEC PDP-11 located at the Lowell Observatory Computation Center. This computer is to be outfitted with an appropriate communications interface to read the cassettes. Provision will be made for backup computation on an IBM 1130 (also at Lowell) or other computer via paper tape data transfer.

There are four field stations involved in the data acquisition system (DAS). Each station collects data from about 10 field sensors on an hourly basis. The data from the sensors are digitized and recorded on cassette tape once per hour. The tape contents are equivalent to standard communications strings used on digital dial-up networks. The data itself is a series of ASCII characters with leading and trailing communications control and identification characters. A conventional telecommunications modulation procedure is used.

The primary storage and processing media for the DAS will be Dectape. Data on the Dectape will be chronological with data from the four field stations cassettes merged. At the nominal data acquisition rate and using two Dectape blocks per

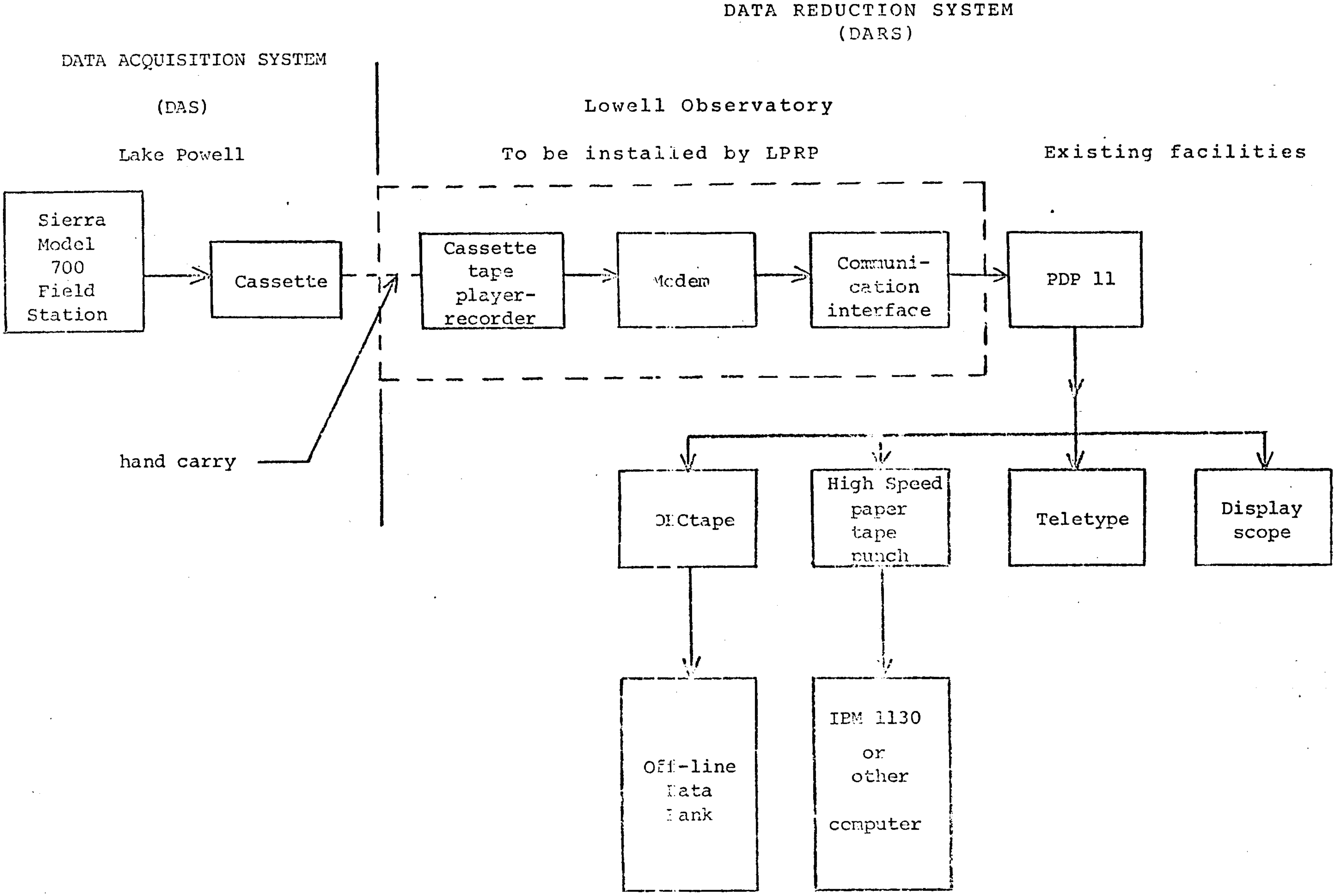


Figure 10. Block Diagram of Lake Evaporation Data Reduction System

(LEDARS)

station per day, a single Dectape will handle 2 months of data. It will also provide storage for intermediate calculations and cumulative statistics.

The software required to support the scientific goals of the subproject is still in the design state. It is likely that the software system will undergo evolution as the nature of the data and its richness in terms of unexpected information content becomes perceived through use. At this point, two concrete outputs are possible: first, a series of six program descriptions which constitute a primitive software support system that can get DARS "on the air"; second, a list of questions and planning activities which can provide the basis for a more powerful software support system. A portion of the software will be written in the PAL-11 Assembly Language. Most of the scientific data reduction programs will be written in PDP-11 BASIC language or in FORTRAN for the IBM 1130.

The LEDARS system is being developed by Mr. Tom Boyle of Flagstaff, Arizona, and the DAS by Robert Cudney at Page, Arizona.

Figures 11 and 12 are plots of monthly evaporation based on data from the Bureau of Reclamation. These plots and data have been furnished to the limnology subprojects for their modeling of the chemical balance of the Lake.

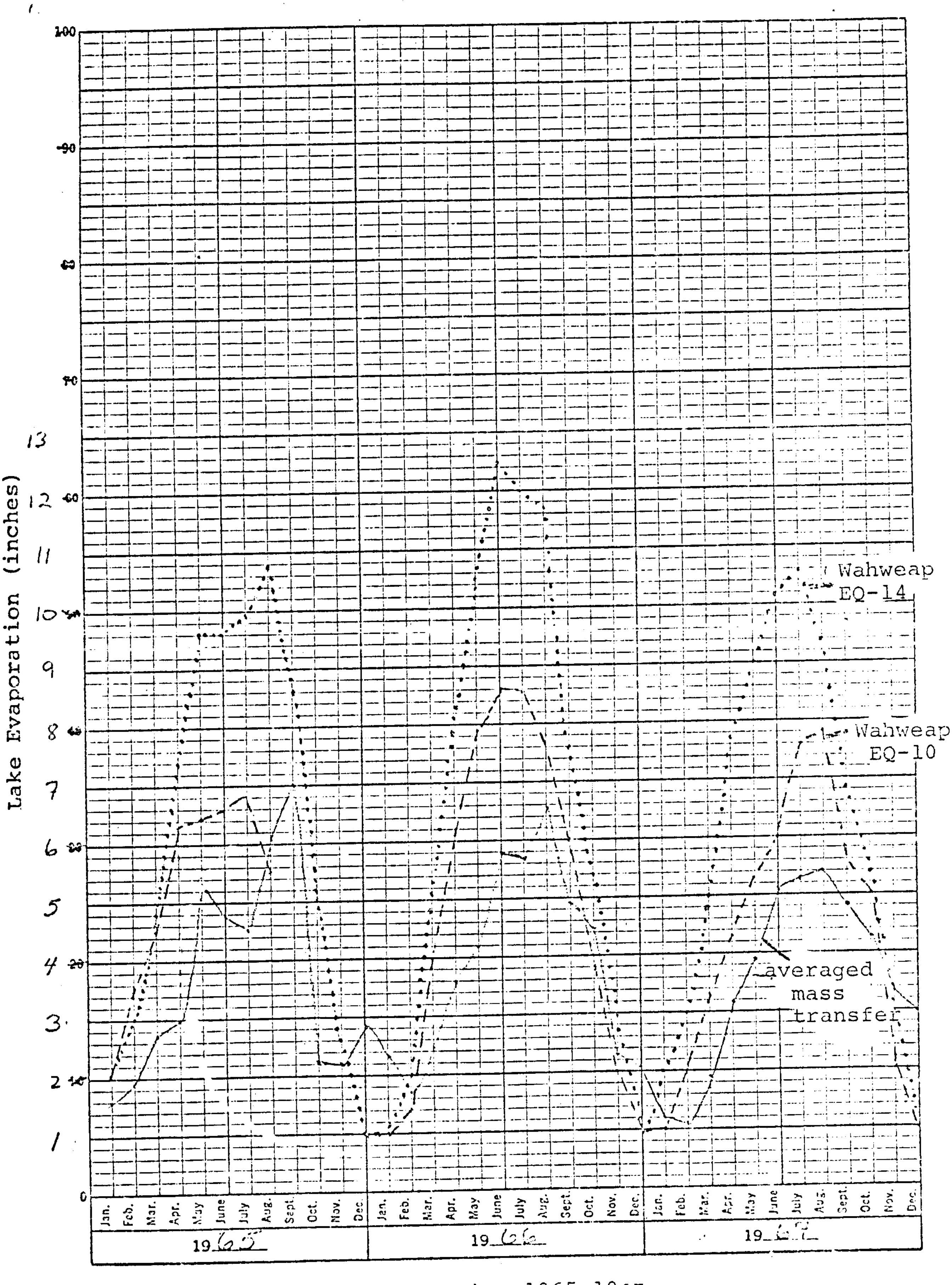


Figure 11. Monthly evaporation 1965-1967.
(based on Bureau of Reclamation data)

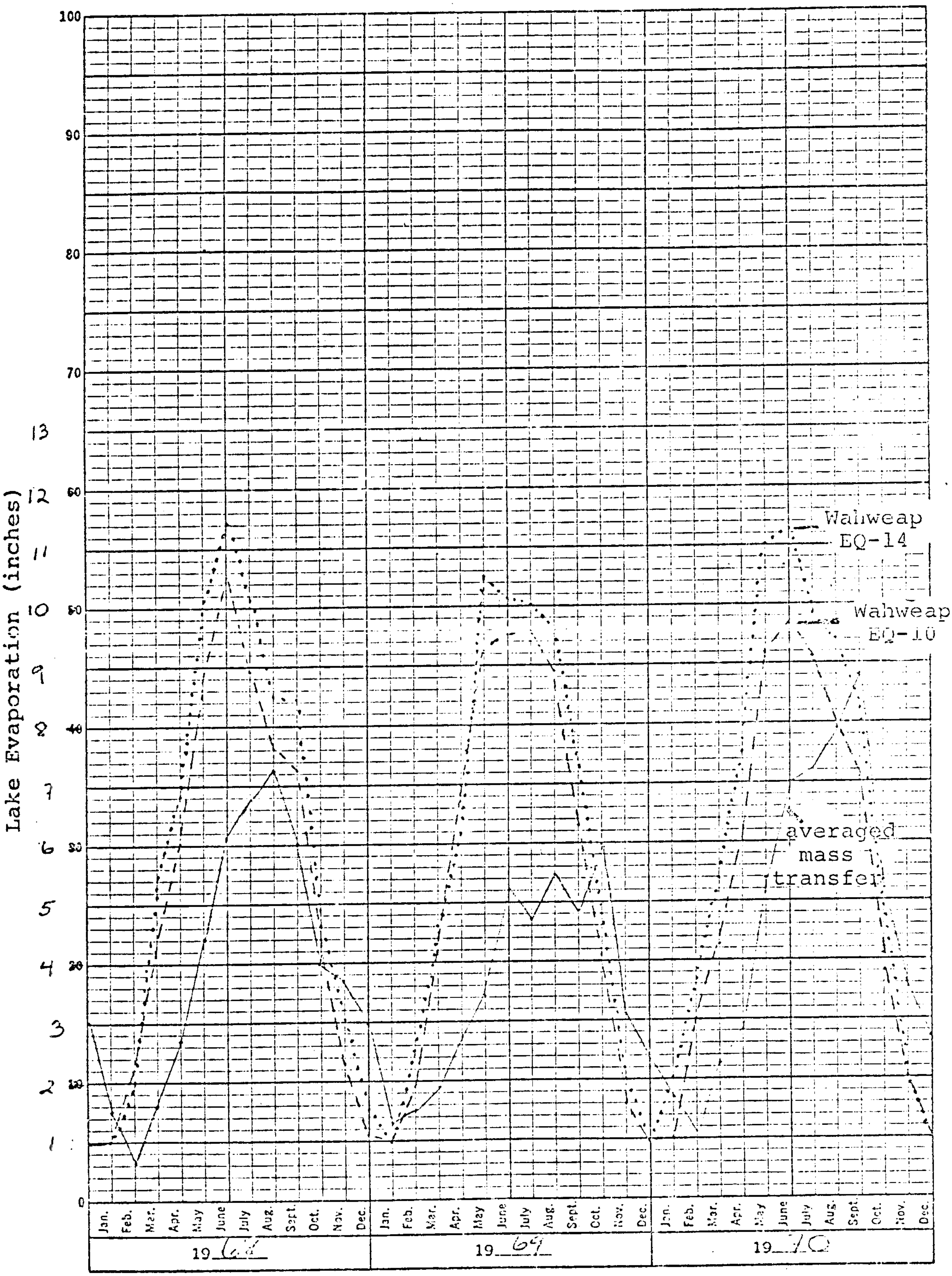


Figure 12. Monthly evaporation 1968-1970.
(based on Bureau of Reclamation data)

BANK STORAGE: Orson Anderson and Gordon Jacoby

In June of 1972, a survey was made of the Colorado River canyon from the dam down to Lee's Ferry. One undocumented spring was examined near the ferry site. There was no evidence that any new springs or seeps attributable to the lake or related to bank storage had developed as of the date of this survey. The exception to this statement is in the immediate vicinity of the dam itself. The formations in contact with the lake are: Entrada, Carmel, Navajo, Kayenta, Wingate, Chinle, Moenkopi, Cutler, and Rico. These formations range from the Upper Jurassic Entrada to Permo-Pennsylvanian Rico. In the summer of 1972, these formations were examined in the field, fracture systems were measured, and transparent overlays were made to show what portions of the Lake were in contact with particular formations.

From the map studies, two tables were developed showing the areas and relative amounts of the formations in the actual substrate and shoreline of the lake and the areas and relative amounts within a 2-mile distance from the lake. These figures are shown in Tables 11 and 12.

In appraising these formations as reservoirs for bank storage, only the Chinle is excluded as an aquiclude. The Carmel and the Moenkopi have some thin low-permeability layers, but, partly due to the presence of these layers, these formations often have a high fracture density and therefore can receive significant amounts of water.

In all cases, the presence of fractures in the formations is of major importance. The mapping and analyses of the fracture systems were done by Ron Nelson during the summer field season. On the basis of this field work, he was able to designate four sites for possible drilling of test wells.

In September, these four sites were examined by Orson Anderson and Gordon Jacoby. The conclusions of this later study were that the sites near Hole-in-the-Rock and Hite would be most feasible for test wells. A third site near the head of Bullfrog Bay would be of great interest; however, there is no access route that would not require extensive and expensive road construction.

The Bureau of Reclamation has tentatively agreed to underwrite the drilling of test wells at the Hole-in-the-Rock and Hite sites.

Thin sections have been made from the rock samples collected in the summer of 1972. Also, triaxial tests have been made on 1/2-inch cores cut from the samples. These tests and examinations have shown the Navajo and Entrada to be relatively weaker and less cemented compared to the Wingate, which has a much higher ultimate strength. The twinning in the calcite cement in oriented thin sections of the formations is being used to study the regional and structural fracture systems.

Table 11. Areas and Percent Areas of Geologic Formations Under Lake Powell

Geologic Formation	Area (sq. mi.)	Area (% of total)
Navajo	103.5	38.2
Carmel	49.5	18.3
Permian & lower (undivided)	44.2	16.3
Chinle	30.0	11.1
Kayenta	14.6	5.4
Moenkopi	10.8	4.0
Wingate	9.5	3.5
Entrada	8.4	3.1
TOTAL:	270.5	99.9

Table 12. Areas and Percent Areas of Geologic Formations Within a 2-Mile Distance of Lake Powell

Area	Area (sq. mi.)	Percentages
Navajo	496.96	40.4
Chinle	168.32	13.7
Cutler	163.68	13.3
Kayenta	160.64	13.1
Wingate	75.68	6.2
Moenkopi	70.24	5.7
Carmel	58.40	4.8
Entrada	34.72	2.8
TOTAL:	1,228.64	100.0

Table 13. Bank Storage

	Calculated (acre-ft.)	Estimated by Bureau of Reclamation (acre-ft.)
Fall 1967	4,000,000	3,814,000
Fall 1972	7,000,000	6,936,000

The data from the observation wells of the Bureau of Reclamation have been analyzed by Orson Anderson. The results so far indicate that increases in head, raising the lake level, produce large, nonlinear increases in the overall permeability of the formations, Navajo and some Entrada, in which the wells are drilled. These increases are attributed to the presence of fractures that dramatically increase the overall permeability when reached by bank storage waters as the lake level is raised.

Model Studies

A model of the bank storage situation was made by drawing a map of the area within 2 miles of the lake at full capacity. This area was then subdivided into different geologic formations that are in contact with the lake. The subareas were measured by polar planimeter to determine the areas shown in Table 12. The total area of this 2-mile zone is 1,228.64 square miles. This does not include the surface area of the lake which would be 266.6 square miles at full capacity. The area of the 2-mile zone is very irregular as it follows the San Juan arm, tributaries, and bays (see Figure 13. For geometric simplicity, the area can be straightened out to a 4-mile wide surface bisected by the lake , as shown in Figure 14. Dividing the area by 4 yields an effective length of 307 miles.

At full capacity, the surface area of Lake Powell is 170,620 acres and the volume is 29,875,000 acre-feet. Dividing the volume by the area yields a mean depth of 175 feet. Using a water table slope of 0.0125, which is believed to be representative, the width, W, of the bank storage zone becomes about 7,000 feet or approximately 1-1/2 miles. Using this water table slope and saturated zone width, the volume of this zone can be calculated to estimate bank storage. Assuming an effective porosity of 25% and subtracting the Chinle aquiclude, 13.7%, the volume is 15.8 million acre-feet.

Twice since the beginning of Lake Powell the level has been relatively constant for a year or two; the first time during 1965 through 1967 and the second time during 1971 through 1972. For each of these stages the average depth and effective length were used to calculate bank storage. The respective calculated figures and Bureau of Reclamation estimates are shown in Table 13. The figures are close enough to indicate that the model may be valid. If it is, the bank storage at capacity could reach about 16 million acre-feet and have a time constant for storage of about 2 years. This model is a vast oversimplification and needs to be refined and re-evaluated as more data become available.

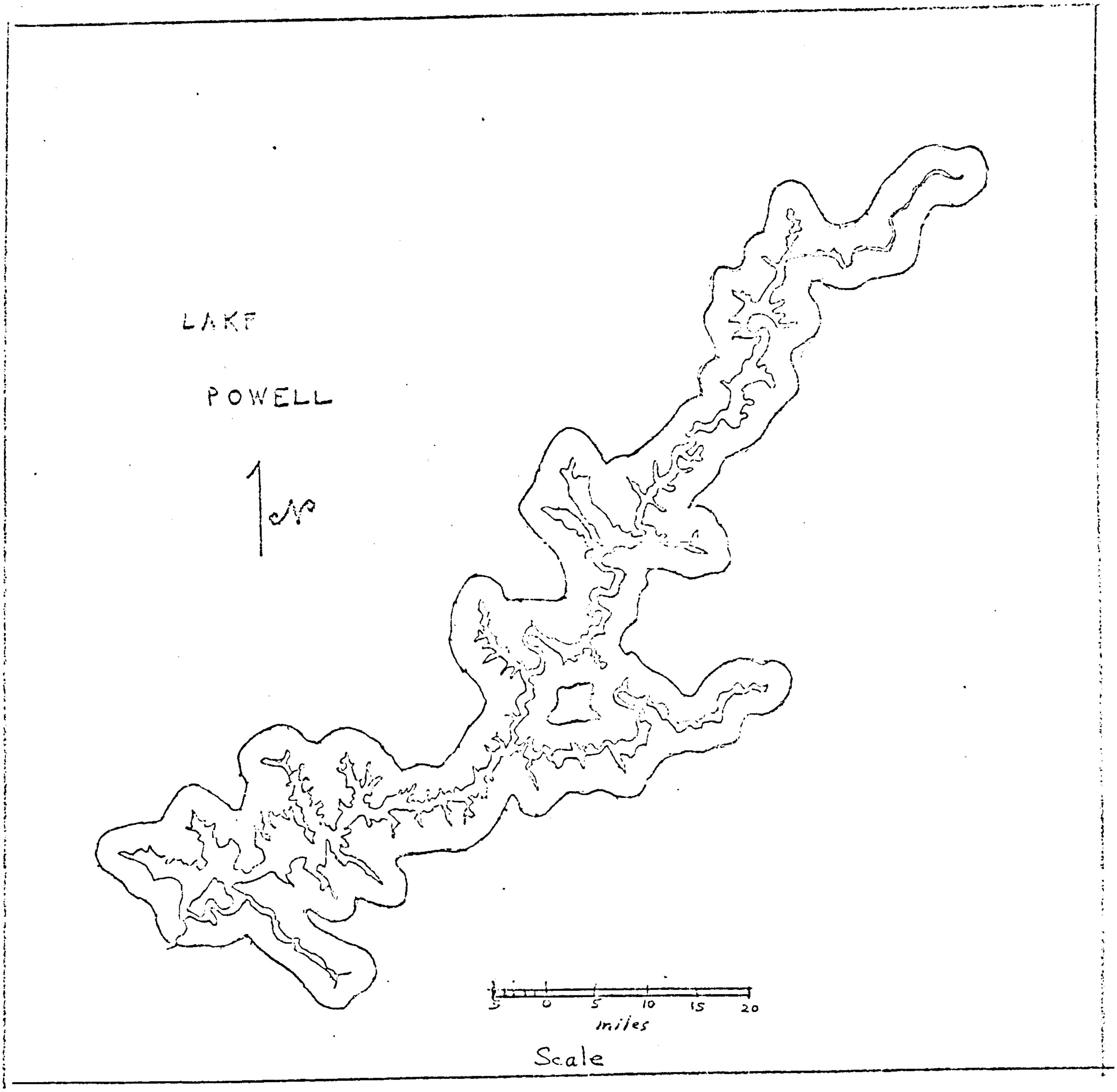
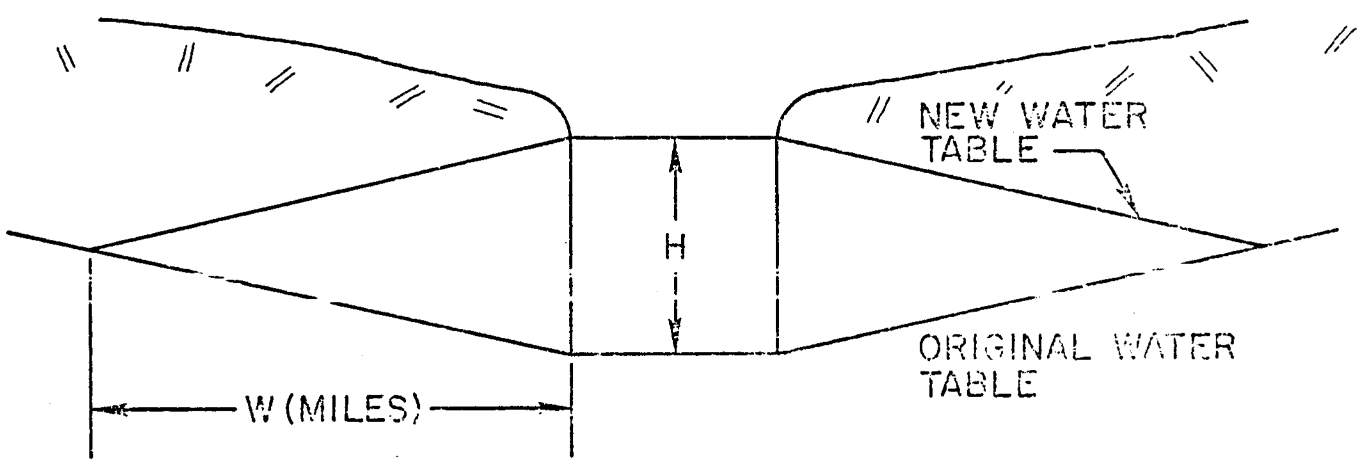


Figure 13. Map of Area Within 2 Miles of Lake Powell.



CROSS SECTION OF BANK STORAGE MODEL

Figure 14. Cross Section of Bank Storage Model.

PHYSICAL LIMNOLOGY: Noye M. Johnson

A quarter-year sampling schedule has been established and maintained during the past year on Lake Powell for the measurement of seasonal (a) temperatures, (b) electrical conductivity (salinity), (c) oxygen, (d) chemistry, and (e) turbidity distribution. An irregular schedule for the direct measurement of withdrawal currents in the lower half of the lake has also been intitiated during the past year. The distribution, change, and rate of change of these parameters will ultimately define the mode and manner of the lake's stability and/or circulation. A sufficient data base of this kind will be in hand by 1975. This data will then provide the stimulus and means by which the analysis and modeling of the lake's dynamics may proceed. In preparation for this phase of the study, a computer data bank has been set up on the Dartmouth computer system to facilitate the retrieval, plotting, and treatment of the Lake Powell data. The data bank presently contains all data collected to date. Although comprehensive analyses and conclusions will probably not be feasible until 1975, several conspicuous and interesting results have already emerged from our study. Significantly, most of these conclusions have resulted from the remarkable and unsuspected role that dissolved oxygen plays in the lake's chemistry and circulation. Some of the general conclusions that may be stated so far include:

1. The lake is by definition meromictic (partially mixed) at its lower end. However, the anaerobic conditions conventionally associated with this state were precluded in 1971-72 by mechanical mixing processes at depth during late spring.

2. In summer, Lake Powell shows an exemplary negative heterograd dissolved oxygen profile. As yet the cause of this oxygen distribution is not entirely certain.

3. In winter, the lower lake shows a remarkably conservative oxygen content at depth. At this time, dissolved oxygen is a convenient and crucial tracer for movement of water masses.

4. The inter-water withdrawal currents in the vicinity of the dam are instrumental in modifying the dissolved oxygen distribution in the lower lake. These withdrawal currents, therefore, have a direct bearing on the water quality of the lower lake.

5. The rate of change of dissolved oxygen in bottom waters seem to provide an accurate index of mixing and/or respiration at depth.

6. The change of salinity in the upper waters during early fall suggest that side tributaries are the major evaporating surfaces in the lake system, outweighing the

main-stem in relative effect.

7. Inflow turbidity currents are present all during the year, appearing below the epilimnion level in summer.

8. No seiches or internal waves at the thermocline level are present in the lake. Vertical mixing by this means is,therefore, precluded.

Some of the observations cited above have a direct bearing on the original questions posed in this study; i.e. the biologic productivity and potential of the lake, and the effect of the lake on downstream water quality.

CHEMICAL LIMNOLOGY: Robert C. Reynolds

The fundamental objective of the chemical limnology sub-project is the development and refinement of a chemical model for Lake Powell. The model will predict (1) the vertical and lateral salinity of the lake, and (2) the net salt output of the Colorado River downstream of the dam. Factors that control water composition in the lake and downstream include (1) water use practices in the Colorado River drainage basin, (2) schedules of water release from Lake Powell, and (3) the detailed circulation patterns within the lake. Because the latter constitutes the main objective of the Dynamic Limnology Subproject (Johnson), close articulation of the progress of chemistry and dynamics will be necessary for the successful completion of both subprojects.

Efforts directed toward development of the chemical model during the past year may be divided into several categories, and these are as follows:

1. Field work and sampling.

2. Chemical analytical work.

3. X-ray analysis of bottom sediments.

4. Computer processing of analytical results.

5. Laboratory studies of calcium carbonate precipitation in Lake Powell water.

6. Input and computer accessing of USGS data on the water chemistry of the major tributaries.

Larry Mayer and Robert Reynolds spent a total of 60 man days on the lake during the summer and fall of 1972. 155 water and 50 mud samples were collected. These were collected from the main channel and from the bays and lesser tributaries that drain into the lake.

Chemical analyses of the water samples is approximately 2/3 completed. Coupled with data collected by the Bureau of Reclamation, these analyses present a comprehensive picture of the lake chemistry for the year 1972.

Reconnaissance x-ray diffraction studies of all mud samples have been completed and refined analyses of clays are in progress. Cores collected by the Sedimentology Subproject (Drake) are a useful augmentation of the sample series. All clay work will be completed by the end of the summer 1973.

A computer model has been completed that takes into account all significant ionic interactions and predicts the degree to to which the waters are oversaturated in calcium carbonate, given a chemical analysis and pH value. The model has been laboratory-tested and is considered sufficiently refined to be used routinely for estimating the saturation of Lake Powell water with respect to calcium carbonate.

A laboratory system has been assembled and tested that measures the kinetics of calcium carbonate formation in samples of Lake Powell water. Temperature and partial pressure of CO_2 are controlled, and continuous recordings are made of pH and conductivity. Calcium carbonate precipitation is indicated by a drop in conductivity, and the pH at that point can be used, in conjunction with the computer model, to calculate the degree of supersaturation necessary to initiate precipitation. This equipment will be used to measure nucleation and precipitation rates. These values constitute an important part of the final chemical model for the lake.

Computer programs were written that utilize USGS water analyses and discharge data from the Green, Colorado, and San Juan rivers; the programs allow an estimate of the annual salt flux delivered to Lake Powell, and these data, together with our water analyses and those of the Bureau of Reclamation, should allow overall evaluation of the extent and types of changes in salt balance in the Colorado River that are caused by the Lake Powell impoundment. To date, approximately 2000 discharge and 100 chemical analyses have been transcribed to computer tape for this purpose. The computer model also indicates which ionic constituents are most closely associated with each of the major tributaries. Such information will allow prediction of the probable effect on the lake of changes in water regime in each of the three main drainage basins, the Colorado, the Green and the San Juan.

The following constitute the major findings to date.

1. Bays such as Halls Creek and Bullfrog do not mix rapidly with water from the main channel. They may constitute separate systems that control certain aspects of lake composition. If the lake is allowed to fill to design maximum levels, the dynamic chemistry of the bay waters may dominate the chemistry of the lake.

2. All bottom mud samples contain mixtures of illite, montmorillonite, kaolinite and mixed-layer illite-montmorillonite. No evidence has been found that suggests alteration of the composition of the clays by reaction with lake waters. On the other hand, quantitative differences in mineralogy from place to place suggest that clay sedimentation will serve as a useful indicator of water circulation patterns, and of the extent of sediment contributions from bank slumping.

3. All surface waters in Lake Powell are oversaturated in

calcium carbonate. The condition is maintained by photosynthesis in the upper waters which withdraws CO_2 and leads to an increase in pH (see Biology Subproject, Kidd and Potter). Calcite precipitation must be a significant factor in changing the quality of water during is transit through the lake.

4. The three anions, SO_4, HCO_3 and Cl are most useful for identifying waters from the San Juan, Green and Colorado rivers. A simple mixture model serves adequately to predict the composition of the input to the lake, given the discharges from these three tributaries (USGS data).

SEDIMENT STUDIES OF LAKE POWELL: Charles L. Drake

Introduction

The sediment studies of Lake Powell are aimed at the problems associated with the distribution of the sediments in the lake, their sources and the means by which they reach their deposition sites. These studies include examination of the character of the sediments and their rates of deposition in different parts of the Lake.

Field Activities

Much time was lost early in the summer field season through late delivery of equipment. When it arrived, the field activities were carried out aboard the UNM Nautaline houseboat, the Kayot barge, purchased by Dartmouth from O. Anderson and the Boston Whaler purchased with contract funds by Dartmouth College.

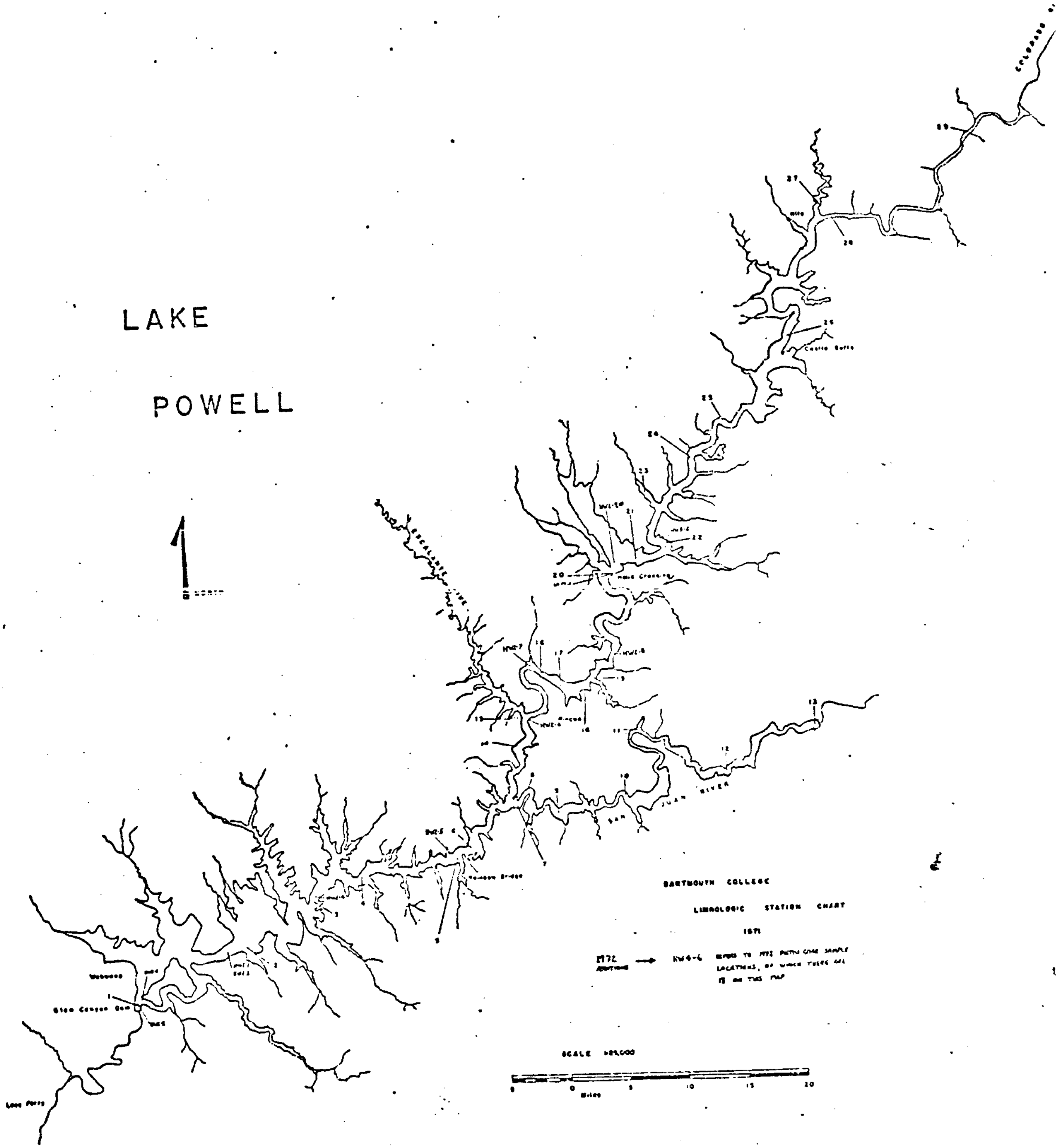
Sounding runs were made of the Colorado River Channel from the Glen Canyon dam to Halls Crossing and of the Colorado River Channel from the confluence of the Colorado to Clay Gulch (mile 51) in August, 1972. Scheduling problems with the houseboat prevented completion of the soundings to Hite until late October, early November 1972.

For reasons of economy, the ORE seismic reflection profiler was replaced by a Ross Fineline echo sounder. This equipment had the advantage of a higher frequency, narrower beam output, which makes for better resolution of bottom features, but the disadvantage of a lack of precision timing so that it is more difficult to compare bottom elevations accurately with those of surveys made before closing of the dam. Thus it is more useful in looking for annual changes than for absolute quantities of sediment. Since the 1971 data using the ORE equipment gave a good measure of absolute quantities, this problem is more annoying than critical.

Coring was carried out aboard the Kayot barge. A gasoline powered winch and a coring frame were installed so that piston cores could be obtained.* During the 1971 field season gravity cores were taken, but these were very short, averaging about one foot in length. The piston corer has the capability of obtaining cores ten feet or more in length that go farther back in time and permit better understanding of sedimentation rates. Fifteen cores were taken in the Colorado River Channel between the dam and Halls Crossing, thirteen in August and two in October-November. These were returned to Dartmouth for examination (Fig. 15).

*Because the buoyancy of the catamaran was marginal with all equipment aboard, the space between the floats was filled with large styrofoam blocks, an arrangement that was satisfactory for all factors except speed of the vessel.

Figure 15. Dartmouth College Limnologic Station Chart.



Results

The 1971 reflection profiling established that the total quantity of sediments in Lake Powell is equivalent to that expected from measurements of suspended sediment and total flow of the various tributaries. As anticipated, the bulk of the sediments are those transported by the Colorado and San Juan Rivers and deposited in deltas near the ends of the Lake. Minor amounts of sediment are brought in by floods in side canyons and locally significant amounts of sediment enter the Lake by sliding and slumping.

The slumps have an effect in addition to contributing to the total amount of sediments in the Lake. Where slumping has occurred in considerable quantities, especially where the Chinle formation outcrops along the Lake, underwater dams have been built that inhibit bottom transport of sediments to regions farther downstream. These underwater dams are especially significant between miles 10-21 (from confluence) along the San Juan and miles 142-152 (from Lees Ferry) (Fig. 16) along the Colorado River. In both of these areas the sediments are considerably thicker behind the slumps than in front of them. Thus these structures have the effect of slowing the movement of sediment down lake towards the dam. Similar slumping takes place below the Rincon (miles 96-101) on the Colorado but because the sediment influx upstream has already been seriously inhibited by the slumps above mile 142, there is little difference in the amount of sediments on the upstream and downstream sides of these slumps.

It appears, then, that sedimentation rates in that part of the lake below mile 10 on the San Juan and mile 142 on the Colorado will be quite slow and due principally to the gradual particle by particle settling of very fine grained material. This is borne out by preliminary examination of the cores which, except in slump areas, tend to be very fine grained clays and muds.

This program benefited from maps of the outcrop geology of the Glen Canyon area, prepared by the bank storage group, which clearly showed areas of outcrop of various formations (especially Chinle) which constitute the wetted perimeter of the lake.

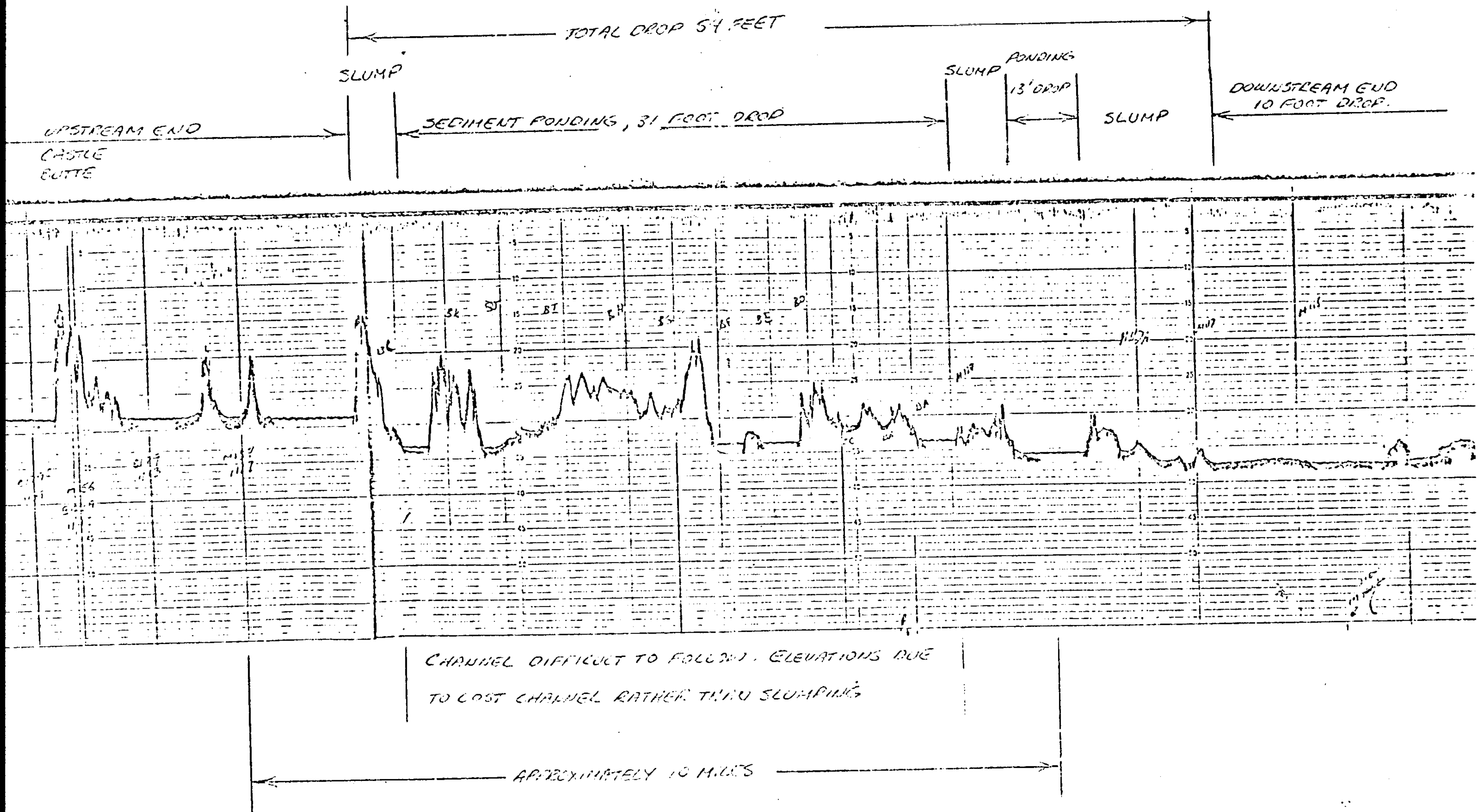


Figure 16. Reflection Profile of Sediments in Lake Powell.

BACKGROUND AIR QUALITY: Eric G. Walther and Michael D. Williams

This report is divided into:

1) Measurement and Statistical Analysis of Ground-Level Background Air Quality.
2) Communication with Systems Analysis Subproject.

1) Measurement and Statistical Analysis of Ground-Level Background Air Quality.

Daily readings of the aerosol number concentrations have been obtained since 3 September 1972 with a Small Particle Detector. Some statistical measures of the aerosol data are given in Table14. The monthly means are all less than 1500 cm^{-3} which is much lower than the mean of 10,000 cm^{-3} for measurements made in Flagstaff, Arizona, [3] but higher than the median of 520 cm^{-3} [4] and the mean of 900 cm^{-3} [5] for oceanic measurements tabulated by others. The minimum of 280 cm^{-3} obtained in December 1972 is an extremely low value usually obtained only in very clean regions. All readings below 5000 cm^{-3} are considered to be background values while higher readings are rejected as contaminated.

Hydrocarbon analysis by gas chromatography is continually being improved, but so far only methane has been confidently measured. The data obtained since 23 October 1972 is statistically summarized in Table15. The overall mean of 1.66 ppm is higher than the 1.5 ppm [6] [7] and the 1.2 ppm [8] but lower than the maximum value of 2.4 ppm [9] measured by others.

Recently, the gas chromatograph was successfully modified with a nickel catalyst column to measure carbon monoxide (CO) after converting it to methane for detection by flame ionization. CO data is expected for presentation in the next progress report.

After extensive testing of the sound instrumentation in the field, it was discovered that it is so quiet at remote sites in the Lake Powell region, less than 30 dBA (decibels weighted on the A scale to simulate the human hearing response), that the instrument indicated incorrectly because of internal electronic noise in the amplifier. This problem has been remedied, by the addition of a preamplifier and recalibration. Preliminary readings since indicate a minimum sound level of 25 dBA near Antelope Rock, Navajo Route 22, and the Navajo Generating Station under construction.

Initially it was assumed that all of the air quality parameters measured by this and other projects would require statistical analysis. Accordingly, computer programs for the analysis of all data were prepared. However, it has since been concluded that some data requires little or no statistical manipulation while in other cases it is felt the data should be examined for

Table 14. Aerosol Number Concentration Statistics

Start Date	End Date	Number of Data*	Concentration (cm^{-3}) Mean	Standard Deviation	Min.	Max.	Rejects
3 Sep.72	30 Sep.72	27	1458	622	580	3450	1
1 Oct.72	31 Oct.72	29	1288	517	580	2460	0
1 Nov.72	30 Nov.72	25	1428	965	580	4750	1
1 Dec.72	31 Dec.72	31	1116	592	280	3100	0
3 Sep.72	31 Dec.72	112	1313	710	280	4750	2

* Values $\geq$ 5000 cm^{-3} rejected as non-background.

Table 15. Methane Data and Statistics

Start Date	End Date	Number of Data	Concentration (ppm) Mean	Standard Deviation	Min.	Max.
23 Oct.72	31 Oct.72	7	1.66	0.63	0.88	2.67
1 Nov.72	30 Nov.72	23	1.55	0.27	0.96	2.05
1 Dec.72	31 Dec.72	31	1.73	0.25	1.26	2.36
23 Oct.72	31 Dec.72	61	1.66	0.32	0.88	2.67

differences related to man's activities. For this purpose the samples have been separated into several categories including urban, non-urban, and those obtained on the lake. Each of these categories has been further divided into weekday and weekend samples (including holidays). Samples related to local meteorology such as relative humidity and wind speeds have not been similarly separated.

Presently, complete statistical analysis programs are running for aerosol samples, noise samples, and relative humidity. For continuous measurements such as noise and relative humidity, daily averages, maxima, and minima plus the percentages of time the parameters exceed ten specified levels are calculated. Daily and monthly averages, minima, maxima, and standard deviations are presented along with frequency and cumulative distributions of daily, monthly, and total data. Aerosol number concentrations are treated similarly except, of course, that only monthly and total parameters are obtained.

Additional computer programs are being modified to handle data from the gas chromatograph and for some of the other parameters presently being measured by other investigations. Furthermore, raw data on measured particulate size distributions, local visual range, and visual range will probably be requested. This data would permit high-lighting of the effects of man's activities at the lake.

2) Communication with Systems Analysis Subproject

There will be four kinds of outputs associated with the air quality sub-contract: (1) predicted effects on visibility, sound and odor of man's activities, (2) predicted stresses of toxic air pollutants on terrestrial vegetation and animal life associated with man's activities, (3) predicted deposition rates on soil and water surfaces of potentially significant materials, and (4) a picture of current air quality in the region.

In each of the first three categories, there will be two components: (1) predicted effects associated with diffuse sources and (2) those associated with power plant activities. The first component will include auto emissions from both recreation related uses and from residents (including those working on power plant construction and operation), and the emissions from power boats. Predictions will be based on estimated emissions, dispersion calculations, and correlations found between man's activities and measured air quality parameters.

Visibility

To illustrate the nature of calculations performed we will consider the impact of air contaminant emissions on visibility. The principal parameter which will be used to characterize the impact on visibility will be the visible range -- the maximum distance at which the average observer can just distinguish a high contrast object. The visible range for an observer right next to a plume is:

$$VR = VR_b - \frac{VR_b}{3.0} \int \sigma dx$$

where

VR_b = the background visible range

$\int \sigma dx$ = the integrated light scattering and absorption across the plume.

The last expression has several components:

$$\int \sigma dx = \int \sigma_f dx + \int \sigma_{ps} dx + \int \sigma_{pn} dx + \int \sigma_{NO_2} dx$$

associated with the contributions from fly ash, particulate sulfate, particulate nitrate, and nitrogen dioxide. Each individual contribution can be written as:

$$\int \sigma_i dx = Q_a \, \chi(s,v,d) \, g(s,d) S_i \, C_{a \to i}(RH, \ell, t)$$

where Q_a = source strength of the contaminant a

$\chi(s,v,d)$ = concentrations resulting from a unit source during stability, s, at distance, d, with wind velocity, v.

$g(s,d)$ = shape function which related concentrations integrated over plume width to peak concentrations.

S_i = scattering and absorption per unit mass as a function of composition and particulate size distribution.

$C_{a \to i}$ = fractional conversion of contaminant a to i as a function of relative humidity (RH), light levels (ℓ), and travel time (t). $C_{i \to i} \equiv 1$.

The source strength Q_a can be further given as:

$$Q_a = (P.P.R.)(1 - E_a)R_a$$

with

P.P.R. = Power Production Rate

E_a = collection efficiency of control devices for contaminant a.

R_a = release rate of a for unit power production rate.

In general χ, g, and $C_{a \to i}$ will be determined numerically. VR_b will be determined from the ambient air quality data, while the distribution of relative humidities will be obtained from meteorological data. The final output will be a distribution function for the visual range, under varying assumptions of viewing angle, control level, and power output.

This treatment relates only to the defined portion of the plume. The contaminant sources will also contribute to the general background; this will be estimated also. In addition to description of the plume appearance a description of the frequency of its location and direction will also be presented.

The diffuse sources will be treated similarly except that the sources will be related to vehicle use rates and the plume will be a diffused one associated with a ground level-area source.

Air Contaminant Stresses on Plant and Animal Life

In this case predictions of ground level concentrations of contaminants known to be toxic to animal or plant life will be made. These concentrations will be given by:

$$\chi = Q_a \chi_g (s,v,d)\ C_{a\to i}(RH,\ell,t)$$

where $\chi_g(s,v,d)$ refers to ground level concentrations. The principal contaminants of interest here are: hydrocarbons (internal combustion engines), carbon monoxide (internal combustion engines), sulfur oxides (power plants), fluorides (power plants), phosphorus (power plants and internal combustion engines), nitrogen dioxide (power plants and internal combustion engines), and particulates (unpaved roads and power plants, both fly ash and converted sulfates and nitrates). This part of the program will identify locations expected for the maximum one-hour, three-hour, 24-hour, monthly, and annual averages. It will also predict frequency of occurrence of levels within 20% of the peak.

Concentrations above odor thresholds will also be identified. Summaries of threshold levels for plant damage will also be presented. Effects on plants can range from death to slight growth reductions.

Surface Interaction Effects

The deposition of a contaminant can be expressed as:

$$D_i = Q_a W(s,v,d) C_{a\to i}(RH,\ell,t) f(\vec{v},s) A_i(m)$$

where $W(s,v,d)$ gives the interaction rate for unit source strength and $f(\vec{v},s)$ gives the frequence of occurrences of stability, s, wind velocity and direction, $\vec{v}$. $A_i(m)$ is the surface absorption coefficient for contaminant i interfacing with surface of material m. The principal materials of concern fall naturally into four categories: (1) nutrients which can increase the growth rate of some types of vegetation, (2) toxic materials which may concentrate to levels in soils which are capable of poisoning plants or poisoning animals which feed on the plants, (3) materials which may interact with material surfaces and alter their characteristics, and (4) materials which can degrade water quality for some uses. The first category includes phosphorus, nitrates, iron and potassium. The second category includes lead, arsenic, selenium, and molybdenum. The latter two share the property that they can accumulate in plants to levels which are toxic to animals without damaging the plants. The third category includes acids such as sulfuric acid, phosphoric acid, and nitric acid. Sulfur oxides may also interact with materials. The result of the interaction could be the elimination of surface features such as pictographs or desert varnish. Features such as petroglyphs which are relatively deeply etched into the surfaces are much less likely to be affected.

Nutrients are apt to be particularly significant in an aquatic environment where relatively small amounts of critical nutrients may produce algae blooms with possible odors and fish kills. Calculations of direct deposition of these materials on water surfaces will be presented along with amounts deposited on watersheds draining into Lake Powell.

Noise

Noise will be a particularly important parameter of the measurement program. It is hypothesized that noise levels will influence the recreation which occurs at the lake. The measurement program will permit some extrapolation of noise levels.

ENVIRONMENTAL IMPACT ASSESSMENT PRACTICE AND ITS REGIONAL IMPLICATIONS, LAKE POWELL REGION: Robert H. Twiss, Luna B. Leopold, Donald W. Aitken, and Nancy Wakeman.

The collection of impact statements, in draft or final form, which has been made, was in itself sufficient to indicate that projects being considered within the Upper Colorado River Basin, may have unevaluated but potentially important effects on Lake Powell, and on the region, as well as in the local vicinity. Yet, nearly without exception, the impact statements were concerned with only the local or near site effects.

The impact statements do not represent all of the construction or development projects that might be in the planning stage, but provide a sample. The reports studied for the Upper Basin, grouped in broad categories, are of the following character and number:

Alterations in wilderness	8
Highway construction	9
Weather modification	2
Power development	10
Water development	14
Mineral development	8

Lists of impact statements were scanned, copies requested and a final selection made from those received. Both final and draft statements were chosen to see if it were possible to compare stages in the development of impact statements.

This avenue does not appear to be fruitful. For example, the impact statements on the AEC's Wagon Wheel Gas Stimulation Project revealed that they were identical with the exception of an appendix of letters from reviewers.

Interviews with agency personnel responsible for writing impact statements were conducted. While most agencies acknowledged problems, the reasons for inadequacies differed from agency to agency. In some cases, staff was narrowly trained or undermanned, in most cases budget was limited, and in a few cases a handpicked staff, while competent, reflected strong bias toward restricted agency objectives.

The available reports have been subjected to an initial characterization dealing with three principal categories:

1. Presentation of Material
2. Technical Content
3. Project Purpose and Justification

Under each of these sub items the impact statements which the investigators thought might profitably be included were listed. A sample of the reports was analysed to see to what extent there was an adequate discussion of each category of subject matter. In this manner a sample of the reports has been evaluated, while at the same time an amended and growing list was compiled of the characteristics which a full and useful impact report should contain.

The development of this as yet incomplete list of the characteristics of a good impact report will help give direction to the work to be carried out in the forthcoming year.

The most important finding to date has been that no agency seems to have developed a method or even an approach to the problem of relating a particular project to the region, and to downstream effects. It is in this regard that the subprojects dealing with water quality, lake sedementation, lake water chemistry, and others are important to -- and will interact with — the subproject on impact assessment. For example, the impact assessment subproject will aim at developing a regional picture of new sources of chemical alteration of water quality, and this will be related to the results of the subproject studying water quality in the lake and in the inflowing rivers.

Table 16. Partial List of Impact Statements, Upper Colorado River Basin

WILDERNESS/REC.

Legis. Prop. to designate as Wilderness 7,700 acres of Colorado Nat'l. Monument, Colorado.

Legis. Prop. to Designate as Wilderness 8,780 acres of Gunnison Nat'l. Monument, Colorado.

Legis. Prop. to Designate as Wilderness 16,303 acres of Bryce Canyon Nat'l. Park, Utah.

Flat Tops Wilderness Routt and White River Nat'l Forests, Colorado.

Legis. Prop. to Designate Pine Mountain Primitive Area as Pine Mountain Wilderness, Prescott & Tonto Nat'l. Forests, Arizona.

Legis. Prop. to Designate Sycamore Canyon Primitive Area as Sycamore Canyon Wilderness, in Coconino, Kaibab & Prescott Nat'l. Forests, Arizona.

Grand Teton Nat'l. Park Master Plan 72-31 Increase Public Use.

Trois Teton Wilderness Area, Wyoming, Designate Wilderness in Grand Teton Nat'l. Park.

HIGHWAY

Construction of Elk Mountain Road in the Santa Fe National Forest, New Mexico.

Colorado River Bridge (Joint Project), Yuma County, Arizona.

Rio las Vacas - Senorita Section, Santa Fe Nat'l. Forest, Sandoval County, New Mexico.

SR-87: Mesa-Payson (Beeline) Hwy., Gila County, Arizona.

Arizona Forest Highway 3 Coconino Nat'l. Forest.

Squaw Flat Confluence Overlook Road, Canyonlands, USDI.

Jim Bridger National Forest, Wyoming.

Confluence Overlook Road, San Juan Utah, const. of paved road. Canyonlands Nat'l. Park.

Shiprock to Farmington San Juan Co., New Mexico four-lane divided highway, Navajo Reservation.

Table 16., cont.

POWER DEVELOPMENT	WATER DEVELOPMENT
El Paso Natural Gas Project, New Mexico.	China Meadows Dam & Reservoir, Lyman Project, Utah.
Broomfield Water Transmission Line, Broomfield, Colorado.	Bear Lake Creek, Colorado.
Transmission Line from Hayden to Wolcott to Vail, Routt & Eagle Counties, Colorado.	Pueblo Dam & Reservoir, Fryingpan-Ark. Project, Colorado.
Construction of Coal-Fueled Electrical Generating Station, Hayden, Colorado.	Guadalupe Watershed Project. Maricopa County, Arizona.
Lyman to Torrington, Wyoming Construction of Transmission Line.	Proposed Waste Treatment Project, Col. 261, Greeley, Colorado.
Navajo Project, Arizona.	Crystal Dam, Curecanti Unit, Colorado River Storage Project, Colorado.
Kortes Unit, Pick-Sloan Missouri Basin Program, Wyoming.	Bear Creek Dam and Lake, Colorado.
Proposed Geothermal Steam Leasing Program: Alaska California, Idaho, Utah, Montana, Nevada, New Mexico, Oregon, Washington, Arizona, Colorado, South Dakota, Wyoming.	Pecos River Basin Water Salvage Project, New Mexico and Texas.
San Juan Generating Station Coal Mine & Transmission Lines, Colorado.	Las Cruces Local Flood Protection Project, New Mexico.
Huntington Canyon, Emery Co., Utah, Coal burning thermal elec. gen. station.	Central Arizona Project, Arizona.
	Legislative Proposal: San Luis Valley Project, Colorado.
	Navajo Project, Arizona.
	Yellow Jacket Project, Colorado.
	Twin Lakes & Mt. Elbert Lake Co. Colorado., Dam & Reservoir.

Table 16., cont.

MINERAL RESOURCE	WEATHER MODIFICATION
Rio Blanco Gas Stimulation Project, Rio Blanco County, Colorado.	Colorado River Basin Pilot Project for Weather Modification.
Navajo Project, Arizona.	Winter Orographic Cloud Modification Experiment.
San Juan Generating Station Coal Mine & Transmission Lines, Colorado.	
Black Mesa, Arizona.	
Project Wagon Wheel, Wyoming.	
Proposed Prototype Oil Shale Leasing Program, Wyoming, Utah, Colorado.	
Experiment "Mixed Co.", Mesa Co., Colorado, Experiment with explosions.	
Colorado, Utah & New Mexico Leasing AEC Land to priv. industries.	

ECONOMICS: Shaul Ben-David and F. Lee Brown

The major progress of the Economics subproject lies in the development of an explicit conceptual framework within which the economy of the Lake Powell region can be currently described and from which projections as to the future course of that economy under alternative internal and external management decisions can be projected. This framework arose from the conjunction of an increased familiarity with the working economy of the region and the necessity of answering questions addressed to the Economics subproject by the project as a whole. Although effort has been and is being expended aimed towards the quantitative fleshing out of this conceptual framework, it seems useful in this progress report to emphasize the economic model as it has been constructed since this model has not been formally laid out heretofore in the literature of the Powell project.

The basic research model will be a regional accounts system in which the financial interactions of the important economic units of the region are linked together as well as to those units outside the region which are either recipients of expenditures from within the region or are purchasers of goods or services from the region thereby being providers of funds to the region. If the qualifications necessary are specified carefully, the term input-output model may be used as a descriptive term for this accounts system. (See Table17.) First it is a financial I-O model and not a materials I-O model. The assumption, therefore, is not of linear production relationships but rather of linear financial relationships. This circumstance raises the possibility that the constancy of financial coefficients will arise in the proportion of sales going to a particular sector as opposed to the usual assumption of a constant proportion of purchases arriving from a particular sector. This raises no theoretical difficulty with the application of the I-O technique, however. A second distinction that should be drawn from the standard model is in the determination of the sectors appearing in the model. The accounts are between economic units on a firm or institutional basis and not be category of product or service. This breakdown stems from an interpretation of the needs of the project as a whole in which there seems to be little need for projections related to a category such as automobile services region-wide and more need for knowledge of the potential effects of alternative policies on such sectors as the Page secondary business community as a whole.

The division of the economic units in the accounts system into internal and external groupings rests on an understanding of the nature of the activity in which the unit is engaged as to whether it is a "local" operation or not. This distinction does not rest on ownership since, for instance, Babbitt's (a grocery and department store) will be included within the Page secondary business sector even though ownership resides in Flagstaff which is considered outside the region. Conversely, the Bureau of Reclamation's

Table 17. Lake Powell Regional Accounts

LAKE POWELL - REGIONAL ACCOUNTS

		INTERNAL																		EXTERNAL									
		Recreation							Secondary Business					Household				Power		Government									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
		RI-1	RI-2	RI-3	RI-4	RI-5	RI-6	RI-7	SI-1	SI-2	SI-3	CI-1	AI-1	HI-1	HI-2	HI-3	TE-1	PE-1	(PE-2)	GE-1	GE-2	GE-3	GE-4	GE-5	GE-6	GE-7	SE-1	CE-1	NE-1
1 Wahweap and Rainbow Bridge	RI-1	a				a		b	b					a	a	a	a			a	a								
2 Bullfrog	RI-2		a	b				b							a	a	a												
3 Halls Crossing	RI-3			a			b	b							a	a	a												
4 Hite	RI-4				a			b							a	a	a												
5 Page Recreation	RI-5	b				a	b	b						a	a	a	a	a		a	a							a	
6 Navajo Rec.	RI-6			b	b	b	a							a	a	a	a												
7 Moab & Other Rec.	RI-7		a		a	a		a						a	a	a	a												
8 Page	SI-1	a				a	b	a	a		b	a	a	a	a	a	a	a		a	a			a		a	b	a	a
9 Hite	SI-2		b		a		b	b		a			a		a	a	a										b		a
10 Glen Canyon City	SI-3	b				b		a	b		a	b	a		a	a	a										b		a
11 Construction	CI-1	a				a			a		b	a	a	a	a	a		b			a			a				a	a
12 Agriculture	AI-1	a	a	a	a	a		a	a	a	a		a										a						a
13 Page Ang. & Nav.	HI-1	a				a		b	a			a	a					a		a	a		a	a		a		a	
14 Non-Page Anglo	HI-2	a	a	a	a	a		a	a	a	a	a	a					a		a	a		a	a		a		a	
15 Non-Page Navajo	HI-3	a	a	a	a	a	a	a	a	a	a	a	a					a		a	a		a	a		a		a	
16 Tourists	TE-1														a	a													
17 Navajo	PE-1																												
18 Kaiparowitz	PE-2																												
19 Bur. of Recl.	GE-1																												
20 Park Service	GE-2																												
21 IRS	GE-3	a	a	a	a	a		a	a	a	a	a	a	[illegible]	a	a													
22 Federal Budget	GE-4	a	a	a	a	b																							
23 State & County	GE-5	a	a	a	a	a		a	a	a	a	a	a	[illegible]	a	a													
24 Navajo	GE-6						a									b													
25 Miscellaneous	GE-7	a	a	a	a	a		a	a	a	a	a	a	[illegible]	a	a													
26 Supply	SE-1	a	a	a	a	a	b	a	a	a	a	a	a		a	a													
27 Construction	CE-1	a	a	a	a	a	b	a	a	a	a	a	a		b	b													
28 Non-resident	NE-1	a	a	a	a	a		a	a	a	a	a		[illegible]	a	a													

The entry in the i^{th} row and j^{th} column represents the expenditures from the j^{th} unit to the i^{th} unit.

The letter a denotes a probable non-zero entry. The letter b denotes a possible non-zero entry.

operations are categorized as external even though they are physically located in the region. In this instance the decision rests on the fact that the scope of this unit's operation are influenced to a large extent by forces completely exogenous to the Lake Powell economy. This classification rule, while admittedly not a hard and fast boundary line, would seem to fit the needs of the project best.

While the I-O model itself describes financial flows, coefficients of employment can be developed which convert the individual economic unit's financial activity into levels of employment. These coefficients, while based on the previous employment and financial history of the unit, can be projected as changing should the underlying flow of events dictate or suggest such a change. In this manner a description of the total regional employment as well as the pattern of employment can be had and projections made concerning future levels and patterns of employment.

Flexibility with regard to projected values of coefficients is not confined to the employment coefficients, however. The transactions matrix of the I-O model, which describes the specific dollar flow from one matrix unit to another are being constructed from the financial records of the units themselves. The constancy of the technical coefficients themselves will be judged not only from the historical record evidenced by the transactions matrix but also through personal interviews with the individuals connected with each unit who are responsible for the pattern of expenditures that the unit has evolved and from whom the determinants of changes in that pattern may best be understood. If the basis for a shift in pattern can be developed for a future year from expected movement in these determinants, then the coefficients matrix for that year will reflect the adjusted pattern of expenditures expected and the totals and pattern of income and employment for the region adjusted accordingly.

Of the three major external sources of expenditures in the region - government, power, and recreation - changes in the pattern and levels of expenditures of the first two are best handled by the interview method outlined above together with input from the political science component. However, in the case of recreation decision-making does not rest with a single individual or small group of individuals. Instead determination of recreational expenditures at Lake Powell both as to pattern and level is a decentralized process with each consuming unit, be it individual, family, or group reaching decisions on their own hook independent of any centralized decision-making body. This is not an unusual situation but is a general characteristic of most of the final consuming sectors of an economy. What is unusual about this category of consumer expenditures is the relatively low degree of success that economists, sociologists, and other researchers have achieved by way of providing a general explanation of recreational behavior. Aside from developing income and distance, both conceptually and empirically, as variables determining this behavior precious little general theory exists which has any significant degree of operational power in explaining observed behavior. Since the first priority is the description of the Powell regional economy according to the framework developed above, the recreational relationship constructed and estimated will be an expenditure function as opposed to the usual demand function although information will be compiled on user days and the ability to convert to demand for purposes of optimization will be present.

Two approaches are being developed for the estimation of this expenditure relationship. The first, more traditional in nature, is to construct a multiple correlation (principal components) linking aggregate expenditure to correlated variables which conceptually can be linked to expenditures or which have been found to be correlated with expenditure in previous studies. The second, which is innovative in nature, is to break the set of recreational users and potential users into subgroups based on a similarity of expenditure habits (examples being considered are an activity basis such as fishing, boating, etc., or alternatively a personality characteristic basis such as persons who like to get away from everyone, persons who like to stay in comfort, etc.). Having broken the set into subgroups, the assumption would then be made that all users in a subgroup have essentially identical expenditure behavior and thus an expenditure relation at the individual consuming unit level can be estimated. This relation would be as equally applicable to potential users as actual users. Given that an individual's subclass could be determined, the only explanation for one unit having remained a potential user rather than an actual user is that his set of determining variables has not yet reached a threshold level for that class of users which must be crossed before that unit becomes a Lake Powell user. The threshold can be estimated by making intensive use of the first time users, gathering identical information on them for both the year before and the year in which they became a user.

Projections of future expenditures can be made by projecting the number of potential users in each subclass who will cross the threshold in a given year by considering a joint density function which describes the distribution of the determining characteristics among the population as a whole and projecting changes in this distribution over time. Aggregating the appropriate expenditures over the subgroups, a total expenditure from recreation to each accounting sector can be estimated as well as a basis for projecting future expenditures.

EPIDEMIOLOGY: Stephen J. Kunitz

The accomplishments of the first 6 months of this sub-project have been rather more methodological than substantive. As noted in the progress report of 23 October 1972, the first problems to be dealt with included: 1. some measure of the reliability of the Indian Health Service computer tapes and; 2. an estimate of the loss to the IHS data system represented by people seeking care in other facilities and paying for it by mechanisms other than government contract.

To deal with the first problem, a random sample of records from the Indian Health Service Area Offices in Window Rock and Phoenix covering fiscal years 1971 and 1972 was coded. To simplify the presentation, results will be shown only for the Window Rock Area Office for fiscal year 1971. For that office and year, 512 records were randomly selected and recoded. An attempt was then made to match the sampled records to the data provided by the Indian Health Service on their IBM tapes, which had been punched from copies of the same records. Of the 512, 47 (or 9.2 percent) did not match (the parameters matched were facility number, individual hospital identification number, and date). The remainder did match on these parameters. Table 18 indicates the other parameters that were matched once the original matching was completed. In general, the agreement is rather high between the recoding and the original, thus giving considerable confidence in the reliability of the IHS tapes. On the other hand, validity, which refers to the actual truth of the various items, such as birthdate, diagnosis, and so on, cannot be measured. Validity could only be established by interviewing the patients, reviewing the original medical record, and talking to the physician who cared for the patient, clearly an impossible task. Thus, validity will have to be assumed for the time being.

The loss of the 47 cases occurred primarily in two months, November, 1970 and June, 1971. In June especially there was a large loss. This is accounted for in the following way. When a patient is discharged from the hospital, a clinical record brief if filled out in triplicate (a specimen is provided in the original LPRP proposal). One copy stays with the original medical record, a second is sent for filing to the Area Office, and a third is used for keypunching directly to the IBM tapes. In June, 1971 several batches of the form used for punching were misplaced and have never been found.

To estimate the loss of patients to the IHS record-keeping system, all hospitals on and around the Navajo Reservation were visited to find out how many Navajo patients they care for and, of those, how many are paid for by other than contract funds supplied by the IHS. Anyone who is paid for by private insurance, workmen's compensation, medicare, or any other means will not enter into the system and would therefore be lost. Tables 19

Table 18: Agreement Between Random Sample and IHS Tape. F.Y. 1971 Navajo Area Office

	Match		No Match	
	Frequency	Percent	Frequency	Percent
Birthdate	450	96.8	15	3.2
Sex	463	99.6	2	.4
Tribe	465	100	0	0
Community of residence	458	98.5	7	1.5
Disposition date	458	98.5	7	1.5
Primary diagnosis	457	98.3	8	1.7
Disposition	461	99.1	4	.9

Table 19 : San Juan Hospital: Male
(minus newborns and stillborns)

Diagnostic Category	Non-Indians Percent	Non-Gov. Ind. (percent)	Gov. Ind. (percent)
Infective	5.51	9.33	7.53
Neoplasms	3.86	2.07	-
Endocrine	1.03	1.55	-
Blood	.66	-	-
Mental	1.43	-	2.15
Nervous	3.75	1.55	2.15
Circulatory	10.03	4.66	-
Respiratory	15.69	20.21	1.08
G-I	17.27	14.51	5.38
G-U	7.27	9.33	11.83
Pregnancy	-	-	-
Skin	1.47	3.11	1.08
Musculo-skeletal	2.79	1.04	-
Congenital	1.36	-	-
Perinatal	-	-	-
Ill defined	7.71	4.66	5.38
Accidents	19.58	27.46	63.44
Special	.59	.52	-
	2722	193	93

and 20 provide information on discharge diagnostic categories of Indian and non-Indian male and female patients from the San Juan County Hospital in Farmington, New Mexico for fiscal years 1971 and 1972 combined. It is clear that: a. those Indians paid for by government contract have a higher proportion of accidents and pregnancy than do either the non-Indians or Indians paid for by other means; and b. Indians paid for by other than government contract have a profile of discharge diagnoses which appear to be intermediate between the non-Indians and the Indians paid for by government contract. What these two findings indicate is that the payment mechanism probably reflects entry into wage work (and therefore coverage by insurance), and this in turn is reflected in a diagnostic spectrum which is more nearly akin to that of the Anglo, wage work world than it is to that found on reservation.

The data from the San Juan County hospital was better than from any other hospital. If it is assumed however that it represents a random sample of the diseases diagnosed by such facilities for Indians not covered by government contract; and if an estimated 500 Navajos in the region each year have hospitalizations paid for by other than government contract; and if it is assumed further that 60 percent of such patients are women; then it would appear that about 120 deliveries per year, 24 accidents among women, and 54 accidents among men are lost from the record keeping system. Other categories are of even less significance.

By these two exercises, it has been shown that the IHS records will cover with adequate reliability the vast majority of hospitalizations for the Navajo tribe. As accidents and pregnancies are two of the categories of hospitalization in which there is most interest, and as the loss to the record keeping system of such events appears to be minimal, it is evident that the data are adequate.

In addition to dealing with these methodological problems, a manuscript on changing fertility patterns of Navajo and Hopi Indians has been written. This will provide background material for analyzing fertility patterns as they are reflected in the IHS data at our disposal. It has also provided background material for a grant application to the National Institute of Child Health and Human Development for a study entitled "Fertility and Family Planning among the Navajo Indians." This study builds on work currently being done on the eastern end of the reservation but also incorporates much of the data from the anthropology sub-project of the Lake Powell Research Project. It should be known by May, 1973 whether this application has been approved and funded.

Finally, it should be pointed out that one of the major objectives of the Lake Powell Research Project and of the epidemiology sub-project is the understanding of the impact of modernization on a tribal society in an undeveloped area. Now that the IHS record keeping system has been explored sufficiently to know

Table 20: San Juan Hospital: Female
(minus newborns and stillborns)

Diagnostic Category	Non-Indians Percent	Non-Gov. Ind. (Percent)	Gov. payment (Percent)
Infective	4.21	6.62	4.69
Neoplasms	5.58	2.44	1.56
Endocrine	1.71	.7	-
Blood	.54	.7	-
Mental	1.35	-	1.56
Nervous	1.66	3.48	-
Circulatory	5.67	1.39	-
Respiratory	9.29	12.20	1.56
G-I	10.28	9.06	3.13
G-U	13.54	8.01	3.13
Pregnancy	29.79	39.02	45.31
Skin	.65	1.74	-
Musculo-skeletal	1.73	1.05	-
Congenital	.2	-	-
Perinatal	.02	-	-
Ill defined	5.24	4.53	3.13
Accidents	7.90	8.36	35.94
Special	.63	.7	-
	4445	287	64

many of its limitations, it ought to be possible to deal with these substantive issues in some detail.

Clearly, the study of changing fertility patterns depends on very close working relationships with the anthropology sub-project. Studies of air quality and respiratory disease have depended on collaboration with the air quality sub-project. As yet there has been no chance to explore some of the epidemiologic consequences of the high coliform counts reported by the biology sub-project.

Excellent cooperation from the Indian Health Service has continued. In addition, as noted in the first progress report, it is hoped that data and analyses provided by the epidemiology sub-project will be of help to the Navajo Health Authority in program planning for the future.

ANTHROPOLOGY : Jerrold E. Levy, Lynn Robbins and Roland Wagner

I. Progress: Data Collection

A. During the period from October 1, 1972 to January 31, 1973, the following tasks of data collection were performed:

1. Half of the field interviewing in the Page - Leche-e area has been completed.
2. Interviews of local Navajo politicians, community leaders, Anglo union officials and employers are continuing.
3. Interviewing in the Red Lake and Black Mesa areas has begun but is proceeding slowly due to heavy snowfall in the area.
4. A survey of earlier community studies on the Navajo is almost completed and most of the economic and demographic data have been tabulated.
5. Navajo workers employed at the dam and power plant have been identified and are currently being interviewed.

II. Problems

A. Current Problems - Integration with Systems Analysis

1. The major problem concerns the need to provide the Systems Analysis sub-project with quantifiable data as soon as possible. The Anthropology sub-project, however, is not scheduled to code and tabulate the field data until the summer of 1973 and computer print outs will not be available until sometime in September or October.
2. The Anthropology research aims primarily at synchronic data from which no causal statements can be made until restudy. Systems Analysis needs some indication of trends over time so that projections and causal links can be made. Restudies of the three areas would not be made until 1978, if then. In consequence, the quantifiable demographic and economic data being collected now cannot provide the directional indicators needed by Systems Analysis.
3. The areas under study represent only a fraction of the total Navajo Reservation and there are considerable differences between communities and areas of the reservation. The Systems Analysis sub-section is concentrating on a small geographic area. Whether the impact area is typical of the Navajo Reservation as a whole cannot be determined by the use of local data alone. There must be some way to place the impact area communities into a larger tribal framework so that the impact of changing tribal-wide policies and demographic trends on the study areas can be estimated in a quantitative manner.

Some attempts to cope with these problems before August, 1973 have been made so that the Systems Analysis can proceed without undue delay. These will be outlined here.

In order to obtain pertinent data for the "pre-impact" period, investigators of the subproject reviewed, initially, work done by Wagner in the Page - Leche-e area in 1969 and by Levy in Red Lake and Tuba City for two time levels: 1960 and 1967. A further review of all earlier community studies of the western Navajo Reservation and of selected studies in other areas of the reservation was made. Demographic and economic data have been tabulated and community differences have become apparent. Possible sources of difference have been identified. In conjunction with preliminary tabulations of the recently collected interview data from the Page - Leune-e area, investigators hope tobe able to provide a preliminary study of economic and demographic trends over time in several "types" of Navajo communities. Anthropology has also worked with Dr. Thomas Boyle of Flagstaff to develop a simple model of the Navajo Reservation using economic, demographic and land base variables. Data from this project would be used by Boyle to refine his model and his findings in turn will help Anthropology identify variables influencing the study communities which are not revealed by micro-analysis at the community level. These added dimensions, in turn, will be utilized by Anthropology when data is fed into the Systems Analysis sub-project. The success of this venture depends upon Dr. Boyle receiving independent funding to proceed beyond the preliminary model he devised this winter. The preliminary results of comparative community survey are presented in the section Preliminary Results.

B. Current Problems: Epidemiology and Systems Analysis

A problem of relating the epidemiological material with the anthropological, and both, in turn, with Systems Analysis has recently emerged. At this juncture, the nature of the problem may be outlined and proposed solution presented. No substantive work has been undertaken at this writing, however.

A very high rate of population growth has been characteristic of the Navajo at least since the establishment of the reservation in 1868. The degree to which economic betterment in the impact area will increase the population both by immigration and by natural increase must be estimated in quantitative terms for Systems Analysis. The reservation wide medical data already collected by Kunitz for the epidemiological sub-project reveals several areas of changing disease and mortality patterns. Kunitz has presented a paper outlining major factors influencing the Navajo population over time. In addition he has worked on a study of fertility in the eastern end of the reservation which indicates that significant changes in fertility rates may be the result of economic and social variables and not the result of the introduction of birth control programs. At this juncture it is necessary to 1) plot accurate fertility trends for the total Navajo population and 2) gather accurate fertility data in the impact area. In the first instance the results will be used in Boyle's reservation model to show long range interrelationships between population growth, changing economy and land base. In the second instance Anthropology needs to know how typical or atypical the communities of the impact area are and what course they may be expected to follow in the next few years. The anthropological questionnaire is already too long to permit adding questions relating to fertility. Levy and Kunitz are looking for some way to reinterview women in families at a later date. Good fertility data in conjunction with the detailed economic, demographic, and social data from the Anthropology project should strengthen Systems Analysis projections considerably.

III. Preliminary Summary of Results

A. Community Survey Baseline Data

Table21 displays the communities for which there is baseline data by area, type community and time level. Table 22displays basic economic and demographic data from the communities closest to the impact area. With the exception of some of the restudies, which used the same data gathering technique

Table 21. Integration of Available Community Studies by Type of Community Over Time.

——→ Restudy of Same Individuals, Families or Kingroups
- - - -→ Restudy of Same Area

INTEGRATION OF AVAILABLE COMMUNITY STUDIES
BY TYPE OF COMMUNITY OVER TIME

	Western Communities			Eastern Communities	
	Pastoral	Wage	Urban	Pastoral	Other
1972	Leche-e G.D. Red Lake2. Red Lake1. Black Mesa	Leche-e Community Tuba City	Page		
1969	Leche-e	Leche-e Community	Page		
1968/69			Flagstaff		
1967	Red Lake	Tuba City			
1965/66	?Black Mesa (Pinyon)			Sheep Springs	
1960/61	Navajo Mt.1 Navajo Mt.2 Red Lake	Tuba City			
1955	Shonto				
1953				Mexican Springs Aneth	
1940	RESERVATIONWIDE	AREA SURVEYS			
1939				Klagetoh	
1938	Navajo Mountain				
1936	RESERVATIONWIDE	AREA SURVEYS			

Table 22. Baseline Data, Western Navajo Communities

BASELINE DATA, WESTERN NAVAJO COMMUNITIES

	Number of Individuals Per Household							Per Capita Annual Income*	$\overline{X}$ Education of Family Heads	$\overline{X}$ age of Camp Heads	$\overline{X}$ age of Household Heads
	$\overline{N}$	$\overline{X}$	Range	N	$\overline{X}$	Camp Range	N				
Red Lake (1960)	104	5.47	3-10	19	14.86	8-26	7	$250	3.32	56.6	45.84
Red Lake (1966)	126	6.3	1-11	20	14.43	9-23	7	$325	2.52	62.86	49.55
Leche-e Grazing District (1969)	213	---	----	--	8.2	2-13	26	$322@	3.4	-----	48.4
Navajo Mountain Community (1960/61)	581	5.19	1-18	112	12.63	2-33	46	($[illegible]&) $37[illegible]	----	62.51	-----
Leche-e Community (1969)	152	6.9	1-14	22	------	----	--	$43[illegible]@	6.4	-----	37.4
South Tuba City (1960)	426	6.76	1-18	63	9.47	1-26	45	$57[illegible] ($[illegible])+	(6.4)¢ 5.8¢	44.7	42.5¢
South Tuba (1966) Sample	115	6.4	2-12	18	10.45	2-30	11	[illegible] ($1,[illegible])	6.7	46.0	41.6
Page (1969)	78	3.7	1-10	21	------	----	--	$1,[illegible]@	9.4	----	28.4

*Per capita annual income for the whole Navajo Tribe in 1960 was $521.
@Figure based only on wages. (Probably an underestimate for the total community.)
¢Camp heads only.

&Figure based only on wage income within the community. Livestock income is much more important.
+Per capita for wage work families only.
¢From sample of [illegible] of the population.

at two different times, the data from each community are not strictly comparable. Different criteria for the basic sociological unit and different gauges of income make comparison difficult. Demographic as well as economic variables do distinguish communities by type so that the problems already noted do not appear to be insurmountable.

Examination of the variables causing differences between communities of the same type in different areas of the reservation has not yet been accomplished. For instance, the degree to which population density is affected by presence or absence of paved roads in communities which are essentially pastoral in subsistence has not yet been examined.

Demography: All of the data show population growth over time. Population expansion has been greater in the central and eastern portions of the reservation in the past but the western communities may be catching up. There is still a lower population density in the western area. Household size appears to be stable both over time and by area for pastoral communities. Not unexpectedly, Navajos in urban areas have smaller households than do pastoral, rural Navajos. Interestingly, there is no clear pattern for the wage-work communities of South Tuba and Leche-e Chapter. Tuba remains large households while Leche-e Chapter has small households comparable to those found within Page. Tuba City is an older community which has attracted large numbers of welfare families due to the presence of federal and state welfare offices which are not found in Page. The job supply in Tuba has been expanding over a long period of time which allows children to stay at home after maturity. Whether Page and Leche-e develop in a similar manner remains to be determined.

Economics: Reservation wide surveys in 1936 and 1940 show clearly the effects of stock reduction and the national depression. Per capita income declined precipitously, but the shift to a wage economy was largely effected at this time for many communities. Since the Second World War, per capita income has risen steadily. Reservation wide figures indicate that the Navajo have not kept pace with the rising cost of living. Data from communities in the western area do not conform to this pattern, however. At Red Lake, annual increases slightly higher than the rise in the cost of living are found. At Navajo Mountain there has been a ten per cent increase in per capita income annually which is in excess of the rise in the cost of living each year. Tuba City has just kept even with inflation. The reasons for these differences are not immediately apparent and will demand attention during the coming months.

As expected there is a higher per capita income in urban and wage-work areas than in pastoral communities. For example, pastoral communities had around $325 per capita in the 1960's; wage-work families in Tuba City had around $1,000 and urban areas from $1,400 (Flagstaff) to $1,600 (Page).

In order to set the Navajo trends into perspective, diachronic data from the surrounding states as well as contemporary data from non-Indian communities in the impact area must be obtained by the economics sub-project.

B. The Page - Leche-e Area

As of this writing, approximately half of the target population of the area has been interviewed. In 1969, Wagner found 80 households in the area. This conformed to the population estimate made for the area by the tribe.

By 1972, however, a large number of jobs had become available at the power plant. Navajos from outside the area arrived, settling in Page and in the immediate vicinity. This migration has swelled the total Navajo population considerably and it will be next to impossible to interview all the wage-worker transients. At present, the area is subdivided into three types of settlement, Page, Leche-e Chapter, and the pastoral Leche-e Grazing District. Within these areas distinction is made between "locals" and "immigrants". Salient impressions may be presented at this time.

Population expansion has been rapid due to immigration. Currently the sources of wage-work are transient or seasonal. Between 15 - 1600 jobs are available at the Navajo Plant. When construction work is over this will decrease to about 300 permanent jobs. How many of these will be held by Navajos is not yet known. The "locals" are less skilled than the "immigrants" and as a consequence, have less job stability. There is very stong feeling that outsiders (Navajos) are getting all the good jobs. Migrant Navajos are union men and are able to get and hold jobs better. The income of locals has increased appreciably. Virtually every household owns a new pick-up truck. Nevertheless, the style of consumption does not appear to have changed. Where is this new wealth going? There is drinking among both groups but skilled workers manage to hold their jobs while unskilled locals do not. A number of workers from the mine on Black Mesa have come to Page to take advantage higher salaries.

The overall picture is one of increasing competition with considerable resentment within the Navajo population. An even more pervasive sense of resentment is expressed about developments in the area generally. Local Navajos do not feel they have any control over decisions affecting their lives. Decisions regarding the dam and power production were made long before they were appraised of what was happening. This feeling of being manipulated is not an uncommon one among Navajos. What is striking in this area is that the locals felt it was not going to be this way. White planners and representatives of various agencies had come into the community personally telling them they would get jobs, etc. But the "locals" feel that the tourist trade has brought jobs for Whites and only menial jobs for them. A feeling of being manipulated by all power groups, including the tribe is a part of the general resentment.

The effects this resentment and community heterogeneity will have on the political structure and tribal decision making will have to be determined. A history of the Navajo settlement in the area and its leadership structure will be an important aspect of this effort.

C. Navajo Tribal Records and Interviews With Other Agencies

From mid-August to mid-December Principal Investigator Robbins collected Navajo Tribal reports concerning employment figures from the Navajo, Black Mesa - Lake Powell Railroad, Black Mesa Mine and Glen Canyon Dam. All of these data were generously supplied by the Navajo Nation and the Bureau of Reclamation. The reports contain the names, positions, hourly wage, and addresses of Navajo workers. With these data it will be possible in the future to calculate the amount of moneyderived fromwages by members of the Navajo Tribe. It should also be possible to plot systematically the areas from which workers are recruited. All of this information is immediately pertinent to the subproject's comparisons of alterations in the kinship structure of Western Navajo communities that are the result of Lake

Powell and associated developments.

To further elucidate changes within Navajo communities and households, Robbins interviewed labor union leaders, Tribal officials, industrial personnel and officials of the Arizona State Employment Service. These interviews dealt with perceptions of environmental change, as well as recruitment and training of Navajo employees, and the expectations and career goals of job-seeking Navajos.

Upper-echelon Navajo and Anglo personnel in the National Park Service, Bureau of Reclamation, power companies, Bureau of Indian Affairs and the Navajo Nation were interviewed to discern development schemes, employment projections, and political and economic decision-making. These interviews were conducted to initiate the goals of the second year of research. These initial contacts will serve to facilitate the interviews that are to be conducted in the second year of research which is to deal with political action and decision-making.

LAW AND POLITICAL SCIENCE: Monroe Price, Dean Mann, Priscilla Perkins and Gary Weatherford

1. Progress Toward Achieving Subproject Objectives. The Glen Canyon Dam and Lake Powell complex was created as the result of the activities of a political coalition of Upper Colorado River Basin interests. Legal rights and political power were asserted within and by this coalition to accomplish the establishment of the Colorado River Storage Project (hereafter CRSP).

The Legal-Institutional Subproject has devoted its first year to the study of the legislative history of the Colorado River Storage Project Act of 1956 (hereafter CRSPA), examining in particular detail the manner in which conservation values and Native American water rights were treated in the legislative process. The Subproject has achieved the research and most of the writing phases of its Year One objectives of preparing a bibliography of published material on the subject of water management decision-making affecting the Upper Colorado River Basin; developing models for evaluating the decision-making; documenting the legislative history of CRSPA; and determining the relative extent to which policies promoting the preservation of the environment and American Indian water rights were expressed, represented and protected in past water management decisions affecting the Upper Colorado River Basin. The findings are being set forth in a group of draft reports and will only be summarized in this limited space.

The Subproject has sought to accumulate and analyze background legal and political information that will make it possible to respond intelligently to questions concerning the implications of change in the many variables which make up the water management system of the region. The Subproject has followed two approaches in developing legal and political information that can be used within the interdisciplinary framework of systems analysis. First, it has attempted to develop a general model of water management decision-making in the region so that a large range of alternatives can be more intelligently handled in the future. Second, it has identified, and sought to interpret, particular legal rights and political demands. This has permitted the Subproject to suggest how various assertions or implementations of an isolated legal right or political demand has implications throughout the geographical region. This approach has been used with respect to the Native American rights to water, the demands of conservationists, as well as the interests of various developmental groups. The advances made by the Subproject in both of these approaches are discussed in this progress report.

a. General Model For Evaluating Decision-Making. Through a process of identifying, describing and analyzing the principal decisions, decision-making institutions and competing values historically involved in Upper Basin water resource development, the Subproject is arriving at a conception of the changing institutional dynamics surrounding water management in the region. This conception can be partially described in terms of two political models suggested by Theodore Lowi. His "distributive" model helps account for the dominant events leading to the formation of a political coalition in support of CRSP, whereas his "regulatory" model provides a conceptual framework for understanding the emergence of political forces which opposed some, and yielded to other, parts of the CRSP system in intense bargaining.

(1) "Distributive": Upper Basin Coalition. Lowi has postulated a "distributive" model for explaining the formation of large coalitions that resolve their internal differences by forming a sufficiently large political bloc to obtain sufficient benefits to satisfy what would otherwise be competing needs. This model is most applicable to the Lake Powell study and to natural resource policy historically. "Distributive" politics are characterized almost by the absence of policy, i.e., that there is really no fixed rule to determine the allocation of public resources but rather a practice of dispensing those resources in a piecemeal fashion, by vote trading and "log-rolling," to those who have established legitimacy as recipients. Thus, potential water users in the West, having legitimacy established by traditional reclamation policy, seek support for projects, not on the basis of fixed economic rules but on the basis of a variable standard of "ability to pay" or a "benefit-cost" ratio.

With many local groups having an interest in promoting projects of interest to their region, it is natural that they will seek allies in their common efforts to extract support from the public treasury. A natural coalition is formed among those seeking support for similar projects. They will endeavor to resolve their differences so that they will not be competitive in facing an indifferent and sometimes hostile political environment. Above all, they will live by what Helen Ingram has called a rule of "mutual non-interference" with each other's projects. Moreover, they will endeavor to extend the boundaries of their coalition by implicit and sometimes explicit bargains with groups having little concern with local or regional problems. Thus, supporters of reclamation policy may gain the backing of those whose principal interest is in flood control, navigation or other public works.

The structural arrangements for distributive politics involve an almost symbiotic relationship among three groups: local sponsors of a particular project, an agency and its local offices to serve as sponsor and technical support for projects, and a Congressional committee made up of members of Congress from the area benefiting from those projects. State agencies may also provide political leadership for local groups when no serious intrastate divisions exist. Reclamation policy fits the model almost perfectly with the Bureau of Reclamation and the Committees on Interior and Insular Affairs of the House of Representatives and the Senate performing the latter two roles.

A further characteristic of distributive politics is that either because of the disaggregated character of the projects -- none of them is so large as to impose an unreasonable and obvious burden on other groups -- or because of efforts to prove that the beneficiaries will in fact pay for the benefits they receive, the impression is conveyed that there are only winners and no losers in adopting a given policy. Thus, in reclamation policy, projects tend to be isolated from each other except when aggregated to make up a formidable political package such as the Colorado River Storage Project. In addition, every effort is made to demonstrate either that no subsidy is involved in reclamation projects, that the investment will be repaid both directly in payments and indirectly in income taxes paid the federal treasury, or that the subsidy is far less than that afforded other groups in the United States, notably the beneficiaries of flood control projects.

The Subproject has been documenting the forces behind the CRSP political coalition to determine ways in which the process comports with or differs from the Lowi "distributive" model. Refinements of the model are being sought and developed. A refined understanding of the competition and cooperation among the state and local interests in the Upper Basin is necessary to any effort made during Year Two to chart the probable legal and political consequences of "action variables" presented by other subprojects.

The distributive model is remarkably apt for use in understanding the broad workings of Colorado River Storage Project, authorized by Congress in 1956. The billion-dollar-plus Project is composed of four storage units and more than twenty participating irrigation projects. These facilities are located variously throughout the Upper Basin, in Wyoming, Utah, Colorado, Arizona and New Mexico. Glen Canyon Dam and Lake Powell constitute the principal storage and power production unit of the Project.

The Colorado River Storage Project is a product of political accommodation at all levels -- local, regional and national. It represents the efforts of a regional coalition of hundreds of interest groups, bound together by a mutual desire for publicly funded and subsidized water resource development, working with and through a sympathetic federal agency and congressional committee structure.

The formation of the coalition can be summarized as follows. At the direction of Congress, the Bureau of Reclamation conducted a comprehensive study of possible irrigation, storage and hydropower projects for the Colorado River. The regional offices of the Bureau consulted closely with representatives of state water agencies in this process. Favorable approval by the Executive Branch of the possible projects was withheld because the water entitlement of each state in the Basin was not yet determined. The Upper Basin states negotiated a compact to divide the water, rather than resorting to litigation. The compact gave birth to the Upper Colorado River Commission, composed of representatives from the affected states. As the primary institution representing the coalition of Upper Basin water interests, the Commission spearheaded the promotion of the Colorado River Storage Project. Each state in the Upper Basin bargained to gain participating projects and units within the major project. Implicitly underlying each state's claim was its water entitlement under the compact.

In order for the Commission to present a united front before Congress, differences within and among states had to be composed. In Colorado and New Mexico, for instance, this involved the compromising of claims between rural interests within and urban interests outside the Basin. The intrastate institutions involved in this bargaining process included municipalities, water districts, farmers associations and Indian tribes.

As the various proposed projects became assembled into a legislative package, their political and economic interdependency became fixed. The federal elective officers from each state conditioned their support of the overall coalition upon obtaining certain project benefits for their own state. The economic dependency of the various proposed irrigation projects on the power production units, principally Glen Canyon Dam, was recognized throughout. Without the inclusion of the San Juan-Chama Project to serve Albuquerque interests, for example, there politically could be no Glen Canyon Dam. Without the prospect of revenues from the sale of Glen Canyon power, there economically could be no San Juan-Chama Project. These linkages established during the legislative history of the Colorado River Storage Project, incidentally, have residual meaning today because numerous participating projects remain to be authorized, funded or built. There are still outstanding promises and expectations awaiting fulfillment.

More than forty parts (participating projects and units) for the overall Colorado River Storage Project were informally put forward by the Upper Basin states. Practical and fiscal limitations prevented all of the parts of the overall project from being authorized at the same time, however. Priorities were established by placing all of the storage units and some 11 participating projects in a category for initial authorization, some 25 other projects in a category to receive, by Congressional direction, "priority planning" consideration, and the remaining went unnamed in the initial legislation, their fate resting on further planning and future legislation.

Three reasonably distinct groups opposed CRSP bills in Congress: California water interests, conservationists, and a small coterie of legislators who questioned the economic feasibility of, and opposed federal subsidy for, the proposed project.

Five general themes appear in the legislative history: the developmental needs of the Upper Basin; the legal constraints of the 1922 Colorado River Compact; the economic wisdom of CRSP; the conservation value of Dinosaur National Monument; and the engineering feasibility and geological effects of the project. An abbreviated list of other concerns would include agricultural surpluses, the potential of atomic energy, civil defense mobilization, effects on Hoover Dam, and weather modification.

The Upper Basin coalition succeeded in having CRSP authorized in 1956. The coalition has since operated with varying degrees of effectiveness to support the lifting of ceilings on funds to complete construction of authorized projects, and the authorization and funding of additional participating projects.

(2) "Regulatory": Assertion of Conservation Values. Although the dominant theme of any discussion of the Colorado River Storage Project is clearly distributive, a major counterpoint is regulatory: the open combat between developmental and conservation interests over an indivisible value known as Dinosaur National Monument and its glory, Echo Park.

Echo Park, at the confluence of the Green and Yampa Rivers, was chosen as the site of one of the major power dams proposed by the Bureau of Reclamation. Proponents considered Echo Park the "piston" that drove the engine of the entire project. Its purported advantages were numerous: lower evaporation rates; comparatively low power production costs; storage for diversion for the Central Utah Project; river regulation; recreation; an economic boom for the region immediately adjacent to construction. Proponents were challeneged on all of these purported advantages but the single most devastating challenge to placing a storage unit there was the charge that such a project would lead to the devastation of a priceless wonder of our natural heritage and that its desecration would be the harbinger of further inroads into the national park system of the country.

On this issue vote-trading and back-scratching would not suffice for the proponents of the project. They were met head-on by a coalition of conservation groups that was prepared to see the entire Colorado River Storage Project go down the drain in order to save Echo Park in its pristine condition. Each side mobilized its constituents and sought the attention of public and office-holder alike to convince them of the rightness of their cause. Conservationists played a conservative game: they restricted their ammunition to the Echo Park proposal, avoiding more general criticisms of the proposed Storage Project emanating from other sources. Echo Park would be bought as the price of acquiescence on everything else.

The result of the conflict over Echo Park was its elimination as an element in CRSP. The Park System was left inviolate. Proponents of CRSP with the inclusion of Echo Park discovered that the engine they depended upon to run the Project could function without a piston. Conservationists withdrew their opposition to CRSP, leaving the forces of distributive politics to draw the drama to its inevitable conclusion in approving the legislation.

b. Case Study of Navajo Water Rights. Indian water rights are among the most dynamic variables in the water management system of the Upper Basin. The Indian water right, announced in *Winters v. United States* (1908) and amplified in *Arizona v. California* (1963), is seemingly superior to most other water rights in the following ways. First, it is created and maintained without the necessity of actual water use. It thus appears to defy the ethic of contemporary utility by honoring wholly undeveloped, yet anticipated, needs. Second, it has a priority dating from the creation of the particular Indian reservation, normally a time in the late Nineteenth or early Twentieth Century. It is thereby commonly senior to most water uses. Third, it can persist in an unquantified state and, when quantified, is based on the purposes for which the reservation was created.

As plans have evolved to develop the last increments of water supply in the arid West, Indians have been pressed to quantify -- set limits -- on their water claims. The impetus to quantify Indian water rights has come from non-Indian interests which have the political support to obtain federally subsidized water resource development. An available water supply is a baseline requirement in establishing the feasibility of a water resource project. Whenever plans for non-Indian water development confront an unquantified Indian water right claim, the issue becomes: "Will there be any water left for Anglo development if and when the Indian reserved water right is satisfied?"

The Subproject has studied the three methods which exist for quantifying Indian water rights: litigation, legislation and contract. All of these methods have been utilized in the Colorado River Basin. Occasionally, they have been combined. There has been an impetus, for example, to employ a legal hybrid -- contract sanctioned by legislation -- to quantify Indian water rights.

In the Navajo Water Rights Case Study, the viability and legitimacy of these various approaches to the quantification of Indian reserved rights has been examined against the backdrop of the Navajo experience with two water-related projects in the Upper Colorado River Basin: (1) Navajo Indian Irrigation Project in

New Mexico, and (2) Navajo Generating Plant in Arizona. A few observations from the study of the Navajo Indian Irrigation Project will be mentioned here.

In 1868, the United States made promises to the Navajo Indians who were gathered in exile at Fort Sumner, Territory of New Mexico. Any Navajo head of the family who desired to farm was promised exclusive possession of a tract of land, not to exceed 160 acres, on the newly created reservation. A small subsidy of seeds and farming tools were included in the package if the agent were satisfied that the Navajo intended "in good faith to commence cultivating the soil for a living." Underlying the promise was a premise: agriculture served a civilizing function.

The 1868 Treaty Reservation encompassed a substantial stretch of the San Juan River in New Mexico. An additional riparian parcel was added to the Reservation by executive order in 1884. Application of the Winters ruling makes it clear that water from the San Juan River was reserved for the Navajos in a quantity sufficient to satisfy the agricultural and other purposes for which the reservation was created.

Water could not be applied to elevated benches of irrigable acreage above the San Juan River without costly water works. The Navajos had an unquantified right to use the natural flow and no economic resources to exercise that legal right. With the emergence of the CRSP political coalition came the pressure and incentive to use the legal water right and unfulfilled treaty obligation as political levers to obtain federal largess for an irrigation project.

The Navajo Tribe participated in the post-compact stages of the Upper Basin coalition by contributing approximately $20,000 toward the lobbying effort in behalf of the Colorado River Storage Project. It was not a participant in the important negotiations which led to the 1948 Upper Colorado River Basin Compact, although water claims were made on its behalf by the then Office of Indian Affairs.

The full assertion of a large, unquantified and superior Navajo water right would have rendered it difficult to achieve the accords and coalition that led to the CRSP. But the Navajo Tribal representatives engaged in discussions from 1950-1957 with the New Mexico Interstate Stream Commission which led to a shortage-sharing agreement facilitating the joint authorization in 1962 of the San Juan-Chama Project (diverting water from the San Juan River watershed into the Rio Grande River, primarily to serve Albuquerque interests) and the Navajo Indian Irrigation Project. The Subproject has explored the interactions and representations that allowed the coalition to go forward despite the existence of the Navajo water right. It has analyzed the manner in which the

Winters doctrine was perceived by the various Indian and non-Indian decision-makers.

The Navajo water right in the San Juan River functioned politically to buy the conditional right to a publicly subsidized water delivery system for the vast (110,630 acres) Navajo Indian Irrigation Project. By sacrificing the 1868 priority date of their right, agreeing to share shortages in water deficient years, and accepting a quantification of 508,000 acre-feet (gross diversion per annum), the Navajos gained Congressional authorization of the $206 million irrigation project, the promise of a regulated water supply from Navajo Dam, a more reliable water supply for industrial lessees on the Reservation, and authorization to expand the Reservation by purchasing irrigable acreage. Authorized in 1962, the Navajo Indian Irrigation Project is only 25 percent complete due to delays in funding, leading a representative in Congress to dub the matter a "national scandal" in 1970. (The companion San Juan-Chama Project, by comparison, is 80 percent complete and delivering water.) Great capital demands will be made upon the Tribe before the land can actually be put into production. Present plans to operate the project on an agri-business scale as a tribal enterprise with non-Indian management initially at the helm may mean a further deferral of net benefits for the Navajo people.

What the experience of the Navajo Indian Irrigation Project indicates is that a legal water right, while translatable into a political bargaining position in a "distributive" setting, is no substitute for a balanced political base which only greater voting strength or economic resources can provide. Although the right to use water is still one of the most important resources possessed by the Navajos, it alone will not dissolve poverty.

The case study of Navajo water rights suggests some hypotheses about the relationship between the judicially defined Winters right and strategies of competing non-Indian water users. The right itself cannot be understood without reference to the necessity of substantial federal funds for its implementation. Yet, indicators point to a diminution in public support for federally subsidized irrigated agriculture. The Subproject has concluded that inadequate attention has been given in the past to the political value and bargaining power of the Winters right and to the restrictions on the use, sale and lease of the right.

2. Contribution To Other Subprojects, Overall Project and Users. In Year One, the Legal-Institutional Subproject began to relate its work to the other Subprojects and the objectives of the total project, laying the foundation for contributions to various users.

a. <u>Other Subprojects</u>.

(1) <u>Anthropology</u>. There has been an ongoing relationship with the Anthropology Subproject, marked by several joint trips to the Navajo Tribal Offices and record center at Window Rock, Arizona; the exchange of data pertaining to tribal decision-making; the briefing of anthropology field workers on the law of Indian Water Rights and the terms of existing leases and contracts; and the exchange of information concerning past patterns of water use on the Navajo Reservation.

(2) <u>Environmental Impact</u> During a two-day conference in August, the senior investigators of the Subproject exchanged ideas and coordinated plans with Dr. Donald Aitken of the Environmental Impact Subproject. The principals of the subprojects again discussed areas of common interest in Washington, D.C., in December.

(3) <u>Lake Evaporation, Bank Storage, Sedimentation</u>. The Legal-Institutional Subproject collected all pertinent references to scientific data in the legislative history materials, including testimony and projections concerning evaporation, bank storage, geologic structure and sedimentation. Dr. Priscilla Perkins volunteered time to review and provide an initial analysis of this material. She found, for example, that the estimated rates of actual bank storage considerably exceed the differences in evaporation cited as reasons for choosing between reservoir sites. The predicted values for bank storage do not resemble either the estimates of the proponents or those of the opponents of Glen Canyon Dam.

(4) <u>Systems Analysis</u>. The Legal-Institutional Subproject supplied the Systems Analysis Subproject with a general description of the nonquantitative "distributive" model, discussed above. In response to the interest expressed in using "lake level" as an "action variable" in the systems model, the Legal-Institutional Subproject outlined some of the legal and political constraints surrounding management decisions on the level of Lake Powell.

b. <u>Overall Project and Users</u>. During its first year, the Legal-Institutional Subproject has contributed toward the stated goal of the Lake Powell Research Project "to study the decision-making process in the development of water resources" in the Upper Colorado River Basin. The Subproject has identified the principal decisions and decision-making institutions which have governed the way the consumptive utility of the Colorado River has been carved up among competing interests. It has studied the skein of legal traditions and seasoned institutional relationships which help make up the policy matrix within which water management decisions are made. As a result, it has begun to contribute to the overall

Lake Powell Project a conception of the larger, dynamic water management system surrounding Lake Powell. One of the reasons Lake Powell has not reached, and may never reach, a "steady state" physically and chemically is found in its role in the water management system. It is the power pool for hydro revenues that subsidize consumptive use patterns of participating projects upstream that, in turn, influence lake inflow. It is the principal storage reservoir for satisfying legal commitments to deliver water to the Lower Basin; therein lie some of the incentives for lake outflow.. In short, the conception of Lake Powell as a unit within a larger management system is fostering the identification of an increasing number of linkages between the disciplines working on the Lake Powell Project.

The Subproject expects that the written reports, now in preparation, covering the legislative history of CRSPA, the decision-making model, and the role of conservation values and Indian water rights in past water management decisions, will provide a necessary and informative foundation for analyzing in Year Two some of the current problems confronting the various governmental and tribal users.

SOCIAL SCIENCES COORDINATOR: Jerrold E. Levy

The duties of the Coordinator of Social Sciences are 1) the recruitment of sub-projects; 2) the establishment of good relations with government agencies, Indian tribes and universities which have responsibilities in the Lake Powell region; and 3) the internal coordination of work of the various sub-projects.

1) Recruitment: Two immediate recruitment needs were identified by Coordinators Anderson and Levy at a meeting held with Dr. Joseph Jorgensen in Flagstaff in October. The need for an economic macro-analysis was discussed as a means to place the findings of the Anthropology and Economics sub-projects into perspective. Dr. Vernon Smith and the Institute of Behavioral Sciences at Stanford has expressed an interest in formulating such a proposal for the third year of the project. At the meetings in Washington, in December, Senior Investigator Ben-David was asked to contact Dr. Smith to explore areas of common interest.

It has been felt for some time that the LPRP needs to understand more of the non-Indian communities in the impact area. A list of competent sociologists with special knowledge of Southern Utah was compiled by Dr. Jorgensen. Coordinator Levy contacted the most experienced of these, Dr. John R. Christiansen of Brigham Young University. Dr. Christiansen expressed great interest and discussed the matter in detail at the general meeting of the LPRP in Salt Lake City in March.

Should these two proposals materialize as real possibilities for the third year, Levy suggests the Steering Committee consider terminating the sub-projects of Anthropology and Epidemiology.

2) Working relationships with the Navajo Tribe through Mr. Jimmy Shorty, Special Staff Assistant to the Chairman and the Navajo Health Authority in Window Rock have been maintained both by Coordinator Levy and by Principal Investigators Weatherford and Kunitz. Mr. Shorty's move to the University of New Mexico in January will make the task of communication with the Tribe more important than ever.

Common concern over the Black Mesa area prompted a meeting between Levy, Public Health Officials and Dr. David Aberle of the University of British Columbia, in Denver, in September. Sharing of data was agreed upon. The Black Mesa area is in turmoil due to the dispute with the Hopi Tribe and all activities in the area must be undertaken with diplomacy.

Dr. Helen Ingram of the University of Arizona, Department of Government, has been appraised by Levy of the nature of the LPRP and of the efforts of the social science sub-projects in particular. Dr. Ingram is interested in problems relating to formulating environmental impact statements. Levy and Ingram will work together to recruit a political science graduate student to work on the Anthropology and Law and Political Science sub-projects in Year Two.

3) Internal Coordination: At various times, Coordinator Levy has met with Principal Investigators in the Social Sciences. At the present there are

two pressing needs a) to facilitate flow of quantitative data between sub-projects and into Systems Analysis; and b) to agree on areas of joint effort in Year Two for the Anthropology and Law and Political Science sub-projects. The efforts to integrate Anthropology and Epidemiology with Systems Analysis are discussed in some detail in the Anthropology section. Some additional tasks have been undertaken in these areas by sub-projects investigators as the types of quantitative data needed by Systems Analysis becomes clearer. Preliminary definition of joint efforts of the Anthropology and Law and Political Science sub-proposals have recently been agreed upon. Coordination of effort between these two subprojects was discussed in detail at the LPRP general meeting in Salt Lake City.

NATURAL SCIENCES COORDINATOR'S OFFICE: Orson L. Anderson and Priscilla C. Perkins

The functions of this office are (1) the establishment of good relationships with government agencies, universities, and user groups which have responsibilities in the research area; (2) the internal coordination within LPRP of natural science subprojects; (3) the recruitment of potential LPRP personnel; (4) the establishment and maintenance of a unifying central office; and (5) the management of LPRP meetings.

Internal Coordination

The main efforts of the Coordinator's Office have been directed towards evolving an effective mechanism to establish a single overall Project program out of the 16 subprojects. One of the key subprojects which deals with this objective is the Systems Analysis subproject. A number of meetings have been held involving Ben-David, Brown, Levy, and Anderson, as well as other Principal Investigators, in order to prepare for the work of the summer of 1973 in which a systems plan will go into operation.

The reorganization of the Impact Analysis subproject was announced by Donald Aitken in October 1972. He added Robert Twiss, Luna Leopold and Nancy Wakeman from the University of California Berkeley to the subproject. This group formulated new goals and launched research in several new directions. During meetings with the new group at Berkeley, Anderson discussed coordination between the goals of the Impact Analysis subproject and those of the Law and Political Science group. These discussions led to subsequent meetings between the Berkeley group and Gary Weatherford.

Project Meetings

A regional eastern meeting of the LPRP was held at the Cosmos Club in Washington, D. C. on December 8-10, 1972. Those attending the meeting were the members of the Steering Committee plus Jacoby, Mann, Price, Reynolds, Wakeman, and economics consultant Allen V. Kneese.

Discussions at the Washington meeting centered around the role and constitution of the Steering Committe and the Coordinator's Office. An Executive Committee was created to deal with problems arising from day-to-day operations which touch on matters that might concern the Steering Committee. The Executive Committee will consist of the two Coordinators plus two persons elected by the Steering Committee. Drake and Weatherford were elected to serve with the Coordinators on the Executive Committee.

At the Washington meeting, there was considerable discussion about ways in which positions on the Steering Committee could be offered to Principal Investigators not presently on the

Steering Committee. A proposal to enlarge the size of the Steering Committee was voted down. A proposal to have individual members voluntarily rotate from meeting to meeting was agreed upon (for example, Reynolds rotating with Drake, Jacoby with Walther, Potter with Kidd, etc.).

The integrative role of Systems Analysis in the LPRP was also discussed at length at the Washington meeting. A subcommittee was organized, headed by Loren Potter, to consider the implications of lake level as an action variable in the Systems Analysis model.

A general meeting of the LPRP was held in Salt Lake City on March 2-4, 1973. All senior and principal investigators attended. Guests included the following:

John R. Christiansen, Professor of Sociology, Brigham Young University

Charles L. Goldman, Division of Environmental Studies, University of California, Davis (RANN Lake Tahoe Project)

Jerold Lazenby, Regional Research Coordinator, Bureau of Reclamation, Upper Colorado Region

David D. May, Assistant Chief, Interpretation and Resources Management, Arches and Canyonlands National Parks

John Neuhold, Director, Ecology Center, Utah State University

A significant part of the Salt Lake meeting was a round-table discussion by all attendees of lake level as an action variable. The selection of lake level as a variable proved especially timely and stimulating for LPRP integration in the light of the order by Chief Judge Willis W. Ritter, U. S. District Court for Utah, on February 28, 1973 to fix the maximum level of Lake Powell at elevation 3606 feet (the level at which Lake Powell waters enter Rainbow Bridge National Monument).

External Coordination

The Coordinator's Office maintains an active program of frequent communication with user groups in the research area. Several illustrations are presented of this coordination between LPRP and external groups in the section below.

1. National Park Service

The Park Service has referred inquiries about two controversial issues to the Coordinator's Office: (a) an article in the Lake Powell Chronicle (Page, Arizona) discussing fecal coliform counts tabulated in the October 1972 LPRP First Progress Report, and (b) inquiries by the Moab chapter of ISSUE? (Interested in Saving Southern Utah's Environment?) regarding possible contamination of Lake Powell by salt, oil spills or fecal coliform.

2. Environmental Protection Agency

The oil spill on the San Juan River in the fall of 1972 resulted in closer relations between LPRP personnel and the Environmental Protection Agency. Donald Aitken spent several days at the site on the San Juan River where cleaning operations were in progress under the direction of Dr. George Rice of the Denver office of the EPA. Charles Drake later attempted to reach the site on the LPRP houseboat, but was turned back by heavy snow.

3. Bureau of Reclamation

Plans proceeded for the drilling of water test wells by the Bureau of Reclamation at sites selected by the Bank Storage subproject Principal Investigators.

4. Agency Briefings

At the Washington meeting in December 1972, a day of briefings was presented at the National Science Foundation for representatives from several government agencies. Attendees at the briefings were the following:

- J. F. Anderson, Bureau of Reclamation
- W. A. Berti, National Park Service
- W. Culy, Bureau of Reclamation
- M. Morris, National Park Service
- S. Plotkin, Office of Research, Environmental Protection Agency
- E. Roper, Bureau of Reclamation
- M. D. Rudd, Office of Regional Planning, Department of the Interior

5. Lectures

Members of the Coordinator's Office present talks about the work of the LPRP to interested university and civic groups. Orson Anderson gave talks at the Department of Geology of the University of Arizona, at Scripps Institution of Oceanography, and at the Geology Department of California State University at Los Angeles. Priscilla Perkins gave lectures sponsored by the Boston College Environmental Center and the Division of Environmental Studies at the University of California, Davis. On March 6, 1973, at the invitation of a science teacher at Grand County Junior High School, Mr. Douglas Gibson, she lectured at the First Western National Bank in Moab, Utah. The audience included Superintendent Robert I. Kerr of Arches and Canyonlands National Parks, representatives of the Bureau of Land Management and the local Water Conservancy Board, Mr. Donald J. Hoffman, Director of Economic Development for Grand County, and the executive staff of the Moab chapter of ISSUE?, a local environmental group.

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