FIRST PROGRESS REPORT

Period Covered

June 14, 1971 - November 15, 1971

for the

"Lake Powell Project"

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

to

National Science Foundation
Research Applied to National Needs (RANN)
Division of Environment Systems & Resources

Participating Institutions

Dartmouth College (GI-29421)
University of New Mexico (GI-29422)
University of California, Los Angeles (GI-29423)
John Muir Institute (GI-29424)

Orson L. Anderson
Orson L. Anderson
Coordinator

December 10, 1971

Summary

The "Lake Powell Project" got underway on June 14, 1971. The original proposal to the National Science Foundation was composed of five general parts. Four were funded, but the anthropology proposal was turned back by NSF, so the Project started off weaker in social sciences than desired by all.

The field work of three of the funded institutions was well launched when the participants were joined by consultants for the workshop on Lake Powell, which began July 4. The workshop allowed the participants to refine the plans for the course of the work, especially with regard to common interests.

By the end of the summer field season, a considerable amount of field data was collected, especially by the Dartmouth and UNM groups. Field work is still going on in the winter by the UNM limnologists. Many of these data will soon be refined for scientific publications, and the results of both the Dartmouth and UNM efforts are having an important effect on proposed future research. The field program undertaken by UCLA led to the clear definition of the hydrology program for the next 2 years, because certain options emerged as unproductive, while others were shown to be quite promising.

The work of JMI consisted of theoretical and analytical investigations which have resulted in the definition of four separate areas of research for the future. Broadly speaking, the basis of an intensive program in air pollution and one in economic impact were laid out by JMI's summer work. Just as importantly, the work in JMI led to the development of a general framework for the integrated Lake Powell Project.

The Coordinators' Office was occupied early with the problem of housing and office space, so that the field parties could function efficiently when they arrived. The Project headquarters was established at the Museum of Northern Arizona 1 month before funding began, with the help of Dr. E. Danson and his staff at the Museum. The Project headquarters at the Museum continue to serve the Project staff when they are in the area.

The recruiting of the social sciences component of the Project was the chief problem occupying the Coordinators' Office in the late summer and early fall. The structure of the Coordinators' Office and the Steering Committee of the Project underwent a major modification in order to accommodate the emerging plan for the Project in which the natural sciences and the social sciences are balanced.

At the present date, the plans for the participation of social sciences in the Project are becoming refined under Dr. Jerrold Levy, the Social Sciences Coordinator. The natural sciences are now expanding their plans for research into a second phase. This progress report is an evaluation of the work to date which can be described as the first phase of the natural sciences part of the Project plus the first phase of economics.

The work on remote sensing associated with this Project began in April, and will be discussed in a concurrent but separate report by Professor (Capt.) Thomas Eastler of the Air Force Institute of Technology (see Section E).

Orson L. Anderson

Orson L. Anderson
Coordinator
December 10, 1971

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A. THE DARTMOUTH COLLEGE PART OF THE PROGRESS REPORT

1. Introduction

a. Purpose The title of the subproject is dynamic limnology. The senior investigators are Professor N. Johnson for physical limnology, Professor R. Reynolds for geochemistry, and Professor C. Drake for sedimentation.

The purpose of the investigations by the Dartmouth group is to examine the dynamic limnology of Lake Powell--the physical limnology, temperature and salinity structure, conductivity, and turbidity, currents and mixing rates; the water chemistry, major ions and pH, identification of water masses and sources, secular changes and effects on the wall rock; and the sedimentation, sources, modes of transportation, rates of deposition and character.

Considerable work has been and is being done by the Bureau of Reclamation, National Park Service, Arizona and Utah Fish and Game Commissions, Geological Survey, and other interested parties, and efforts are being made to integrate the results of this work with these others.

b. Preliminary Investigations During June 1971, Professor Johnson took advantage of a field trip to the Colorado Plateau to collect water samples from all of the major tributaries of the Colorado River. These data have been analyzed for principal ions and are very valuable in determining, in a synoptic way, the variations in water chemistry at this particular time of year.

In late June and early July an aerial reconnaissa was made of the Lake and its tributaries to determine variations in surface turbidity, joint patterns, and other geological controls and extent of flow from smal side streams. This extended into the workshop, held ir Flagstaff and on Lake Powell in early July when the principals had the opportunity to compare programs and identify common problems with other principal investigators and consultants. A special effort was made to coordinate with the New Mexico group who would be on the Lake during the same period as the Dartmouth group.

c. Field Work During most of July, Professor Drake and three students were working on the Lake. A sub-bottom reflection profiler was installed on a 24' cabin cruiser to determine sediment thickness. In addition, a small hand winch was installed on the boat to allow water samples to be taken at all depths, for lowering a bathythermograph and to permit the obtaining of sediment cores from the bottom of the Lake

The sub-bottom profiler was used to make a profile of the Lake from Glen Canyon Dam to the vicinity of Clearwater Canyon in Cataract Canyon above Hite and of the San Juan River from Paiute Farms to its confluence with the

Colorado. Bathythermograph stations were taken at 27 points spaced along the Lake, and about 20 sediment core samples were obtained. Representative soil samples were also taken along the shores of the Lake. Thirty water samples were obtained from various depths in the Lake, from tributaries and from seeps for analysis during August before the field work in early September.

During the first two weeks in September, Professors Reynolds and Johnson and one student concentrated on the water properties, chemistry and circulation. An additional 30 water samples, mostly in vertical sections, were obtained as well as 20 additional bathythermograph measurements. In order to check the validity of the earlier water analyses, for which only temperature and pH were measured in the field, bicarbonate and oxygen were determined on board the boat. Conductivity profiles were made at 10 locations and turbidity profiles were made at 8 stations. Three temperature recorders, capable of recording for a year, were installed just above the Glen Canyon Dam, two at Rainbow and one at Hall's Crossing to record the annual variations of temperature at various depths.

2. Preliminary Results

a. Physical Limnology

During the 1971 summer field season several categories of physical limnologic data were collected and/or arranged for. Synoptic temperature, chemical and turbidity distributions were obtained at various times during the summer season. To the extent that these factors control the density stratification of the lake, and consequently the withdrawal currents (Riesbol et al., 1971) and inflow-density currents (Stone et al., 1967), these factors are vital in an understanding of the dynamics of the lake circulation.

The lake at present is decidedly lotic (river) in character having a mean residence time for the water of only one year or so. As the lake fills, however, the lengthening residence time of water within the lake (up to 3 years) will emphasize the lentic (lake) components of overall circulation within the lake. These circulation factors will be vital in the analysis of the mineral budgets of the lake water and the subsequent diagenesis of bottom sediments. The intensity and timing of convective transport in the lake in the future will have important implications on any chemical fractionation presently underway within the lake (see accompanying sections).

In order to examine more intensively the vertical structure and stability of the lake, recording thermographs were installed in three locations in the lower lake during the past season; at the dam, Rainbow Crossing, and Hall's Crossing. These instruments record temperatures every hour continuously for 400 days. Three instruments at 100, 200 and 300 feet were strung from the log boom upstream from the dam; two instruments at 100 and 200 feet from the sign buoy at Rainbow Bridge; and one instrument at 100 feet at the sign buoy at Hall's Crossing. From this array of data, the displacement of distinctive water masses down the lake and perhaps the existence of standing waves within the lake may be discerned. The thermographs will be retrieved early in the summer of 1972 and reinstalled later that summer.

In spite of the tentative nature of the turbidity profiling accomplished to date, one important fact has emerged from this data. It appears that a practical and convenient "tracer" for water masses within the lake may be turbidity concentration. Conspicuous layering of water masses is readily discernable by means of a turbidity profile, especially in the upper reaches of the lake north of Hall's Crossing. It seems likely that the inter-tonguing of turbidity layers reflects the source and trajectory of various water types entering and flowing from the lake. The measurement and analyses of <u>in situ</u> water turbidity should benefit in the future from absolute calibrations of the turbidometer and a more judicious selection of sampling stations.

In summary, the dynamic properties and parameters of the lake which relate to the biology, sedimentation and chemical flux within the system are presently under surveillance. In this function the present study continues and builds upon the extensive work of the Bureau of Reclamation and the Utah Fish and Game Commission during the past 6 years (Section 8 Program, Colorado River Storage Act) which entailed data collection during the incipient stages of lake filling. At the present time, it appears that turbidity distributions and/or fine-scaled time series temperature information will delineate most clearly the pertinent controlling factors in the lake's circulation as it approaches full volume. The phenomenon observed may eventually be related to existing and/or new theoretical models of dynamic limnology.

Riesbol, H. S., N. L. Minckley and R. F. Kilmartin (1971) Lake Powell Quality Studies for the Navajo Plant, 1971 ASCE National Water Resources Engineering Meeting, January 12, 1971, Phoenix, Arizona, 48 p.

Stone, R., K. Miller, J. K. Summers, C. Thompson, and A. F. Regenthal (1967) Glen Canyon Reservoir Post-Impoundment Investigation, Prog. Rpt.-5, Section 8 Program, Glen Canyon Unit, Colorado River Storage Project, Utah State Division of Fish and Game, 121 p.

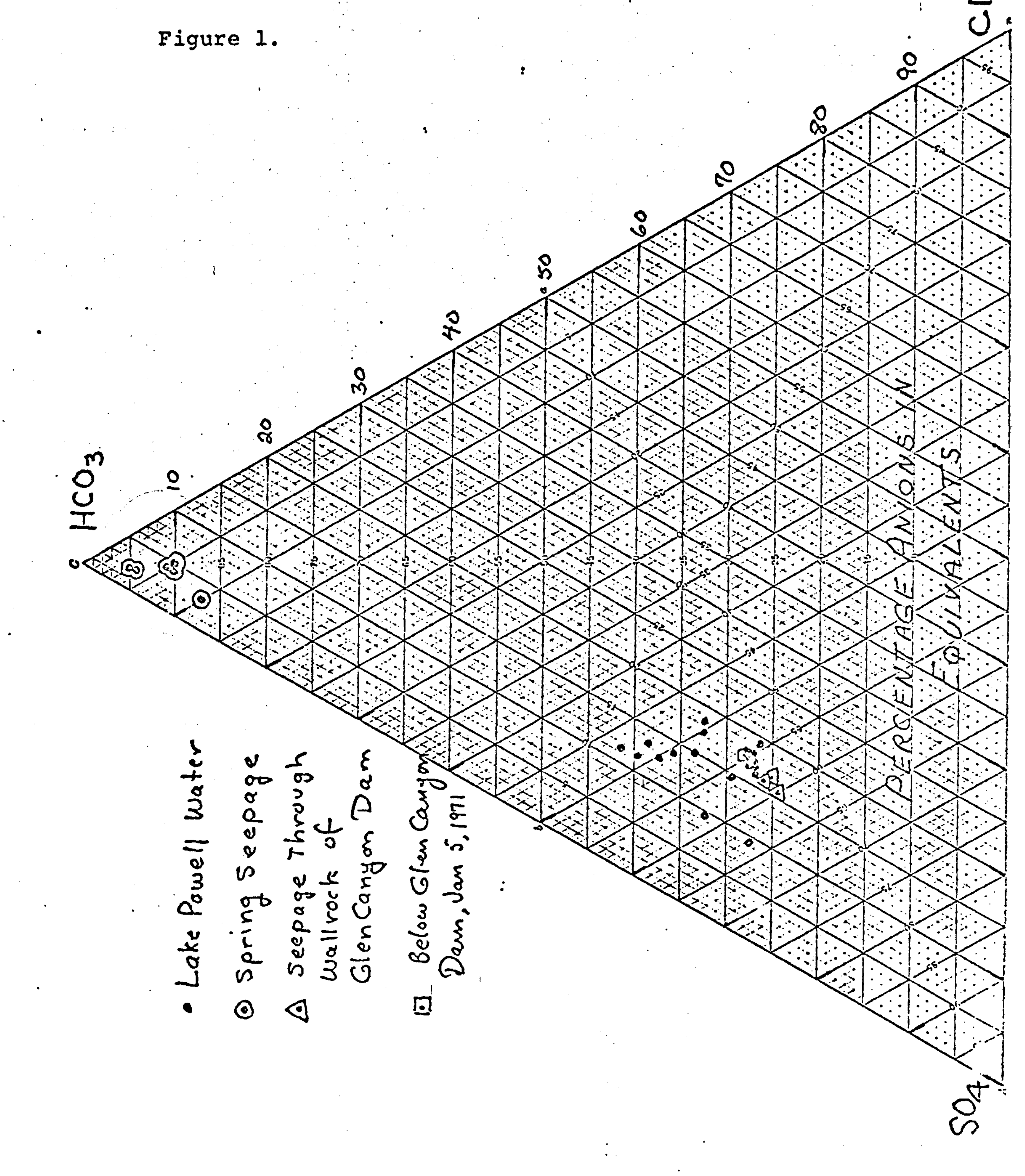
b. Geochemistry   Chemical analyses for Ca, Mg, Na, K, HCO_3, SO_4, and Cl, and measurements of specific conductance and pH have been essentially completed for 50 water samples from Lake Powell, seeps around Lake Powell, and major tributaries. In addition, conductivity, pH and HCO_3 data have been taken on site for an additional 30 samples. Preliminary X-ray diffraction work on bottom sediemnts from Lake Powell has been initiated, and a computer program has been developed that allows the calculation of the activities of simple and complex ions from a water analysis.

It is premature to specify probable developments from much of the work, but two significant findings have emerged and these will be treated in some detail here.

Ground Water vs. Lake Water

Figure 1 shows a triangular plot of the anion composition of (1) Lake Powell water and (2) waters collected from seeps

Figure 1.


HCO3
Cl
SO4
10
20
30
40
50
60
70
80
90
PERCENTAGE ANIONS IN EQUIVALENTS
• Lake Powell Water
⊙ Spring Seepage
△ Seepage Through Wallrock of Glen Canyon Dam
⊡ Below Glen Canyon Dam, Jan 5, 1971

at various sites about the lake. In addition, a single analysis is shown for water below the dam (Bureau of Reclamation Report). The samples from the seeps are distinctly different in composition from the lake; the seep samples are essentially bicarbonate waters, whereas the lake water contains abundant SO_4 and Cl.

The significance of the relationship shown by Figure 1 lies in the fact that the lake water can be easily differentiated from local ground water. Samples from wells, near the lake, can be examined for evidence of lake water encroachment on the local water table, and mixtures of the two water types should be easily resolved into estimates of the relative fractions of the two water types in any sample. In short, sequential analyses of local well water should provide some insights into the patterns and rates of lake water migration into surrounding subsurface aquifers.

Carbonate Precipitation in Lake Powell

The effects of ion complexation cannot be ignored for waters as saline as those in Lake Powell. Ion complexation causes the effective strength of Ca, Mg, HCO_3 and SO_4 to be less than the analytically measured values because of the formation of complex species such as $CaHCO_3^+$, $MgHCO_3^+$, $CaSO_4^\circ$ and $MgSO_4^\circ$. Calculations of the degree of saturation for calcite and gypsum require that ion complexation and activity effects be considered. These considerations have been incorporated into a computer model of the chemistry of Lake Powell waters.

The computer model utilizes a chemical analysis of a water sample expressed in molar units. The ionic strength is calculated, and activity coefficients for the simple ions are computed according to the Debye-Huckle theory. Then, a set of eight equations is solved simultaneously to provide molar concentrations and activities for free Ca, free Mg, free HCO_3, free SO_4, $CaHCO_3^+$, $MgHCO_3^+$, $CaSO_4^\circ$, $MgSO_4^\circ$, and Na, K, and Cl. The calculation then is reiterated from the beginning until a stable solution is achieved. At that point, a table of ionic composition is printed and tests are made of the degree of saturation of calcite and gypsum. If a pH value is entered as data, the program calculates effective pCO_2 (partial pressure of CO_2), or if a value for pCO_2 is entered, a value for pH is obtained. In addition, the program allows the operator to extract various amounts of calcium carbonate and determine its effect on the abundances of the ions and on pH or pCO_2. A sample sheet of output is shown by Figure 2.

Figure 2 shows a study of bottom water from the vicinity of Hall's Crossing. The top portion shows the calculation for a pH value of 7.5, which was measured in the field.

IONIC STRENGTH= 1.33384 E-2

ION	M	ACT-COEFF	ACTIVITY	TOTAL M
CA	1.42759 E-3	0.643582	9.18775 E-4	1.7415 E-3
CAHCO3+	4.28797 E-5	0.889217	3.81293 E-5	-
CASO4	2.71026 E-4	1	2.71026 E-4	-
MG	8.8101 E-4	0.66029	5.81722 E-4	0.001095
MGHCO3+	2.15782 E-5	0.889217	1.91877 E-5	-
MGSO4	1.92412 E-4	1	1.92412 E-4	-
NA	0.003696	0.889217	3.28654 E-3	0.003696
K	0.00008	0.885671	7.08537 E-5	0.00008
SO4	2.30316 E-3	0.627585	1.44543 E-3	2.5705 E-3
HCO3	2.56688 E-3	0.889217	2.28251 E-3	0.00263
CL	0.00174	0.885671	1.54107 E-3	0.00174

CALCITE IS UNDERSATURATED
CALCITE AP= 3.32246 E-9 CALCITE KSP= 5.01 E-9
PH= 7.5
PCO2= 14.8603 TIMES ATMOSPHERIC
CALCITE PPT= 0 UE/LI= 0 PPM
GYPSUM AP= 1.32803 E-6 GYPSUM KSP=2.4E-5

IONIC STRENGTH= 1.10951 E-2

ION	M	ACT-COEFF	ACTIVITY	TOTAL M
CA	4.58515 E-4	0.664581	3.0472 E-4	5.665 E-4
CAHCO3+	7.96449 E-6	0.897321	7.14671 E-6	-
CASO4	1.0002 E-4	1	1.0002 E-4	-
MG	8.66173 E-4	0.679449	5.8852 E-4	0.001095
MGHCO3+	1.22257 E-5	0.897321	1.09704 E-5	-
MGSO4	2.16601 E-4	1	2.16601 E-4	-
NA	0.003696	0.897321	3.3165 E-3	0.003696
K	0.00008	0.894282	7.15426 E-5	0.00008
SO4	2.47282 E-3	0.650414	1.60835 E-3	2.5705 E-3
HCO3	1.43754 E-3	0.897321	1.28993 E-3	0.001455
CL	0.00174	0.894282	1.55605 E-3	0.00174

CALCITE AP= 5.22984 E-9 CALCITE KSP= 5.01 E-9
PH= 8.42
PCO2= 1 TIMES ATMOSPHERIC
CALCITE PPT= 2350 UE/LI= 117.5 PPM
GYPSUM AP= 4.90098 E-7 GYPSUM KSP=2.4E-5

2.834 SEC. 27 I/O
READY

Figure 2.

Under these conditions, gypsum and calcite are undersaturated, and the effective pCO_2 is 15 times atmospheric. Presumably, this high pCO_2 is due to the effects of depth and/or CO_2 generation by detritus feeders.

The lower portion of Figure 2 shows the effects of transferring bottom water to the surface, i.e. to a region of normal atmospheric CO_2 pressure. This change is accompanied by a pH rise to 8.4 and the precipitation of 118 ppm $CaCO_3$, which is more than half of the calcium in the original water. This observation is important, for it suggests that carbonate precipitation must occur in Lake Powell during the period of fall and winter overturn. All analyses treated by the program to date provide the same results.

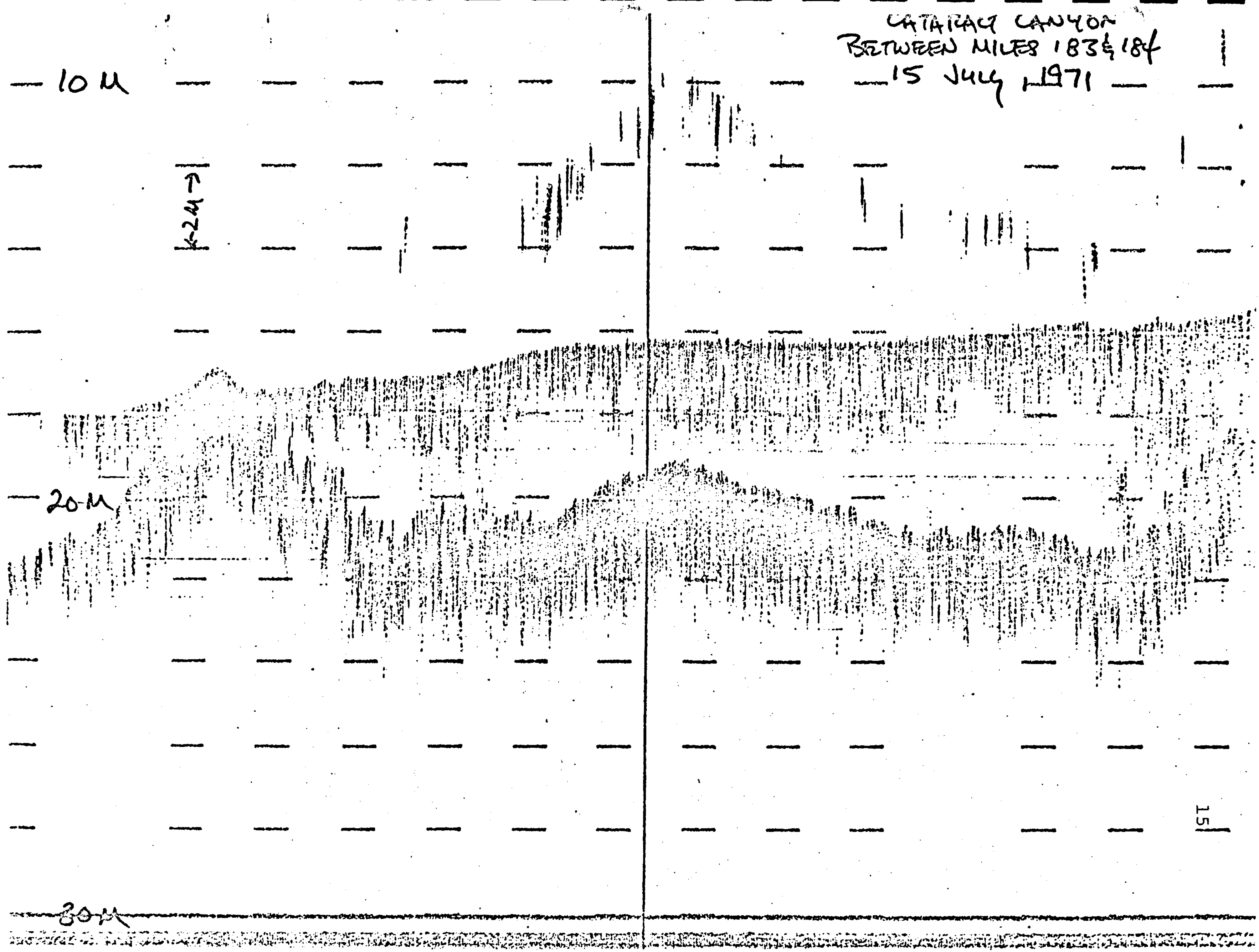
A very tentative model of the lake chemistry, then suggests that calcite is precipitated by photosynthetic withdrawal of CO_2 from surface waters, and that this settles to deeper more acid waters where it is dissolved. During the overturn, a portion of this calcite is precipitated and may accumulate in the bottom muds, thus representing a permanent withdrawal of calcite from the lake and from the Colorado River below the dam. Carbonate precipitation has been reported in Lake Mead, hence it is a matter of interest to inquire into the possible effects of Lake Powell on the chemical processes in Lake Mead. Future work will evaulate this possibility by (1) examination of the bottom muds of Lake Powell for calcite, (2) laboratory measurements that will refine the various equilibrium constants used in the computer model and determine calcite nucleation and precipitation rates in these waters, and (3) a calcium carbonate annual budget for years preceeding construction of Glen Canyon Dam and a comparison between these values and the present flux of calcium carbonate through the lake and into the Colorado River. The results should be of significance to any evaluation of the effect of Lake Powell on the chemistry and salinity of the Colorado River below Glen Canyon Dam.

c. Sedimentation Sub-bottom reflection profiles of the Colorado and San Juan River portions of Lake Powell were made between 3 July and 23 July. Over two-hundred-and-forty miles of records were made, at speeds between four and five knots including one-hundred-and-seventy-five miles along the Colorado portion of the Lake between miles 15 and 190 (from Lees Ferry) and approximately fifty miles along the San Juan between Paiute Farms and its confluence with the Colorado. Since profiles made at the start indicated that sedimentation was taking place primarily in the old river channels, efforts were concentrated upon obtaining a longitudinal profile of the Lake.

In the Colorado River, the maximum thickness of post-dam sediments was about eight meters and the average thickness in the channel is approximately three and one half meters. There are three distinct areas of ponding. One is directly behind Glen Canyon Dam, another is the Rincon. In the latter area, where the Chinle formation outcrops, there has been considerable slumping creating a sill some 10 meters above the former channel and with resulting ponding of sediments behind this sill. The third area of ponding is in Cataract Canyon where the former plunge pools below the cataracts have been filled in (Fig. 3). Sediment thicknesses in the Hite area are somewhat reduced from those mentioned in the Bureau of Reclamation study of 1968 (Bureau of Reclamation, Department of Interior, 1968) and the sediments have moved further downstream.

In the San Juan River, the maximum thickness of sediments was about five meters (probably more above Paiute Farms) with the average about two meters. Ponding occurs near the confluence with the Colorado and in the region between miles 23 and 27 where the Chinle outcrops. Slumping has occurred here in a similar manner to that near the Rincon.

A rough estimate of the quantity of sediment which has been deposited in the Lake since closing of the dam gives


CATARACT CANYON
BETWEEN MILES 183 & 184
15 JULY 1971
10 M
20 M
30 M
←24→

about 325 acre-feet for the San Juan River portion and approximately 1100 acre-feet for the Colorado River portion, both exclusive of slumping. The quantity does not appear to be large with respect to the total volume of the Lake, but it is not insignificant with respect to the volume of the canyon portion of the Lake.

The sediments are fine-grained lutites, mostly tan but with red and black streaks. A number of cores were taken but these have not yet been examined and remain, together with some bottom water, in the plastic tubes in which they were taken. Several of these smelled of hydrogen sulphide when recovered and most have turned black, at least on the outside, while in their plastic tubes. The cores were taken with a small gravity corer and are only about one foot in length. It is planned to take piston cores of greater length during the coming field season in order to study possible annual variations in the character of the sediments.

Bureau of Reclamation, U. S. Department of Interior, 1968, Sedimentation Ranges on Lake Powell, Glen Canyon Unit, Colorado River Storage Project, Reconnaissance Report of Lake Powell Sedimentation Surveys, Power Operations Office, Montrose, Colorado, May 24, 1968.

d. Limnological Stations

The limnological stations of this program are shown in appendix A on the following page, and also on the chart at the end of the report.

LAKE POWELL PROJECT – DARTMOUTH COLLEGE

LIMNOLOGIC STATION LOG

Station	Location	BT	Water Sample	Core Sample	Turbidity Profile	Conductivity Profile
1	Adjacent to Glen Canyon Dam	x	x	x	x	x
2	Mouth of Labyrinth Canyon	x		x		
3	Between Last Chance & Rock Creek Bay	x	x		x	x
4	Wild Horse Bar	x		x		
5	Rainbow Canyon Entrance	x	x	x	x	x
6	Oak Creek Canyon Entrance	x		x		
7	Mouth of the San Juan River	x	x	x		
8	San Juan River	x	x			
9	San Juan River – Cha Canyon	x		x		
10	San Juan River – Piute Creek	x	x	x		
11	San Juan River – Alcove Canyon	x	x	x		
12	San Juan River – Nokai Canyon	x		x		
13	San Juan River – Piute Farms	x		x		
14	Hole-in-the-Rock	x				
15	Mouth of Escalante	x	x	x	x	x
16	Oil Seep Bar	x		x		
17	Oil Seep Bar			x		
18	The Rincon	x	x	x		
19	Mouth of Iceberg Canyon			x		
20	Halls Crossing	x	x	x	x	x
21	Halls Crossing Airport	x	x	x		
22	Mouth of Moki Creek	x	x			
23	Hansen Creek	x	x			
24	Tapestry Wall	x	x	x	x	
25	Good Hope Bar	x		x		
26	Castle Butte	x				
27	Dirty Devil	x				
28	Hite Bridge – Route 95	x	x	x	x	x
29	Just Downstream from Clearwater Canyon	x	x	x		

B. THE UNIVERSITY OF NEW MEXICO (UNM) PART OF THE PROGRESS REPORT

1. Introduction

a. Purpose The title of the subproject is "Primary Productivity, Indexes of Eutrophication Processes, and Marginal Vegetation of Lake Powell." The senior investigators are Associate Professor David E. Kidd, in charge of aquatic investigations, and Professor Loren D. Potter, in charge of terrestrial and shoreline vegetation.

The general goals of the overall subproject are to: (1) establish biological indexes of water quality based upon primary productivity, and by an algal community diversity index, (2) establish transect studies of the shoreline vegetational succession and relate them to control and nutrient relations of the Lake, and (3) to begin a source-sink study of heavy metal contaminants (especially mercury) in Lake Powell, the San Juan River, and Navajo Lake.

2. Preliminary Results

a. Aquatic Investigations

(1) Specific Objectives The following are specific objectives of these investigations:

- Determine the value of C^{14} primary productivity and algal diversity as indexes of autrophication

- Determine primary productivity of various depths throughout the year
- Determine phytoplankton species composition numbers, and biomass at varous depths throughout the year
- Compare the productive capacity of Lake Powell with other lakes
- Determine sources and movements of heavy metals in Lake Powell as well as in the San Juan River and Navajo Lake

(2) Sampling Plan Five stations were established as follows: Station One - 23 miles from the dam at the Warm Creek Bay entrance; Station Two - 15 miles from the dam at the entrance to Navajo Canyon; Station Three -- at the boomline in front of the dam; Station Four -- 5 miles from the dam at the entrance to the Wahweap Bay Marina; Station Five - 8 miles from the dam at the northeast corner of the Wahweap Bay swimming area. At each station, samples for chemical analysis, algae enumeration, and C^{14} primary productivity are taken from six depths: surface, one, two, four, six, and eight meters. The "light" and "dark" bottles are incubated *in situ*.

Sampling began on June 26 and continued at weekly intervals through August 9. This time sampling is done every fourth week until the investigation is terminated.

(3) Progress We are in the process now of counting algae and determining the radioactivity of filters. These data will then be plugged into computer programs which calculate algal diversity indexes and rates of carbon fixation.

We believe we are progressing quite well toward completion of the first four objectives.

Samples for heavy-metal analysis have been obtained from bottom samples of sediments, shore region terrestrial deposits, vegetation, and fish (blue gills and carp). Collections have been taken from Wahweap Bay, the dam, Navajo Canyon, Warm Creek Bay, Padre Bay, San Juan River, Rainbow Bridge Marina, and Reflection Canyon.

(4) Mercury Analysis Progress has been relatively slow in the fulfillment of our last objective because of the length of time required to set up our Perkin and Elmer Model 306 atomic absorption unit.

Some results for mercury analysis are found in the appendix to this section.

b. Terrestrial and Shoreline Vegetation

(1) Field Strategy During the month of July, the shoreline of Lake Powell from Wahweap Bay to Seven Mile Canyon, approximately 22 miles upstream from

Hall's Crossing, was mapped. The shoreline of the Lake and of all tributaries, except the San Juan River, were included, a total distance of about 600 miles. The water level during July 1971 was at approximately 3620 feet. The surface materials and physiographic characteristics within the zone of 3620 to 3700 feet, which represents the maximum flood level of the reservoir, were mapped. Superimposed on a geological classification of the bedrock on U.S. Geological Topographic Quadrangle Maps at 1:62,500 scale were the following delineation types:

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

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

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

2 Talus slopes, common along cliff walls and alcoves;

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

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

5 Landslides, mixtures of coarse rubble and blocky material, most common where sandstone formations overlay shale of the Chinle formation.

(2) Relation to Remote Sensing It is hoped that mosaics and stereo pairs of 9" x 9" black and white photo coverage will soon be available to use at Flagstaff, or here at UNM. The New Mexico Archeological Center, a cooperative venture between the National Park Service and UNM emphasizing research on the Chaco Canyon region, has laboratory facilities for photointerpretation and various remote sensing film. This laboratory, which is to become a principal regional center of remote sensing for the National Park Service, is available to use. It is planned to recheck the field mapping on photo overlays and to add a system of indexing the carrying capacity of each area in regard to potential campsites. There are a number of specifications for a good campsite. These include proper shoreline for landing or tying up a boat, which might vary from sandy shoreline, gently sloping smooth rock, or a protective steeper-walled alcove; relatively level spot of slick rock or sand for a campsite; and the availability of areas of weathered soil used instead of portable toilets. As the population pressure and overnight camping increases, it is likely that some regulation of campsite use and distribution will become necessary to protect the very scenic features which people come to enjoy.

(3) Progress Ten permanent transects were established on a variety of shoreline areas running from the waterline at approximately 3620 feet to the 3700-foot contour. These were marked with permanent stakes, photographed in color and black and white, and located on topographic maps. The exposure and degree of slope throughout the transect were determined , and the surface material was classified. Along the 3-foot wide belt transect in 3 x 10 foot units, the surface was classified and put into percentages of bare rock, bare soil, dead wood, litter, lichens, mosses, herb and shrub cover. The foliage cover and density of the vascular vegetation were determined throughout the length of the transect. These transects will serve as permanent vegetational indices of the influence of the rising water level, the effect of exposure of the lower segment during draw-down, the possibility of succession into the previously flooded zone during its exposure, and, hopefully, an indicator of shoreline stabilization should the level of the reservoir finally be determined and controlled.

Soil samples were obtained from the area of each transect. These will be used for textural and for chemical analysis. They will also be available as part of the material to be analyzed for mercury and other heavy metals in order to establish a baseline concentration in the soils at the present time.

Studies of rates of decomposition and input into the nutrient cycle of the Lake still remain to be done.

Increment borings of woody vegetation were made at six selected sites to determine any influences of increasing water level and to establish some growth indices at varying physiographic and soil sites. Trees sampled included Cercis occidentalis, Rhamnus betulaefolia var. obovata, Juniperus utahensis, Fraxinus anomala, and Celtis douglasii.

Photos were taken at permanently located stations of seepage lines supporting calciphilic vegetation. These are usually in alcoves or on vertical walls and at varying elevations wherever a layer of limestone is present in the cross-bedding and provide for horizontal water movement. These may be useful as indices of change in volume of water seepage as the hydrology of the area is changed by the rising water level.

c. Limnological Stations The limnological stations of this program connected with aquatic sampling sites, as well as shoreline transects, are shown on the chart at the end of the report.

3. Appendix B

Mercury Concentrations

Material	ppb/g	Location	Remarks
Flesh	ave. 39	Reflection Canyon	Blue gill: wt. 120 g, l. 19.5 cm
Flesh	ave. 49	Reflection Canyon	Blue gill
Rock	ave. 6.1	San Juan River	Red mudstone, terrestrial
Rock	ave. 6.0	San Juan River	Red silt soil, terrestrial
Rock	ave. 6.7	San Juan River	Thin-bedded gray sandstone, terrestrial
Rock	ave. 18.6	San Juan River	Red silt, terrestrial
Rock	ave. 12.3	San Juan River	Red silt and sand, terrestrial
Rock	ave. 4.0	San Juan River	Gray shale - Chinle formation, terrestrial
Rock	ave. 3.5	San Juan River	Blue Chinle shale, terrestrial
Rock	ave. 8.8	San Juan River	Wingate sandstone, terrestrial
Rock	ave. 4.6	San Juan River	Gray dune sand, terrestrial

C. THE JOHN MUIR INSTITUTE (JMI) PART OF THE PROGRESS REPORT

1. Introduction

a. Purpose The title of the subproject is "An Analysis of the Environmental and Economic Impact of Technological Enterprises enabled by the Impoundment of Colorado River Water (A Case Study of Tourism, Mining, and Electrical Power Production in the Vicinity of Lake Powell)." The senior investigators are Professor Don W. Aitken and Dr. Michael D. Williams of the JMI. Professors S. Ben-David and F. L. Brown, of the Economics Department of the University of New Mexico, although originally brought in as consultants to this proposal, actually did a considerable amount of work (for example, supervised students) and are therefore named here. Williams and Aitken were in charge of the air quality investigation, and Ben-David and Brown were in charge of the economics investigation.

b. Reappraisal of the Proposal The original proposal was designed for a 2-year program. It proposed the construction of an "inventory" of environmental contaminants affecting air, water, and land, resulting from activities brought about by the construction of Lake Powell. As a result of the change in financing, from 2 years to 1, the aims were restated to be as follows.

The objective of the first year's work in the JMI program was to (1) document the physical changes created by man's activities on and near the Lake, the changes in the Lake itself, and to project these changes into the future; (2) to develop a methodology (that is, a mathematical model) for translating physical changes into economic costs or benefits; and (3) to begin obtaining information on social values which can be used in the models developed.

2. Preliminary Results

a. Air Quality   This section of the report will deal primarily with the projection of physical changes and will touch only briefly on data which may be of use in the assessment of social values.

The physical changes we have examined so far this year are those connected with contaminants of the environment near the Lake. Our assessment of the physical changes arising from contaminants has three components: (1) the identification of the significant characteristics which describe the present situation around the Lake; (2) the projection into the future of the contamination load; and (3) the translation of the impact of the contaminants into descriptions meaningful to the layman. A general search needs to be made for all possible contaminant sources. As a result of our preliminary investigations, the principal contaminant sources fall into three categories: (1) air and water emissions related to power plant development; (2) air and water emissions related to recreational development; and (3) water contaminants released by shoreline changes. Data for (1) and (2) will be found from JMI's own activities; data for (3) will be sought from Dartmouth and UNM. (One could also argue that wind-blown dust or particular transport from other areas represents another major source of air contaminants, but this is relatively stable and we will assume that is is not related to the impact on the environment arising from the establishment of Lake Powell.)

The work of Dames and Moore[1] is providing us with a detailed description of air quality in the Lake Powell region. Perhaps only one feature of importance is lacking from their work--that of distribution of the contaminants with altitude. Estimates of altitude distribution will be obtained by comparison with areas elsewhere in the Southwest. The Dames and Moore work has in it certain meteorological data specific to the location of our interest, while other studies have given us general meteorological characteristics of a much larger area. The present situation regarding contamination of aquatic environment will be drawn from investigations conducted by the State of Utah Fish and Game Department and by the Biology Department of UNM.

Some estimates of fuel and oil consumption and visitor usage have been obtained from the recreational development of the Lake area. Information sources for visitor usage have been sought out. (National Park Service material has detailed information on the type and quantity of usage.) Data on fuel and oil sales are now being requested from the concessionaires at the Lake.

All the relevant data on the composition of the coal for two plants, Navajo and Kaiparowitz, are not yet available. For the coal to be used in the Navajo plant, the composition, especially sulfur, nitrogen, iron, aluminum, phosphorus, is well documented. The data on this coal permit an accurate projection of sulfur oxide and particulate emissions providing that the control devices of the plant are known. For nitrogen oxides, estimates can be made which are only slightly less reliable. We have estimated the gross emissions of sulfur oxides (no control assumed), nitrogen oxides (no control assumed), and particulates (99.5% on a mass basis). Samples of coal have been taken from the Kaiparowitz and Black Mesa fields and these will be analyzed in the near future for mercury. Another group has run experiments at the Four Corners plant which describe the fate (air, water, or solid waste) of mercury in coal.[2] The results of the Four Corners experiment can be used to estimate the mercury contributions to the air, water, and waste dumps when the coal analyses become available. Information on trace elements is also being requested from the participants in the Navajo and Kaiparowitz projects.

For the coal to be used in the Kaiparowitz plant, the situation on the data is more confused. Mineral resources data on coal composition obtained from State of Utah publications[3] seem to differ from the initial results of tests run by Bechtel Corporation. As the important features of the analyses of the coal are resolved, the results of the calculations of the plant emissions will change correspondingly.

We plan to make two types of calculations with respect to effects of air contaminants. The first relates to the effect of air contaminants on vegetation, human, and animal life. For this we need the general distribution at ground level of toxic contaminants and the frequency and duration of the exposure. Calculations relating the effects of air contaminants on vegetation and human and animal life will require data input from the biological subprojects of the Lake Powell Project, as well as data input from an epidemiological investigation to be added to the Lake Powell Project.

The other calculation relates to the impact of the plume on visibility. The light-scattering and absorption characteristics are important to visibility along with the plume shape, size, location, and time characteristics. The following is an example of the type of physical calculation on scattering which is now being made.

In order to assess the effect on scattering, size distributions of the particulates are required. There are, of course, no size distributions available from the Kaiparowitz or Navajo plants; however, there are size distributions available from the collector installed at the Four Corners plant. The size distributions required for the scattering computation are those passed by the collection devices. The actual distribution needs to be estimated by taking account of what is generally known about such collection devices. More detailed information on these specific devices and other measurements of the size distribution are being sought. Using size distribution data from the Four Corners plant as a reasonable approximation, it is possible to estimate the particulate size distribution of material passed by collection devices at Navajo or Kaiparowitz. For scattering calculations, an important parameter is the total cross-sectional area of all emitted particles of larger size than 0.2 microns. The coefficient of scattering efficiency b is given by

$$b = NK\pi r^2$$

where the factor k is the scattering area ratio, N is the number density, and r is the radius of the particle. The value of k depends on the radius of the particle, as well as some parameters such as the wave length of the incident light, and the refractive index of the particulate material. Variations in the value of k of between one and three occur for the material in fly ash, whose radius is between 0.2 and 2 microns. The available particulate distributions are not sufficiently precise to define the actual value of k so that an average value of two is used for k. We calculated the effectiveness of scattering for 1 $\mu g/m^3$ (micrograms per cubic meter) of normal haze, effluent from a 99% wet scrubber (a type of collector) or a 97% precipitator as shown below:

Table 1

Source	Scattering Efficiency b
Normal haze	$.33 \times 10^{-5} \frac{m^{-1}}{\mu g/m^3}$
99% effluent	$1.12 \times 10^{-5} \frac{m^{-1}}{\mu g/m^3}$
97.3% effluent	$.95 \times 10^{-5} \frac{m^{-1}}{\mu g/m^3}$

A higher scattering efficiency b indicates that for the same mass more light will be scattered and thus the visibility will be reduced. The total emissions from a 99%

efficient scrubber will be less than those from 97.3% efficient electrostatic precipitator so that total scattering from the plume will be less. However, the effluent from 99% efficient wet scrubber is composed of a higher percentage of smaller particles which are more effective scatterers of light. For the same mass, it thus scatters light more effectively.

With this type of data, estimates of plume opacity are being made. Plume dispersion models are being used to describe the mass distribution within the plume. The plume opacity is dependent upon the concentration integrated along the line of sight. Thus, when the objects viewed are more distant than the furthest edge of the plume, the plume opacity will vary inversely with the plume spread in the direction transverse to the line of sight.

For viewing in or near the horizontal plane, the fanning dispersion condition will produce the most opaque plumes at distant locations. The vertical extent of such plumes will be more limited than that of other modes, and it is clear that this mode will necessarily be the most objectionable in all situations. For a fanning plume the concentration along the centerline is given by

$$x = \frac{1.05 \times 10^{7} Q \, e^{-1/2}}{\sqrt{2\pi \tau_y \tau_z \tilde{u}}} \quad \frac{y^2}{\tau_y^2}$$

with χ , the centerline concentration in $\mu g/m^3$; Q , the emission rate of contaminant in tons/day; $\tilde{u}$, the average wind speed between the stack top and the plume top in meters; τ_x , the standard deviation along the y axis for class E stability; and τ_z , the standard deviation along the z axis for class E stability. Then

$$\int b dx = \frac{1.05 \times 10^7 Q}{2\pi\tau_z\tilde{u}} (2.24 \times 10^{-5})^*$$

(* = assumes scattering and absorption equal)

so that for 14 tons per day and $\tilde{u}$ = 2 m/s,

τ_z	Distance Downwind	χ	$\int b dx$	I/I_o
68 meters	10 km	660 $\mu g/m^3$	9.65	.00002
145 meters	100 km	83 $\mu g/m^3$	4.65	.0096

The vertical extent will be very strictly limited as indicated by the standard deviation. Similar calculations can be made for other dispersion modes, and a picture of where and under what circumstances significant plume opacity will arise can be developed.

In the future, the additional contributions of nitrogen dioxide and particulates converting from sulfur oxides and nitrogen oxides will be estimated. At present, only limited data are available on the conversion rates of the oxides.

In order to assess the hazards of plant or animal life damage in the area, calculations must be made of the maximum ground level concentrations, their durations, and their locations. Preliminary calculations indicate that levels near those which have damaged plants in laboratory exposures are to be expected if no controls are instituted at the Navajo plant. With controls required by the proposed Arizona regulations, there would be little likelihood of plant damage from sulfur emissions from the Navajo plant. The effect of emissions from the Kaiparowitz plant has not yet been calculated.

The summer's activities have also included a literature search on control techniques for fine particulates, oxides of nitrogen, and oxides of sulfure. This material is expected to be useful in identifying options and in assessing their costs.

1. Progress Report Number 1, "Air Quality Monitoring Study," 1970, Navajo Generating Station, Dames and Moore report.
2. "Analysis of Mercury Emissions from Unit--Four Corners Plant," APSCO, Fruitland, New Mexico, Environmental Sciences Associates, Inc., July 19, 1971.
3. Hachman, Frank C., Craig Bigler, Douglass Kirk, and Rodger Weaver, "Utah Coal-Market Potential and Economic Impact," Bureau of Economic and Business Research, University of Utah, September 1968, p. 13.

b. Economics

(1) Background Study and Literature Review of the Lake Powell Area We began our study by examining the history of the development of the region, particularly the development of electric power generation and mining activities. With this background we undertook a literature survey. In researching the history of Lake Powell, it became apparent that this was synonymous with the history of the Colorado River Storage Project, which in turn required an understanding of the development of the entire Colorado River system. The general topics covered in obtaining this necessary background include the legal framework of the River development, the political events resulting in development, and the role played by the Department of the Interior in planning and executing River development. Relying on sources available in UNM libraries, it was possible to construct a fairly thorough picture of the processes that resulted in the creation of Lake Powell. The principal sources were legal documents, transcripts of Congressional hearings, government reports (especially Bureau of Reclamation reports), histories of the Colorado River and its development, and a political analysis of the process of obtaining Congressional approval of the Colorado River Storage Project (the Echo Park Controversy).

Then we collected and analyzed information about current power generation activities. These activities covered (a) power plants at Four Corners, San Juan, Navajo, and Kaiparowitz; (b) the coal mines at Black Mesa and at power plant sites; (c) power transmission lines; and (d) the impact of the proposed railroad from Black Mesa to the Navajo site. The information was obtained from proposals and environmental statements issued by the power companies, environmental impact statements of various governmental agencies, and environmental impact studies conducted by private groups or individuals. The general aim of this analysis was to get a feeling for the scope and magnitude of existing and proposed power developments in the area, the likely economic and environmental consequences of these developments, and of possible pollution control measures.

The availability of and demand for recreational facilities were also studied. While there are several published sources, the unpublished documents of the National Park SErvice are the best source of information on recreation, especially the monthly reports by Park Service personnel which give estimates on the use of individual parks and recreation areas by type of recreational activity (fishing, camping, hiking, etc.). These reports provide estimates based on traffic counts and occasional surveys to determine type of activity as a percent of total use. The available data report user-days rather than demand or value of recreational experience. We would like to estimate changes in values of recreational experience resulting from such things as crowding of recreational facilities and increases in air pollution from the power plants in the area. We are currently investigating possible survey techniques which would allow us to generate the necessary information ourselves.

The legal environment in which the various economic activities in the study are are conducted has also occupied some of the research effort to date. Major data sources have been the law library at UNM and state government offices.

In addition to those specific acts which were directly responsible for the creation of the Upper Colorado River Storage Project, several types of law which have affected, and will continue to affect, economic activity in the study area can be distinguished. These include federal land law, federal and state water law, laws relating to Indians and Indian lands, law regulating pollution or environmental quality, public utility regulation, and laws defining or regulating activities of government agencies such as the Bureau of Reclamation, National Park Service, Environmental Protection Agency, etc.

Another line of research has been aimed at determining the methods used by government agencies and private firms (particularly power companies) in planning, evaluating, and promoting developments, and the criteria used by legislative bodies in evaluating projects. For the most part environmental impact has been given very little weight. Matters have improved considerably since the approval of the Upper Colorado Storage Project, notably with the passage of the National Environmental Policy Act (PL 91-190). There is a new set of procedures for project evaluation being developed by the Water Resources Council which makes consideration of environmental effects the specific part of the process of project evaluation, but these have not as yet been approved by the Office of Management and Budget.

There are special methodological problems associated with an economic analysis of activities of a type that predominate in the Lake Powell region. Recreation provided at zero or nominal prices, industries which cause pollution problems, provision of irrigation water at prices below cost--all have the common characteristic of having "external" costs or benefits associated with them. What this means, essentially, is that the value of a particular resource cannot be estimated from readily available data. For example, a $2 entrance fee to a National Park does not necessarily reflect the value of a day of recreation to a park user. It becomes necessary, then, to develop techniques for the collection and analysis of more appropriate data. Searching the literature for such techniques has been one of the major research activities so far undertaken.

(2) Developing Data Sources A second major pursuit of our study has been to identify major sources for economic data. The following agencies and institutions will be able to provide useful information:

- Department of the Interior
  National Park Service
  Bureau of Reclamation
  Bureau of Land Management
  Bureau of Indian Affairs
- Four Corners Commission
- Power Companies
- State Fish and Game Departments
- State Environmental Quality Agencies
- State Departments of Development
- Federal Environmental Protection Agency
- Southwestern Monuments Association
- Museum of Northern Arizona
- Other subprojects of the Lake Powell Project

In most cases, contact has been made with representatives of the above groups, and they have expressed willingness to provide information. In some cases (particularly the National Park Service and the Bureau of Land Management) we have already obtained some preliminary data.

(3) Preliminary Conclusions Below are listed the preliminary conclusions of our research thus far:

* The appropriate study area would have to be larger than Lake Powell and its immediate vicinity. There are two main reasons for this: The effects of activities at or near Lake Powell extend for a considerable distance outside the area; and, Lake Powell was not planned or developed as a separate entity, but was part (the main part) of the Upper Colorado Storage Project.
* In dealing with a large geographical area, we have a complex system of interrelated variables. The research project is faced with the task of analyzing the interrelationships within and between three subsystems: physical, biological, and socio-economic. The general term for the process of analyzing such interrelationships is systems analysis. Deutsch offers the following definition of systems analysis: "Essentially the system concept is that of examining the overall interactions of a group of items rather than focusing attention on the operation of each of the

component elements in turn," or "stripping non-essential details from a collection of interacting elements so that the structure of the interrelations is laid bare for study." (R. Deutsch, System Analysis Techniques). Such an analysis is necessary to evaluate the effect of any of man's activities in the study area.

* Considerable effort was required to operationalize the terms in the phrase "An Analysis of the Environmental and Economic Impact of Technological Enterprises Enabled by the Impoundment of Colorado River Water." Several questions had to be answered first: Who will use the information generated? Environmental and economic impact on whom or what? What is a technological enterprise?

The research will be most useful if it can be used by people responsible for making decision about resource allocations in the study area and also be those making similar decisions in similar areas. There are several such decisionmakers: The Department of the Interior, the Environmental Protection Agency (federal), state environmental agencies, state and federal legislative bodies, state departments of development, and private firms and individuals in the area. People in all of these groups are in a position to affect resource allocation decisions.

In order to provide information to the above groups, we need to answer several questions:

- o What are the policy variables available to the various government agencies and industries in the area? That is, what changes in type or level of activity can be brought about and how can these changes be implemented?
- o What will be the socio-economic impact of the implementation of a given policy in an area similar to the Lake Powell area?
- o What will be the socio-economic effect of the development of other river basins?
- o What further research is needed to better answer these questions?

In order to provide answers to these questions, a systems analysis approach has been undertaken.

3. Appendix C

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D. THE UNIVERSITY OF CALIFORNIA, LOS ANGELES (UCLA) PART OF THE PROGRESS REPORT

1. Introduction

a. Purpose The title of the subproject is "Secular Trends in Hydrology of the Upper Colorado River Basin." There is within this subproject, in addition to this title, the responsibility of the coordination program of the overall project. The senior investigators are Dr. Gordon Jacoby, in charge of hydrology, Professor Orson L. Anderson, the coordinator of the entire project, and Professor Priscilla Dudley, executive secretary to the entire project.

The stated purpose of the hydrology subproject is to record and present secular trends in hydrology of the Upper Colorado River Basin, and to develop methods for monitoring future changes.

b. The Coordinators' Office This aspect of the activities of UCLA, funded under this subproject, was involved with those activities required to launch the project, in the field, and was analogous to those activities required for the establishment of a field base-camp of an interdisciplinary expedition.

2. Preliminary Investigations for Hydrology

a. Purpose The proposed research and mission of the UCLA hydrology subproject were to do a quantitative assessment of secular trends in available surface water in the Upper Colorado River Basin (UCRB). It is the surface water flow from this basin that supplies the water to maintain Lake Powell as a power-producing water-storage and recreational reservoir. Lake Powell, the largest impoundment in the entire 109,500 square mile basin, is located in the extreme southeast corner of the UCRB. The outflow from the Lake is only supplemented by the comparatively small flow of the Paria River before the main Colorado River reaches the Colorado River Compact point, the terminum of the UCRB. It is this point to which the UCRB must supply the quantities of water to the lower basin as specified in various legal agreements.

b. Results In a conference with members of the Bureau of Reclamation in Salt Lake City, the problem of discerning real trends in local and basinwide streamflow was mutually recognized and discussed. They showed much interest in our Project and were extremely cordial and cooperative.

As of 1968, there were 526 surface-water gaging stations in the UCRB. Of these, 515 are USGS gages and 11 are maintained by other government agencies. The flow data for the Survey gages are available on magnetic tape and were obtained by UCLA. Unfortunately, the quality* of

* Quality of a streamflow record is rated by the USGS as follows: excellent, the data are believed to be accurate to within ±5% for 95% of the time; good, ±5% for 90% of the time; fair, ±5% for 86% of the time; poor or nonrated, is just worse than fair.)

the data must be obtained from other sources. This information relating to quality of data is available in various Water Supply papers of the Survey. There is no annotation on the magnetic tapes of data. There are three other factors affecting streamflow data: diversions for consumptive use, reservoir construction, and large-scale terrain modifications.

The importance of accurate flow data cannot be overstressed because streamflow data are the foundation of all conclusions about secular trends in surface-water runoff. The hazards of basing conclusions on dubious flow data have been documented by Jacoby, 1971. Research based on questionable streamflow and precipitation data have caused confusion instead of enlightenment in some instances.

Of great importance also is the length of records. The real statistical distribution and trend of streamflow through the recent centuries is inadequately sampled by several decades of recorded measurements. The longest records barely extend back to the turn of the century, and there are very few of these records. As one progresses from 1900 to the present, the number of gage installations increases dramatically. Thus the quest for long-term good-quality records with little or no disturbance of natural flow becomes a compromise between the various desirable factors. In July 1971, all the 515 USGS stations were cross-checked as to length of record, quality of data, and diversions. A group of "best" basins for our purposes was selected for field reconnaissance.

Approximately 85% of the flow of the UCRB comes from only 15% of the basin. The major input areas and estimated percent contribution to estimated virgin flow at Lee's Ferry are as follows (see Figure 1):

- o The west flank of the Wind River Mountains in Wyoming, 9%
- o The Uinta Mountains in northeastern Utah and southwestern Wyoming, 9%
- o The western portion of the Rocky Mountains in Colorado, 53%
- o The San Juan Mountains in southwestern Colorado, 14%

The ranges in central Utah also contribute appreciable run-off to the Colorado River system but far less than the four areas mentioned above.

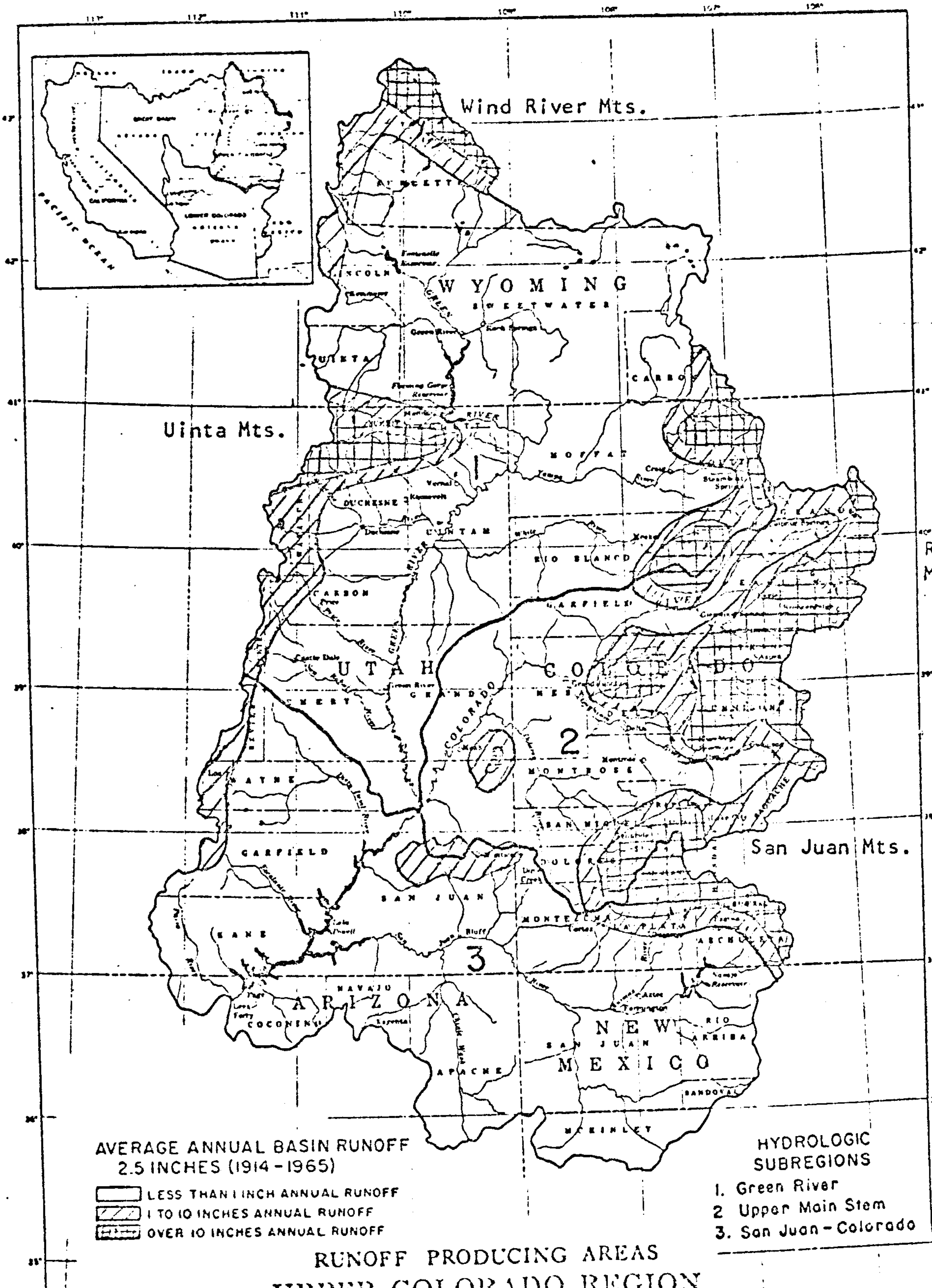
After checking USGS publications for length of record and quality of data, 82 basins were selected for further study. These basins, with a few exceptions, had areas of less than 500 square miles.

Reconnaissance was made of 38 basins, and samples were taken as shown by the following chart and Figure 2:

Location	Basins	Water Samples	Soil Samples	Tree Cores or Cross-Sectional Specimens
Wind River Mountains (9%)	5	5	5	4
Uinta Mountains (9%)	8	7	6	22
Rocky Mountains (53%)	15	14	13	24
San Juan Mountains (14%)	10	14	8	--
Sites near Lake Powell	--	--	--	4

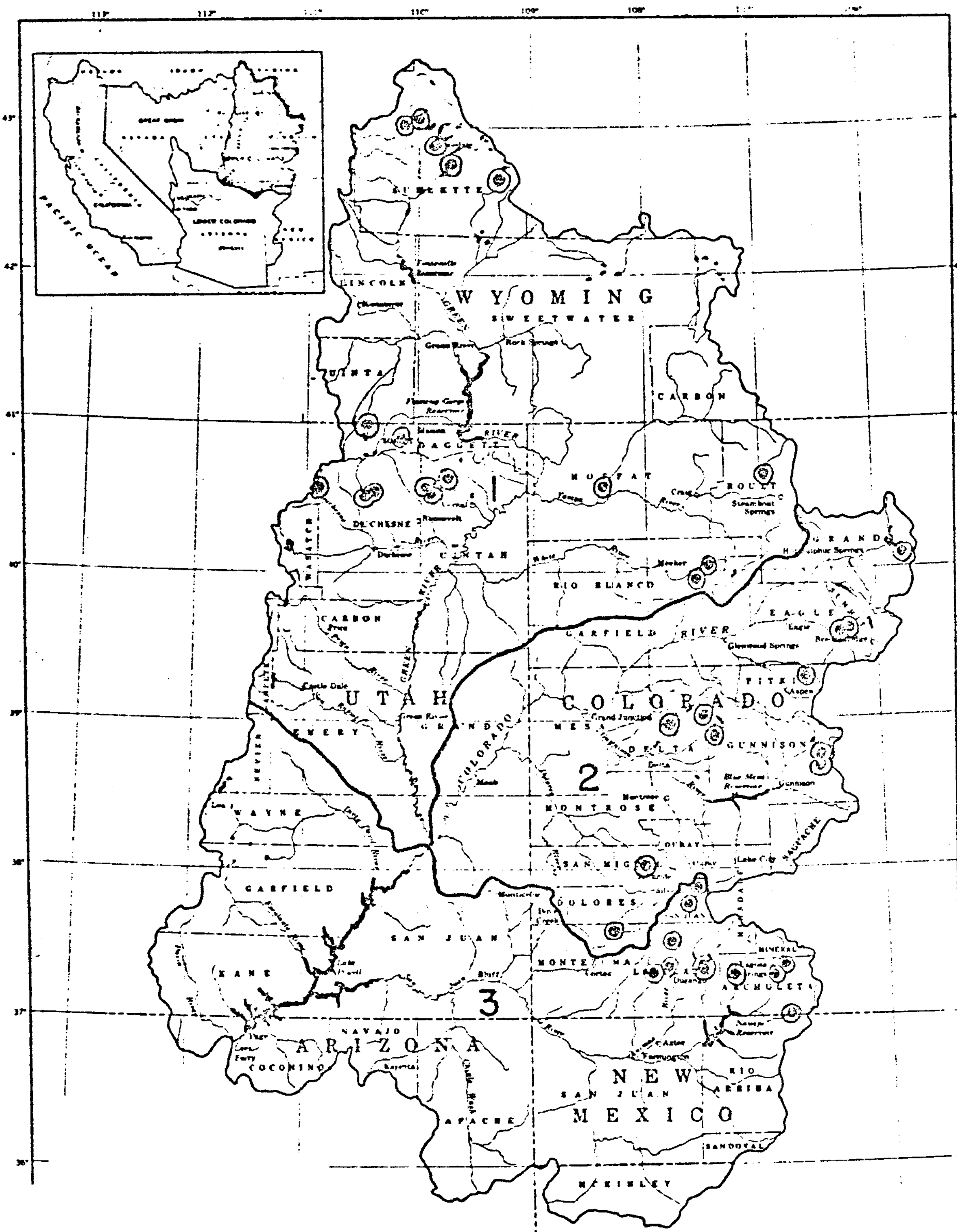
Reconnaissance was made of the four major contributing areas and individual basins within these areas. The purpose of these field investigations was to visually check the stream gage installations and note any modifications of the basins which could produce changes in streamflow. Fortunately, most of the basins appeared to have been in a stable configuration for a long time with regard to vegetation, man's activities, and other factors which influence streamflow (long time meaning for the duration of streamflow records and beyond).

Of the 38 basins checked, the following conditions were observed. There were two with irrigation diversions built since 1965, the year of the latest published USGS survey. One basin had an anomalous flora; scrub oak extended over a vast area, much larger than the basin



RUNOFF PRODUCING AREAS
UPPER COLORADO REGION
COMPREHENSIVE FRAMEWORK STUDY

Figure 1



UPPER COLORADO RIVER REGION

⊚ Basins field checked in summer 1971

Figure 2

itself. The usual vegetation near this region is mixed pine, aspen, and open meadow grasses. A number of local inhabitants stated that to their knowledge the scrub oak had always been there. An increment core revealed an age of 48 years. This figure is a lower limit to the age of the scrub oak vegetation. The stream gage record for this basin is only 31 years. Therefore, it should be consistent as the unusual flora predates the record by at least 17 years.

There were five gage installations whose intake configuration was such that low flow data probably has substantial error.

As a result of the field investigations and detailed evaluations of flow data, there may be additions or deletions of basins in the study.

There are two reasons why smaller drainage basins were chosen for study: (1) these are the only basins where there is little or no disturbance of natural flow by man; (2) as previously stated, these areas are where most of the runoff comes from (see Figure 1). Most of these smaller tributary basins are remote from major roads, and reaching them is somewhat time-consuming. Therefore, while in the various basins, soil and water samples were collected, although these samples are not essential to the first year's study. Also, the soil samples were of interest to the biology subproject.

In an effort to extend the runoff data back in time, increment cores were taken where there were trees near the stream gage sites. Preliminary plotting and comparison of streamflow data and tree-ring data has shown good correlation. The best correlations are between ring width for a particular year and flow for that year and the previous one.

Low-flow years and narrow rings correlate better than high-flow years and wide rings. The stress of insufficient water is a definite limiting factor in tree growth. However, the storage of nutrients and growth hormones from the previous year leads to a lag-one correlation between growth and water stress.

When there is no water stress, the growth is often a function of solar radiation, temperature, length of gorwing season, and nutrient and hormone availability from the previous year's growth. Therefore, the correlation between wet years and wide rings is not as close, since water is no longer the limiting factor.

In addition to analyzing the smaller unmodified tributaries for basin-wide input trends, the three principal gage stations just above Lake Powell are being studied. These stations are the Green River at Green River, the Colorado River at Cisco, and the San Juan River near Bluff. Results thus far show that these three major rivers furnishing inflow to Lake Powell are not always in phase with regard to high-runoff and low-runoff years.

The Green River has contributed a maximum of 51.8% and a minimum of 28.2% to the UCRB outflow. The Colorado has had a maximum contribution of 55.2% and a minimum of 38.0%. The San Juan has furnished a maximum of 28.2% and a minimum of 7.2%. Thus, the inflow to Lake Powell is a varying composite of these three rivers. It is well documented that the water quality of the three rivers is not the same. Therefore, the average quality of water entering Lake Powell can vary greatly from year to year.

3. A Report of the Coordinators' Office

a. History It became clear early in the year when the first signs of project acceptance were detectable, that one of the first problems was to acquire a base camp commonly used by all four funded institutions but not located at any one of the institutions. This need was particularly acute with Dartmouth and UCLA being on opposite sides of the country, each with its own extensive and different needs for field work and field equipment. An appeal was made to Dr. E. Danson, Director of the Museum of Northern Arizona, in Flagstaff, to provide housing for the Project. Although no money was available for this purpose, since the Project was not funded until June 14, Dr. Danson and his staff found some very nice quarters which were formerly used for storage. This space was refurbished by the Museum, and furniture was provided by UCLA and the Museum, so that by July 1, when Project personnel gathered for the first workshop, field support facilities and meeting rooms were available. The entire Project is indebted to the Museum of Northern Arizona for its help in this regard.

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

The first officially funded workshop of the Project was held on Lake Powell in the vicinity of Hall's Crossing, on July 4, 5, and 6, 1971. A Steering Committee meeting was held on July 3, to determine the program of the workshop, and then the Project personnel proceeded by car, boat, and air to the workshop site. Planes were provided by JMI and Dartmouth; boats by UNM and the Coordinators' Office. The meeting was too short to examine all the interfaces, but nevertheless a great many problems were resolved, affecting the interplay of the programs within natural sciences, and with regard to remote sensing. The meeting adjourned at the Lake without much progress being made regarding the role of the social sciences in the Project. The meeting reconvened at the Museum of Northern Arizona, and there was a summary statement from all participants.

Especially pertinent to this final meeting was a summary by the project monitor, Dr. Philip L. Johnson of RANN, who emphasized to all the Project personnel the need for the Project to find a common identity. He spoke of the goals of RANN in the National Science Foundation, and of the problems the Project faced in connecting the subjects somehow to these goals.

In particular, Dr. Johnson emphasized the following points:

- The Project needs to define itself with regard to a natural need or social issue;
- The methodology needs to be developed to use the Project's research to bear upon the problem;
- The management of the Project needs to connect the subprojects together;
- It is important to investigate and to find ways in which the results of the Project can be communicated as a product to the users of the results;
- It is important to establish a centralized Project, with general Project goals, rather than a loose consortium.

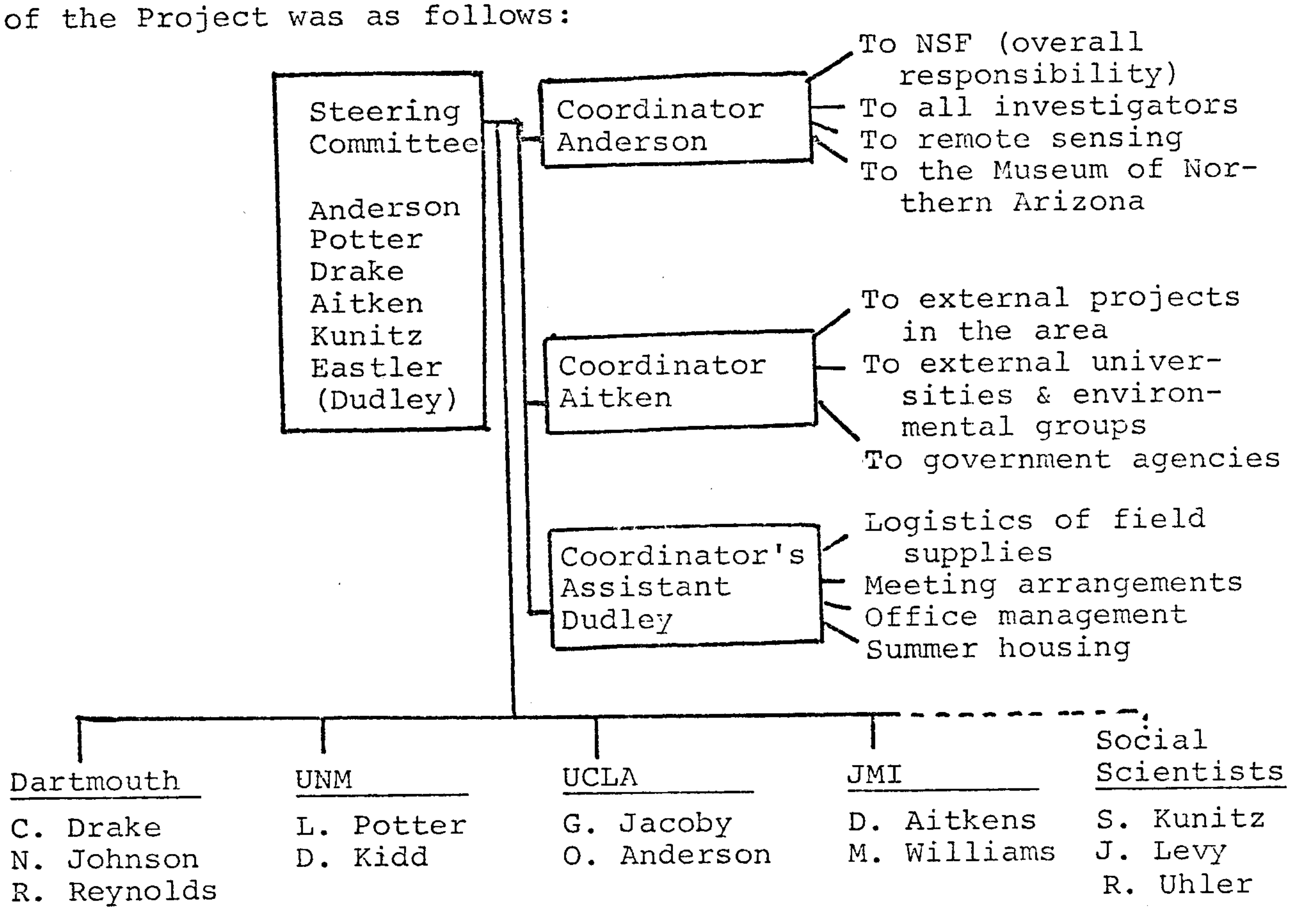
Subsequent to this meeting, the field parties continued their research. Dr. Ben-David took upon himself the task of helping to establish a plan to help find the methodology of the Project and the Project goals, and Dr. Anderson began the quest for social scientists needed to define the other goals.

The remote sensing part of the Project began early. Dr. Anderson recruited Professor (Capt.) Thomas Eastler from the Air Force Institute of Technology to help run the remote sensing program in the spring, at no charge to the Project. He was able to have a flight made in May, using personnel and a plane based at Hanscom Field in Bedford, Massachusetts, and turned the unprocessed film over to Dr. Anderson. Anderson appealed for funds necessary to process the film from the National Science Foundation and from the U.S. Geological Survey. The Flagstaff offices of the Survey pledged $1000.00 for this purpose, provided that they would receive one copy of the film, and the remainder of the bill was raised as (additional) funds from the National Science Foundation sponsors. The film was processed and turned back to Dr. Eastler, who is arranging to have copies made and mosaics completed, at the Army Engineers Topographic Office in Washington, under the direction of Robert Frost. The USGS paid $1075 to the Project.

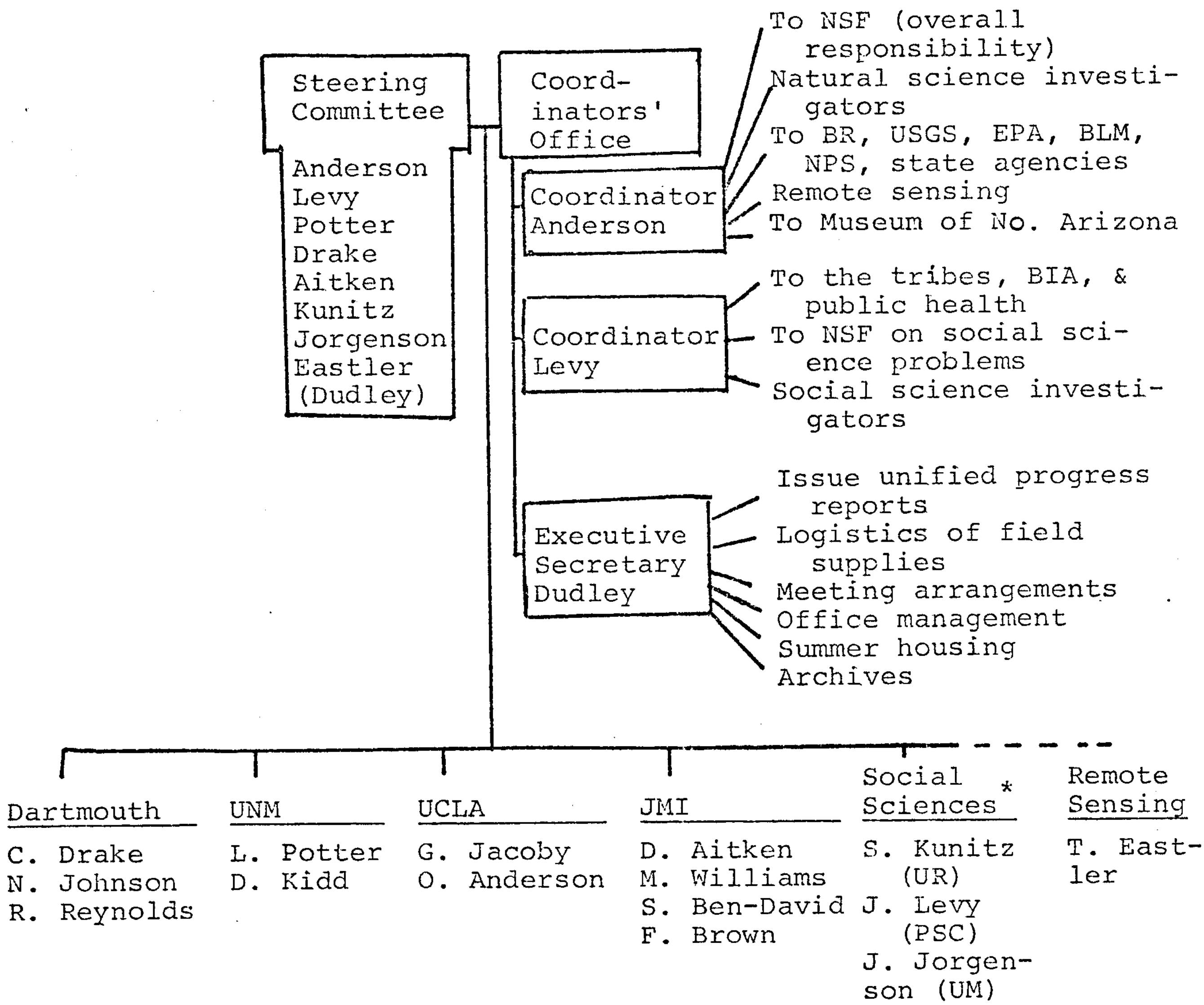
The problem of recruiting social scientists continued. By the end of the summer, the Project took in as Co-Coordinator Professor Jerrold Levy of the Anthropology Department at Portland State College, who has had extensive experience working on the Navajo reservation. Dr. Donald Aitken bowed out as Co-Coordinator, due to the press of his duties as Chairman of a department at San Jose State College.

At the present time, Coordinator Levy is working on the proper balance of people and effort in the Project, representing anthropology, preventative medicine, sociology, economics, and law.

b. Administration On July 1, the administration of the Project was as follows:

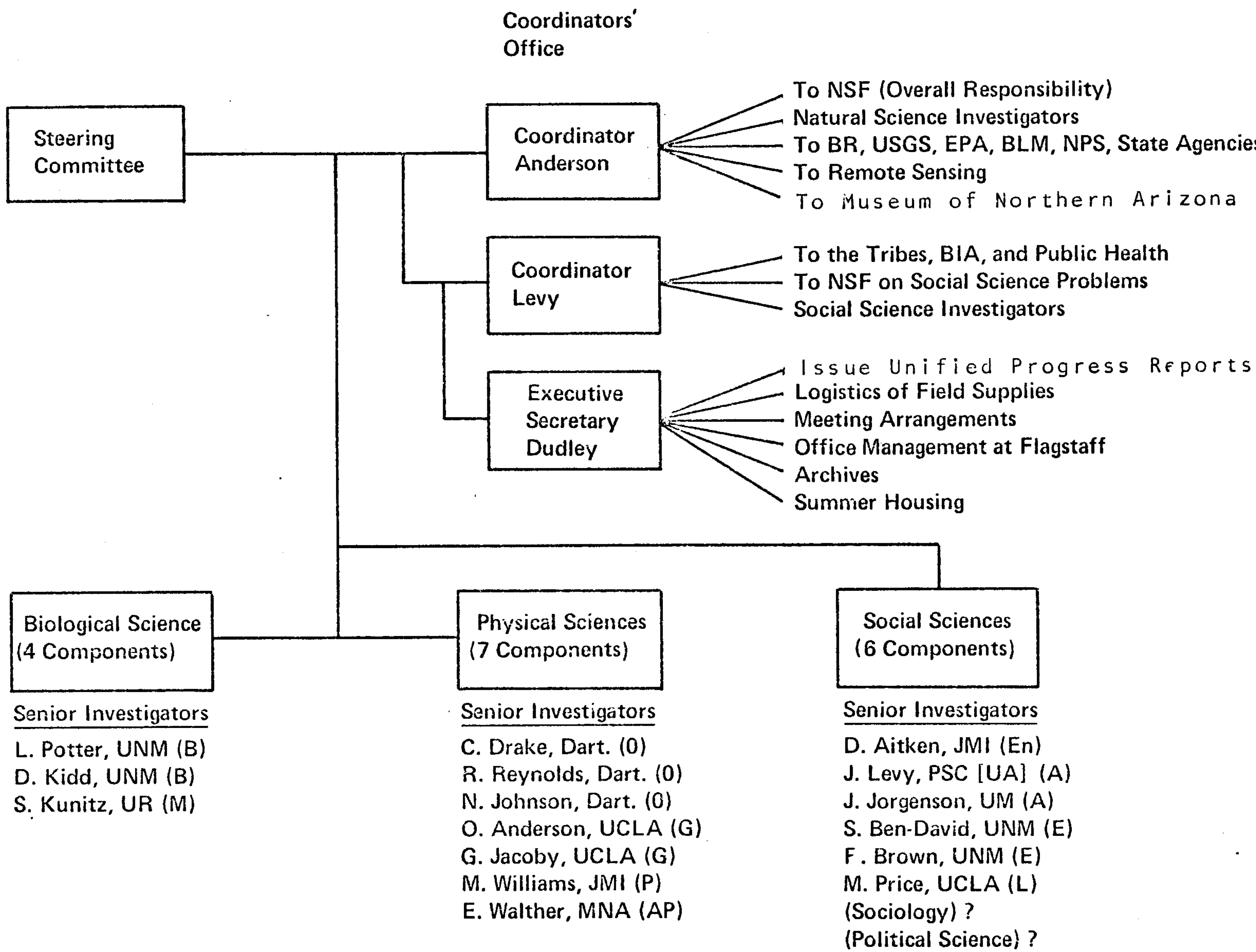


On October 1, the administration was as follows:

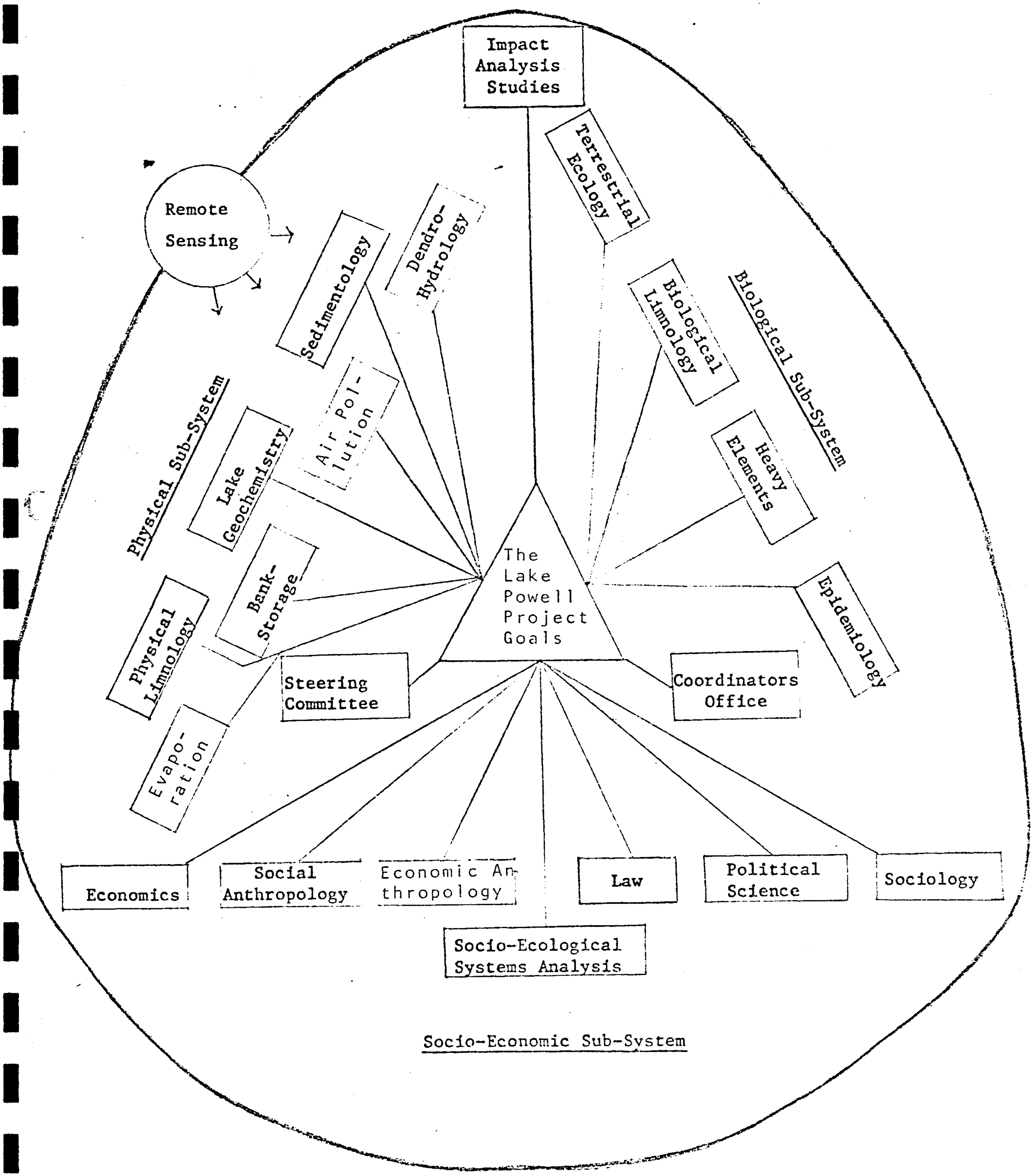


*not organized fully

On December 5, the administration is that shown on the next page. This is followed by a page showing the functional relationships of subjects. The institutions have been relegated to a role of funding mechanisms.


Coordinators' Office
Steering Committee
Coordinator Anderson
To NSF (Overall Responsibility)
Natural Science Investigators
To BR, USGS, EPA, BLM, NPS, State Agencies
To Remote Sensing
To Museum of Northern Arizona
Coordinator Levy
To the Tribes, BIA, and Public Health
To NSF on Social Science Problems
Social Science Investigators
Executive Secretary Dudley
Issue Unified Progress Reports
Logistics of Field Supplies
Meeting Arrangements
Office Management at Flagstaff
Archives
Summer Housing
Biological Science (4 Components)
Senior Investigators
L. Potter, UNM (B)
D. Kidd, UNM (B)
S. Kunitz, UR (M)
Physical Sciences (7 Components)
Senior Investigators
C. Drake, Dart. (0)
R. Reynolds, Dart. (0)
N. Johnson, Dart. (0)
O. Anderson, UCLA (G)
G. Jacoby, UCLA (G)
M. Williams, JMI (P)
E. Walther, MNA (AP)
Social Sciences (6 Components)
Senior Investigators
D. Aitken, JMI (En)
J. Levy, PSC [UA] (A)
J. Jorgenson, UM (A)
S. Ben-David, UNM (E)
F. Brown, UNM (E)
M. Price, UCLA (L)
(Sociology) ?
(Political Science) ?

INTERRELATED SUB-SYSTEMS



At the present time, one of our major administrative problems is to tighten up the Steering Committee organization so that it is more functional.

E. REMOTE SENSING PART OF THE PROGRESS REPORT*

1. Introduction

a. Purpose Below are presented the objectives of the remote sensing portion of the Lake Powell Project:

(1) To establish a pre-Glen-Canyon-Dam environmental datum for the Upper Colorado River Basin (UCRB), and to document temporal change from that datum, which has resulted from the establishment of Lake Powell;

(2) To undertake independent research efforts (e.g., structural lineament analysis, etc.), where appropriate, which will involve the analysis of specific remote sensing data, and which will contribute significantly to the overall mission of the Lake Powell Project;

(3) To aid all senior investigators of the Lake Powell Project in the utilization of existing and proposed photographic and imagery coverage of areas of concern to them;

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*The section on remote sensing was prepared by Professor (Capt.) Thomas Eastler of the Air Force Institute of Technology, as an addendum to the Lake Powell Project progress report.

(4) To generate and execute an overall mission plan which will assure continued remote sensing coverage of the UCRB throughout the duration of the Lake Powell Project.

2. Preliminary Results

a. First Objective A survey of all existing aerial photographic coverage of the UCRB has been completed. Information has been compiled from the files of the following agencies:

- U.S. Geological Survey
- Bureau of Reclamation
- Soil Conservation Service, USDA
- National Aeronautics and Space Administration
- Defense Documentation Center
- Ten Commercial Aerial Photographic Corporations

A partial list of the existing aerial coverage is shown as Appendix E-1. Reduced photo-mosaics of all coverage have been ordered, and individual photos will be ordered subsequently.

Transects will be established at various locations (if possible, some will coincide with smaller transects already established by UNM) on the composite photo-mosaics (at the largest possible scale) and time variant changes which have occurred along these transects will be documented.

b. Second Objective Three photo-mosaics have been constructed from photographic data collected by the U.S. Air Force this past April. Preliminary studies have been conducted on all three areas. Two photo-mosaics were used as a basis for "desert environment analysis" in a short cource on "Aerial Photographic Interpretation for Environmental Analysis," taught at the PHotographic Interpretation Research Division of the U.S. Army Engineering Topographic Laboratory, U.S. Army Topographic Command Center, Fort Belvoir, Maryland, by Robert Frost, Vern Anderson, and Tom Eastler. Xerox copies of reduced mosaics and student-generated overlays are attached as Appendix E-2.

A preliminary structural lineament analysis has been initiated. The study is inconclusive at this time.

c. Third Objective This objective was not fulfilled because of unforeseen administrative obstacles and the press of other duties. It is hoped, however, that photos will be in the hands of UNM's senior investigators before long. There will be much information made available to the anthropology, hydrology, and limnology groups soon. It is stressed that the anthropology group expects that a good deal of their "visual anthropology" may come from a combination of "already-on-the-shelf" aerial photography and "to-be-generated" aerial photo coverage.

Some help of a consulting nature has been afforded to the JMI group in an effort to optimize their pollution studies.

d. Fourth Objective Discussions with, among others, the USGS Eros group in Washington, D.C., and the USGS group at Flagstaff have been undersay for some time now. Plans are being made to utilize orbital data acquired over the Lake Powell area. RB-57 flights, by NASA, are a distince possibility at this time, as well as U-2 and other high-alitutde, and hopefully low-altitude, over-flights. Albuquerque may be the ultimate sink for all of this information.

Plans currently are underway for the collection of specific remote sensing data from the UCRB sometime early in the spring and again in the fall. Of primary importance at this time is collection of thermal infrared data and slope stability data for the upper reaches of the watershed. Specific projects are being planned which will interface with each of the major Lake Powell investigations.

Thomas E. Eastler
THOMAS E. EASTLER, PhD
Captain, USAF
AFIT/ENB WPAFB OH 45433

LAKE POWELL PROJECT

Existing Aerial Photographic Coverage

Utah Coverage

Project Date	USGS Project Code	Scale	Contractor	Mosaics
Sept 1951	RB	1:47,000	Engineering Service Corp. Los Angeles, Calif.	9
Sept 1951	RC	1:47,200	Engineering Service Corp. Los Angeles, Calif.	3
Sept 17, 1951	RO	1:37,400	Mark Hurd Mapping Co. Minneapolis, Minn.	10
Oct 15, 1951	RR	1:62,500	Aero Service Corp.	20
Nov 20, 1952	WD	1:37,400 Circle Cliffs Area	Mark Hurd Mapping Co. Minneapolis, Minn.	18
Nov 27, 1952	WI-'52 Roll 3 only	1:20,000	Joe Jacobson Flying Service (Hughes Aerial Surveys) San Antonio, Texas	25
Nov 10, 1957	VRF	1:20,000	(?)	1
June 29, 1958	VQT	1:20,000 Straight Cliffs	(?)	4
Oct 1, 1958	VVR	1:62,500	(?)	19
June 13, 1966	VBMV	1:34,000 Straight Cliffs # 1,2,3	Western Aerial Contractors Inc.	3
April 28, 1971	----	1:20,000	USAF	--

Arizona Coverage

Project Date	USGS Project Code	Scale	Contractor	Mosaics
Oct 6, 1951	QZ	1:47,000	Engineering Service Corp. Los Angeles, Calif.	8

Arizona Coverage (Cont.)

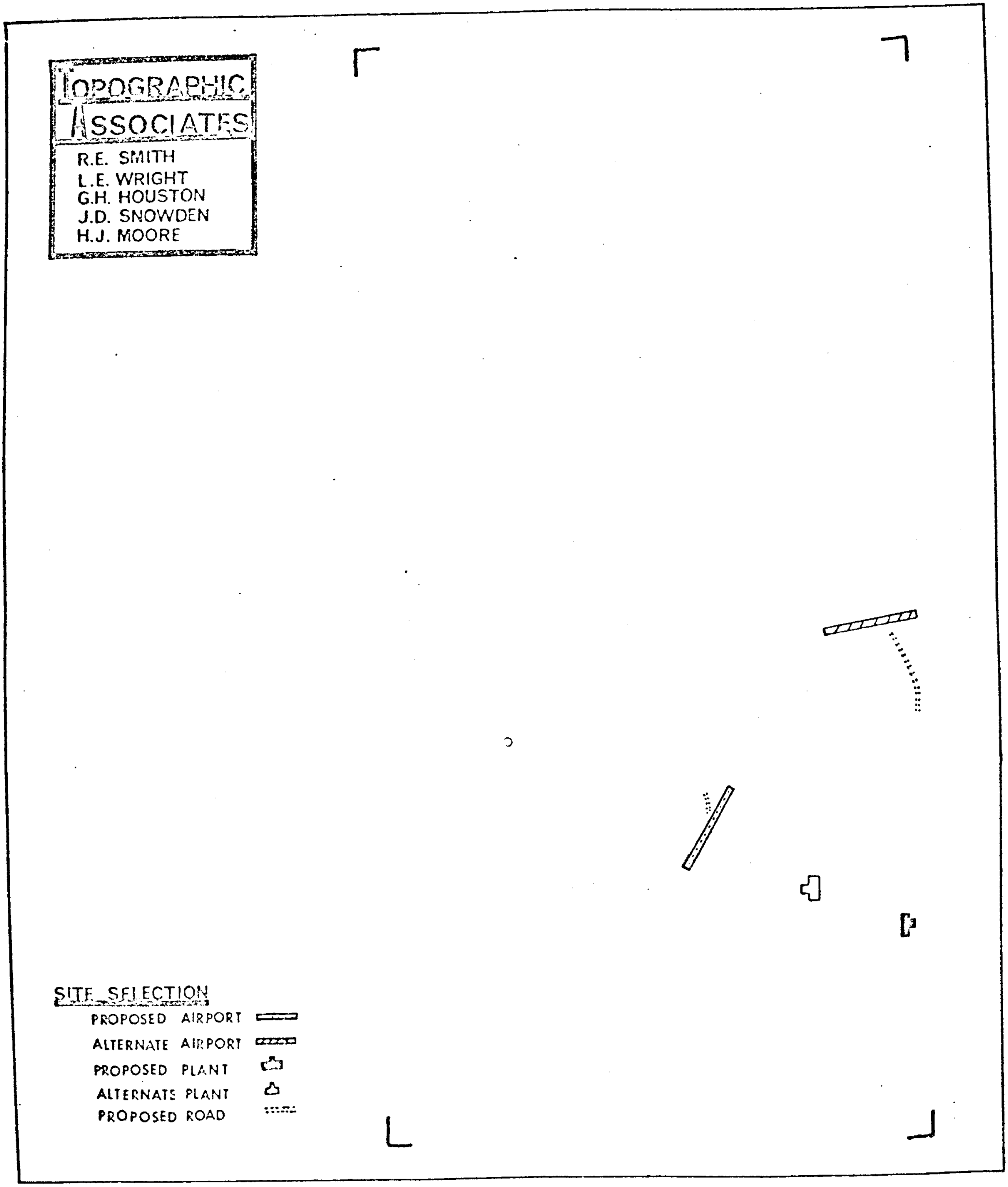
Project Date	USGS Project Code	Scale	Contractor	Mosaics
Oct 23, 1952	WE	1:20,000	Park Aerial Surveys, Inc. Louisville, Kentucky	21
May 24, 1966	VBMW	1:34,000	Mark Hurd Aerial Surveys Minneapolis, Minn.	4
July 21, 1968	VCAB	1:34,000	Mark Hurd Aerial Surveys Minneapolis, Minn.	6

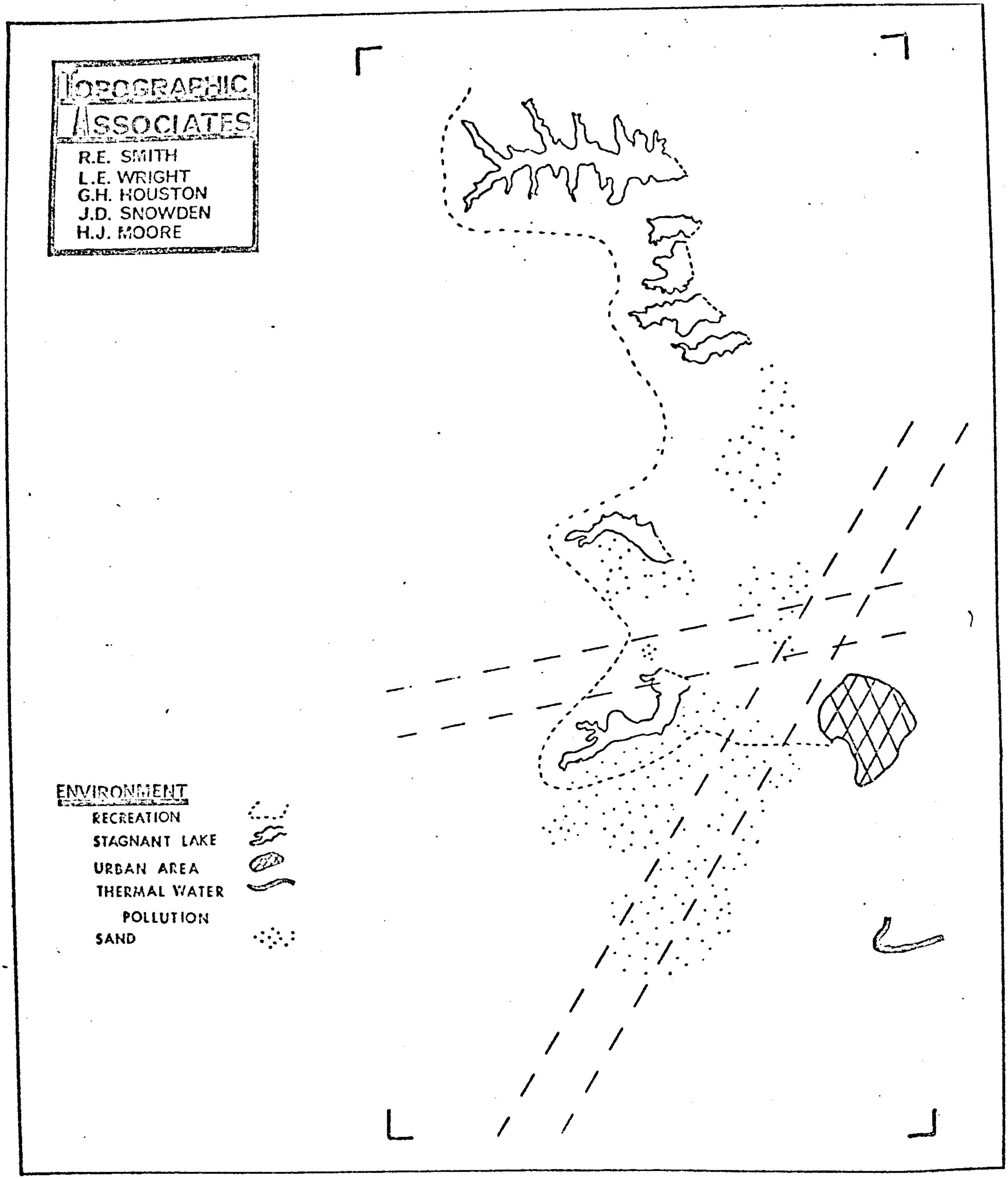
4. Appendix E-2

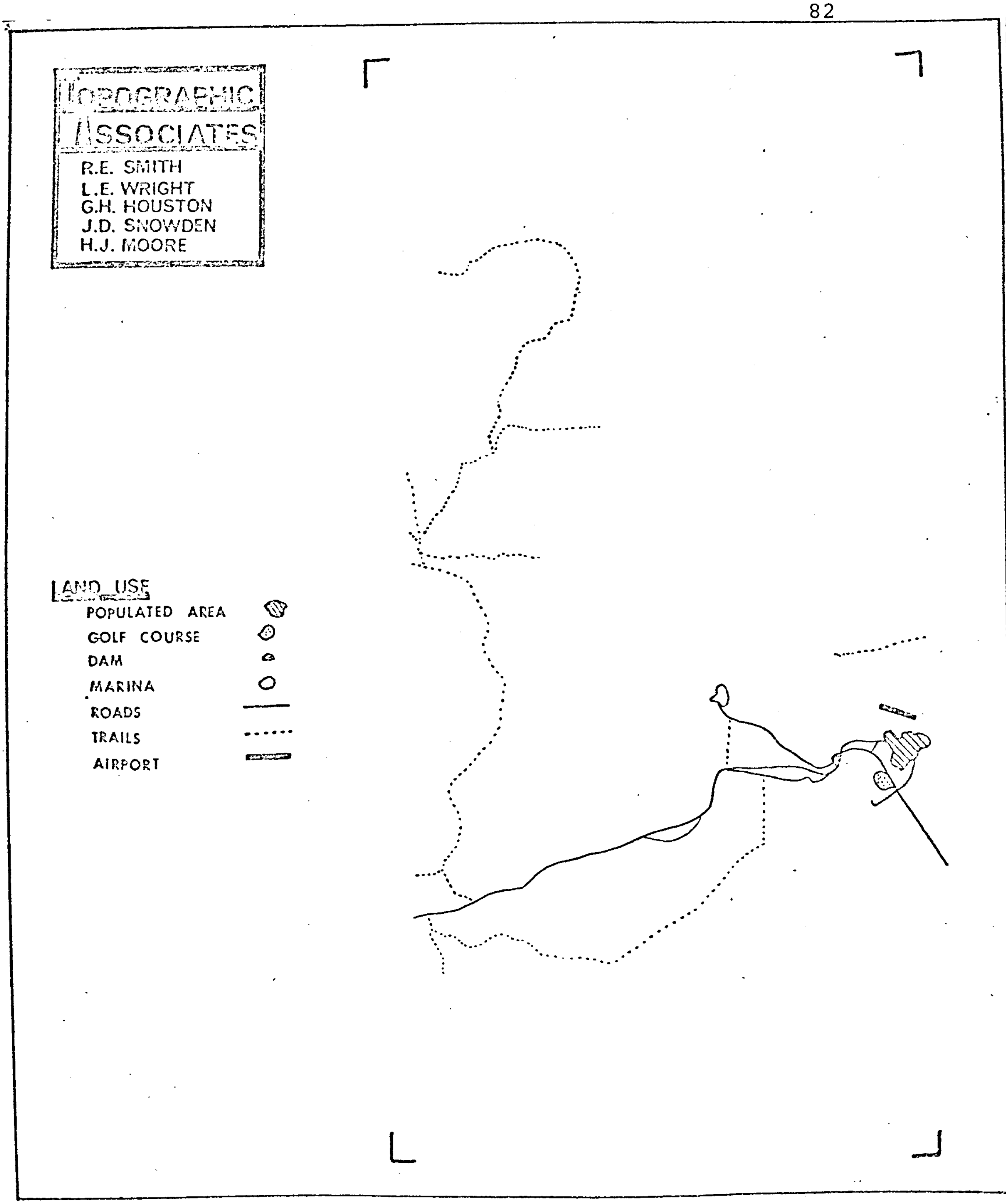
Xerox copies of overlays generated by U.S. Air Force and U.S. Army students attending a short course on aerial photographic interpretation for environmental analysis. Areas covered are the following: Powell area 1S - Page, Arizona, and vicinity; Powell area] - Hite, Utah, and vicinity.

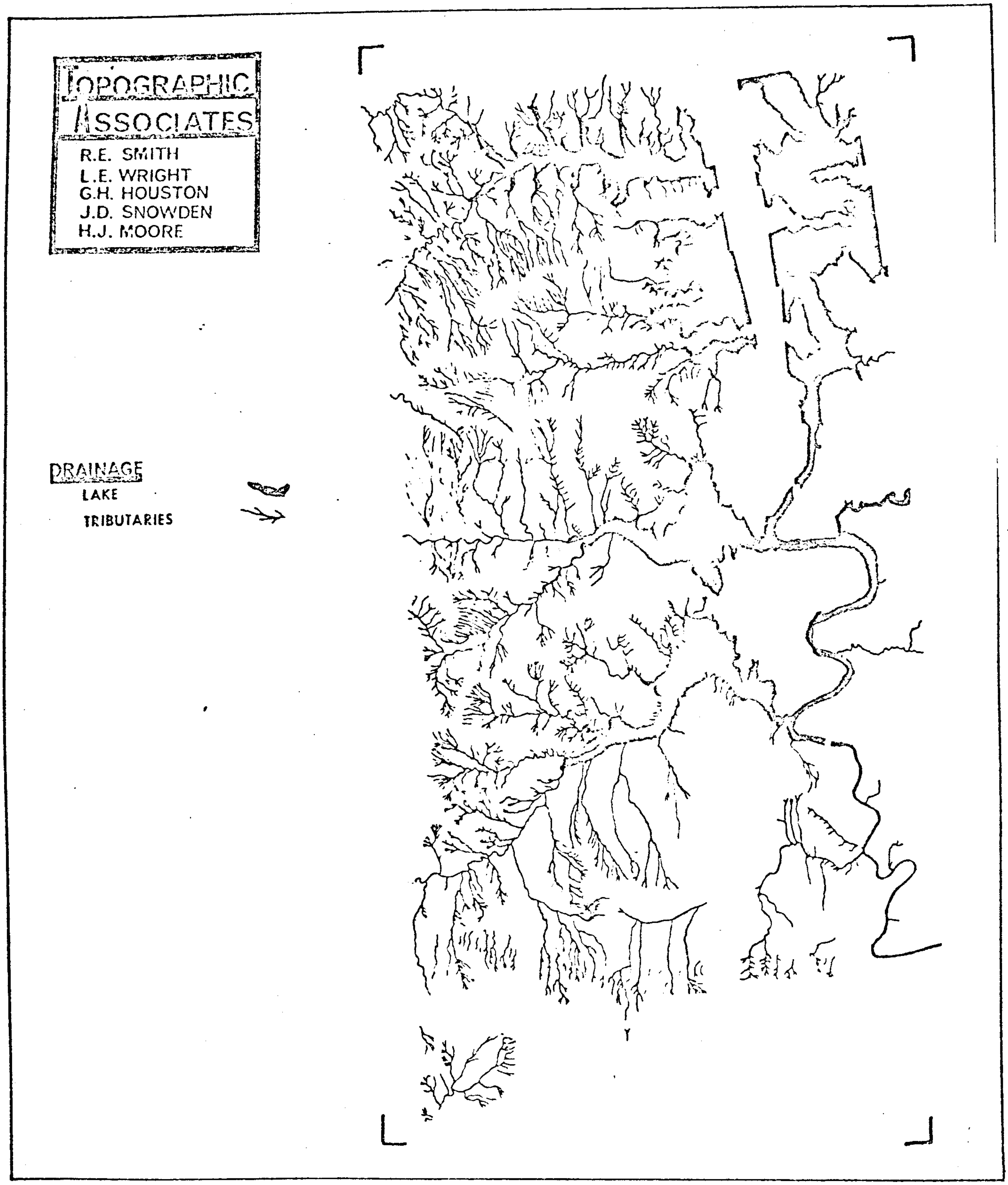
Information on each area was generated and compiled on large mosaics (4-feet by 8-feet) by a group of five students of varied background (civil engineers, foresters, architectural engineers, and geologists), none of whom had prior experience with photointerpretation. These overlays were incorporated into a report which was completed within 16 hours (1-1/2 working days) after the initial assignment.

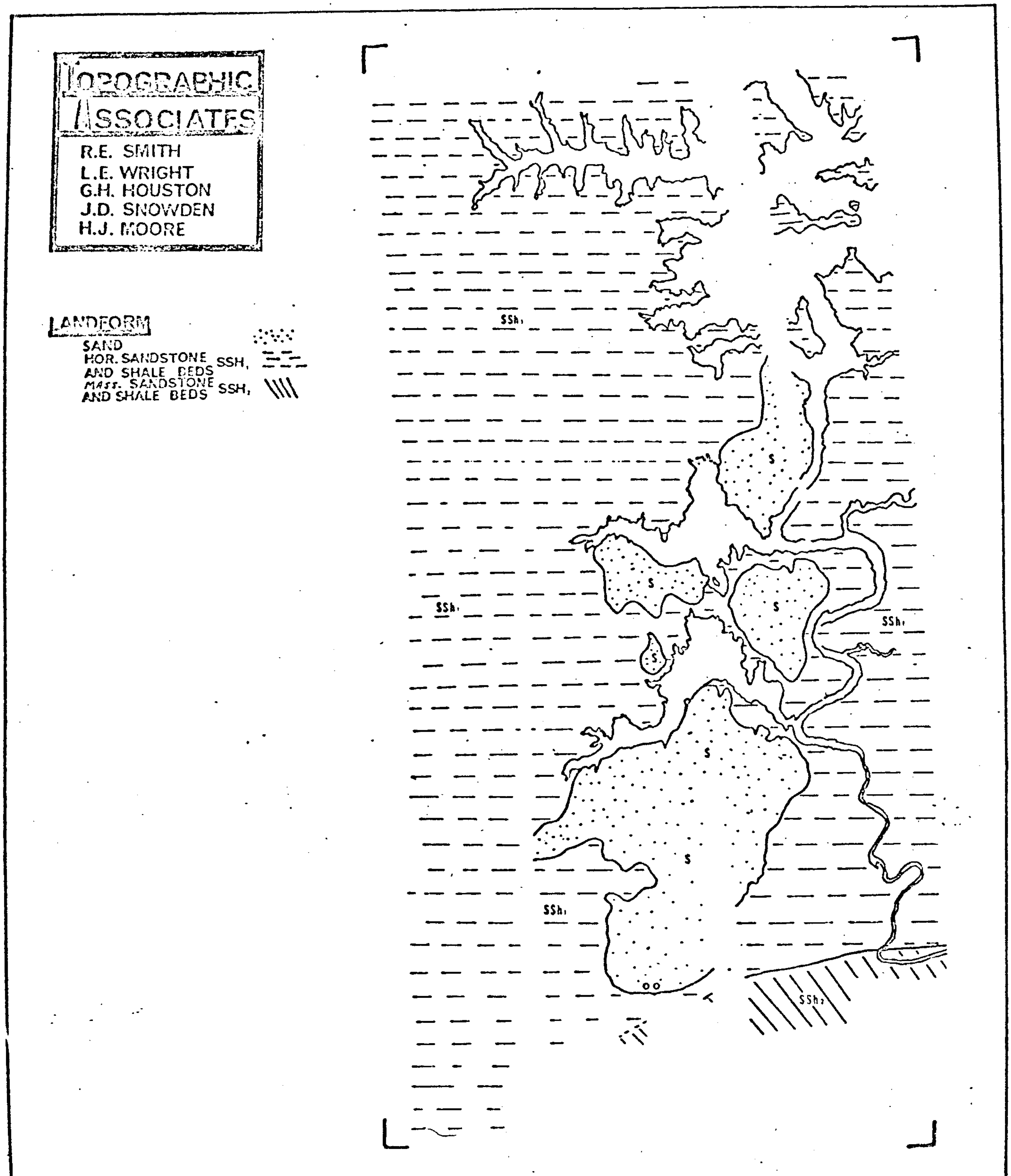
To see how overlays mesh together, simply thermofax each sheet onto a transparency, and align the several transparencies over the poor-quality Xerox reproduction of the photo-reduced mosaic.


TOPOGRAPHIC ASSOCIATES
R.E. SMITH
L.E. WRIGHT
G.H. HOUSTON
J.D. SNOWDEN
H.J. MOORE
SITE SELECTION
PROPOSED AIRPORT
ALTERNATE AIRPORT
PROPOSED PLANT
ALTERNATE PLANT
PROPOSED ROAD

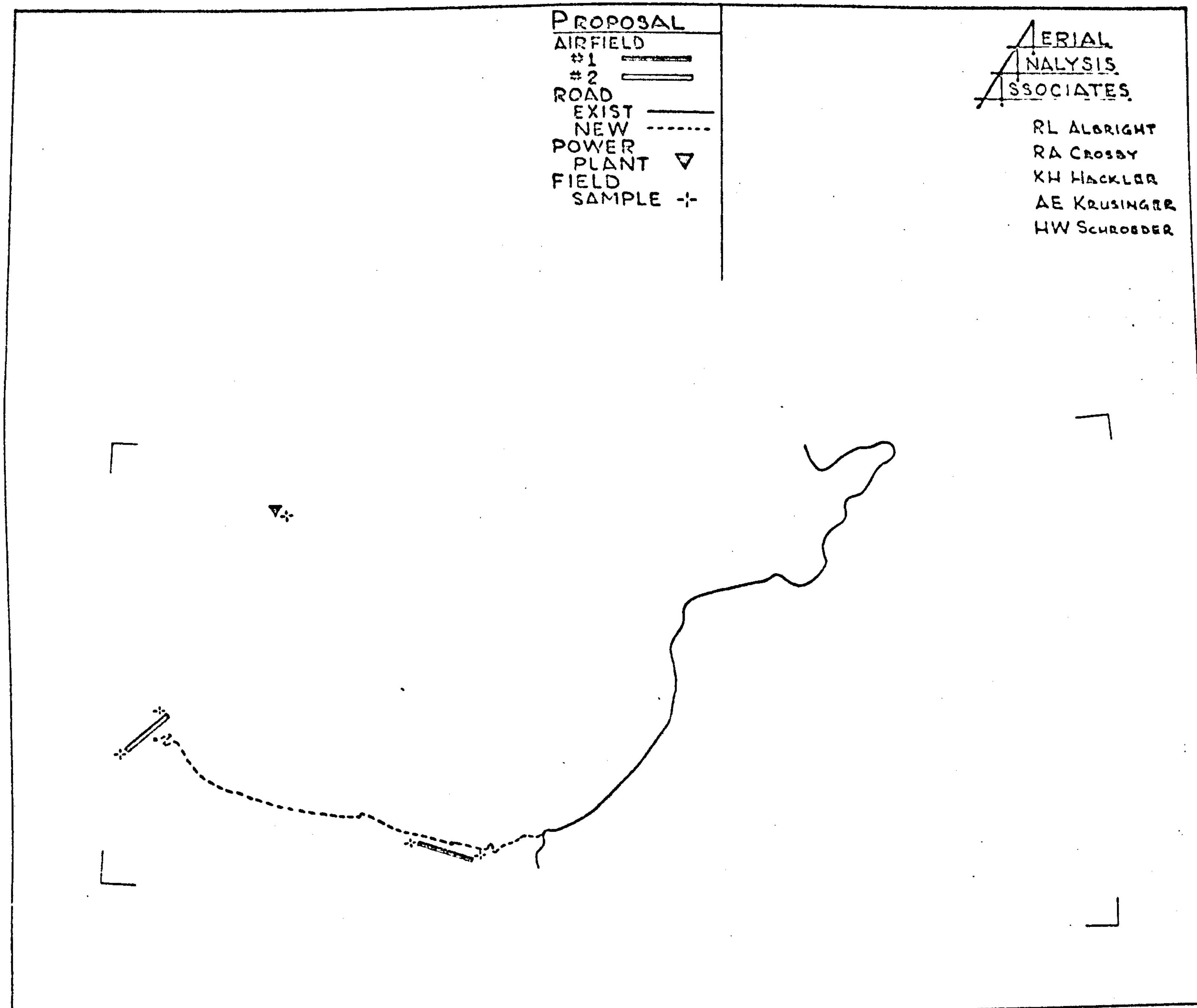

TOPOGRAPHIC ASSOCIATES
R.E. SMITH
L.E. WRIGHT
G.H. HOUSTON
J.D. SNOWDEN
H.J. MOORE
ENVIRONMENT
RECREATION
STAGNANT LAKE
URBAN AREA
THERMAL WATER POLLUTION
SAND

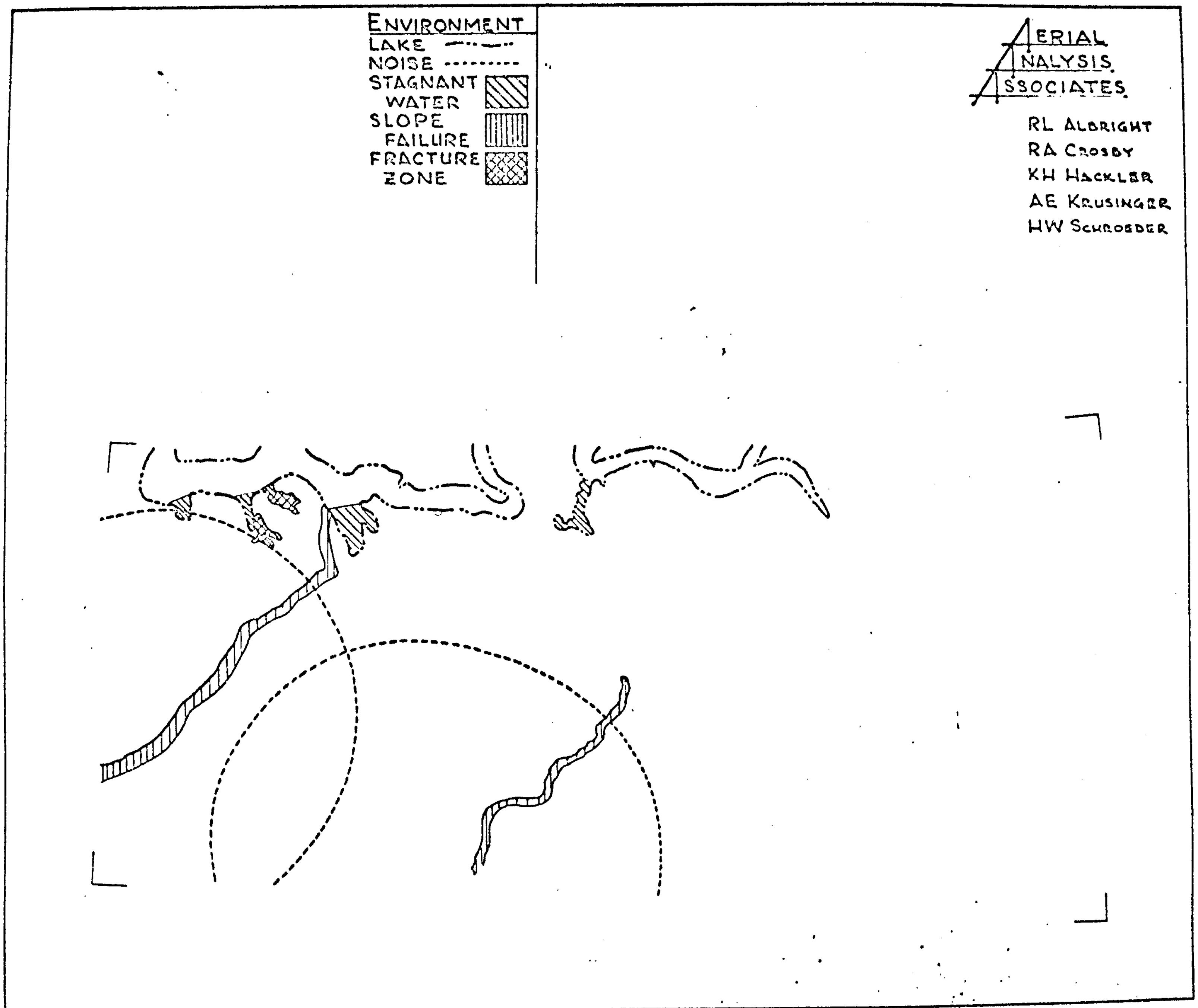

TOPOGRAPHIC ASSOCIATES
R.E. SMITH
L.E. WRIGHT
G.H. HOUSTON
J.D. SNOWDEN
H.J. MOORE
LAND USE
POPULATED AREA
GOLF COURSE
DAM
MARINA
ROADS
TRAILS
AIRPORT

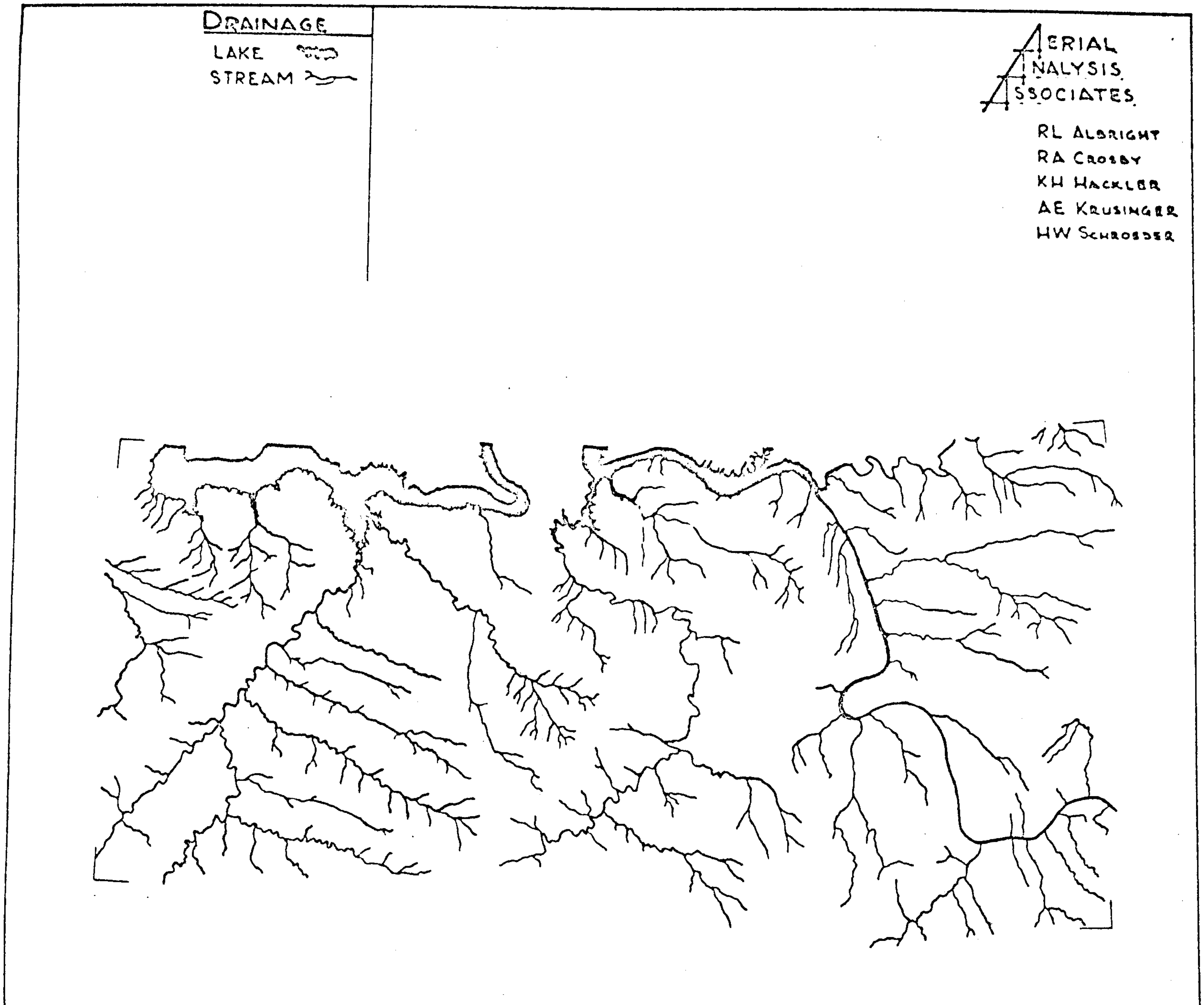

TOPOGRAPHIC
ASSOCIATES
R.E. SMITH
L.E. WRIGHT
G.H. HOUSTON
J.D. SNOWDEN
H.J. MOORE
DRAINAGE
LAKE
TRIBUTARIES

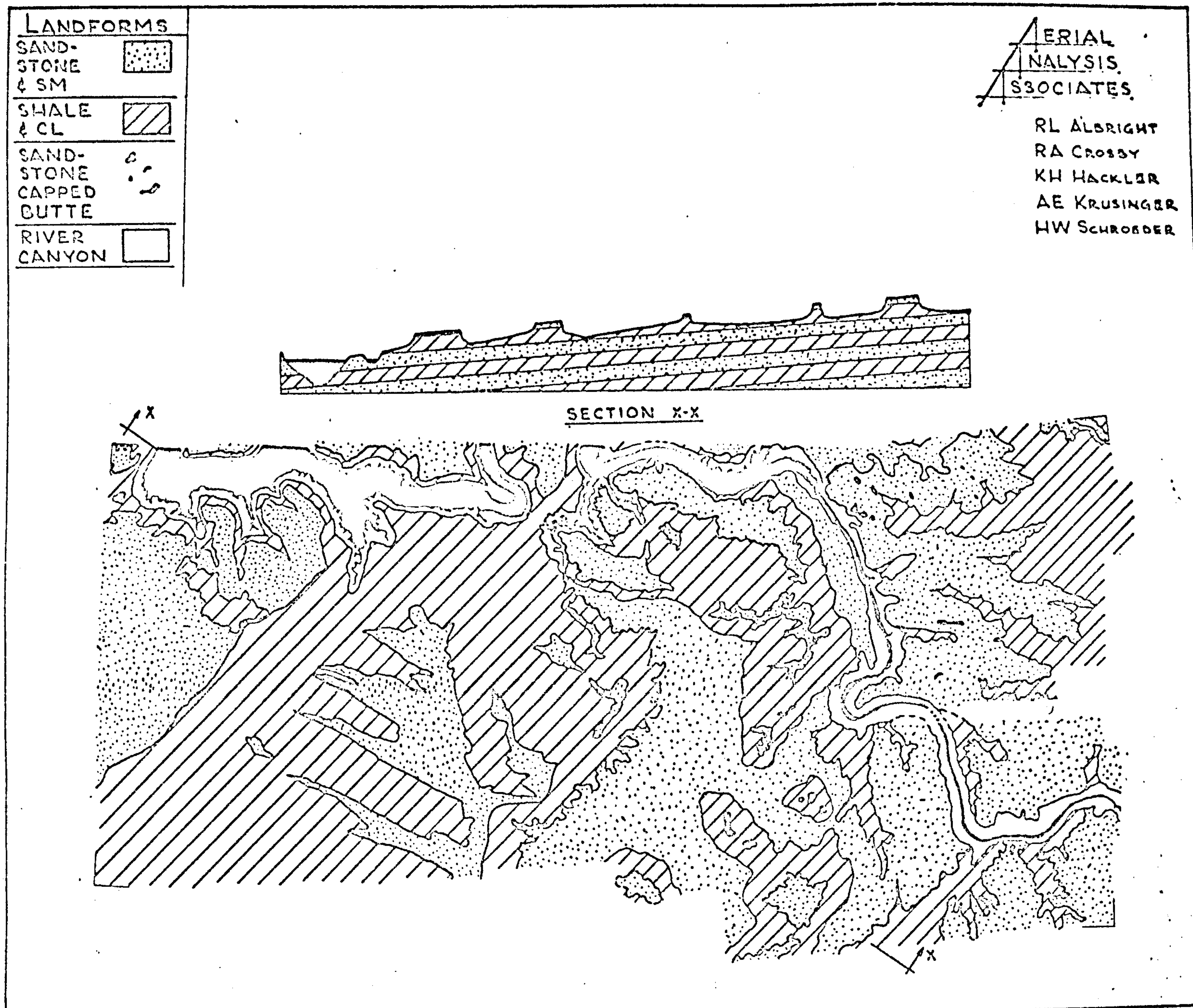

TOPOGRAPHIC ASSOCIATES
R.E. SMITH
L.E. WRIGHT
G.H. HOUSTON
J.D. SNOWDEN
H.J. MOORE
LANDFORM
SAND
HOR. SANDSTONE AND SHALE BEDS SSH1
MASS. SANDSTONE AND SHALE BEDS SSH2
SSh1
S
SSh2

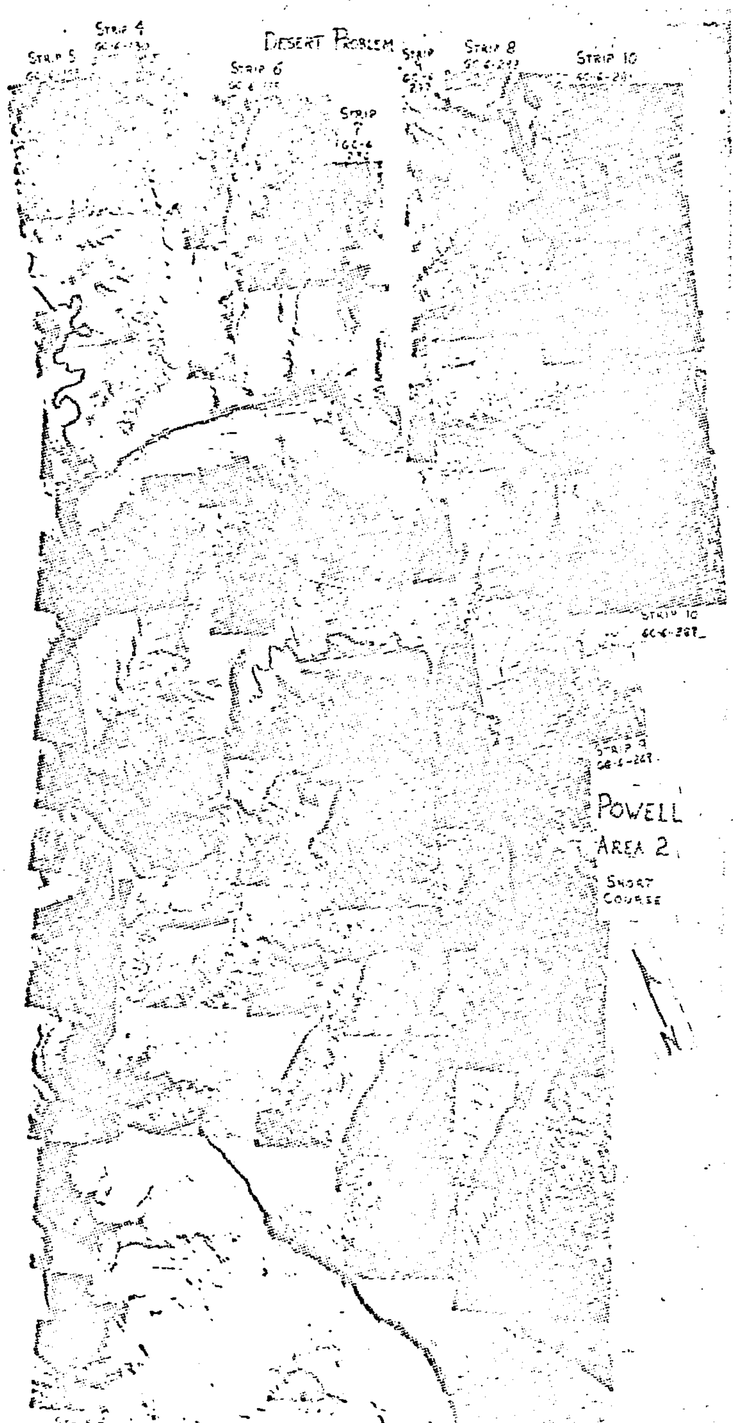

Strip 2
Strip 3
Strip 6
Strip 7
Strip 8

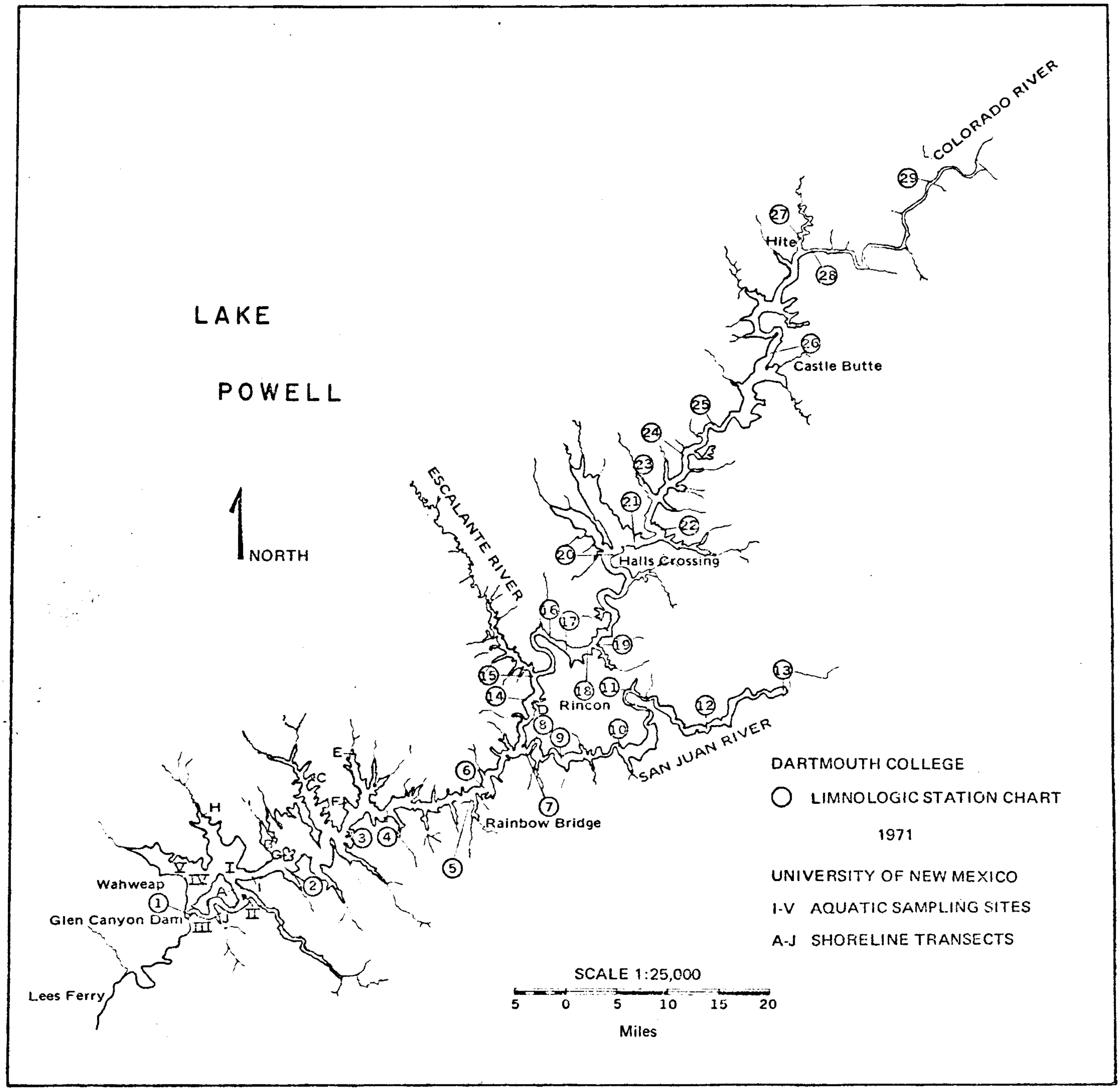

PROPOSAL
AIRFIELD
#1
#2
ROAD
EXIST
NEW
POWER PLANT
FIELD SAMPLE
AERIAL ANALYSIS ASSOCIATES
RL ALBRIGHT
RA CROSBY
KH HACKLER
AE KRUSINGER
HW SCHROEDER


ENVIRONMENT
LAKE
NOISE
STAGNANT WATER
SLOPE FAILURE
FRACTURE ZONE
AERIAL ANALYSIS ASSOCIATES
RL ALBRIGHT
RA CROSBY
KH HACKLER
AE KRUSINGER
HW SCHROEDER


DRAINAGE
LAKE
STREAM
AERIAL ANALYSIS ASSOCIATES
RL ALBRIGHT
RA CROSBY
KH HACKLER
AE KRUSINGER
HW SCHROEDER


LANDFORMS
SAND-STONE & SM
SHALE & CL
SAND-STONE CAPPED BUTTE
RIVER CANYON
AERIAL ANALYSIS ASSOCIATES
RL ALBRIGHT
RA CROSBY
KH HACKLER
AE KRUSINGER
HW SCHROEDER
SECTION X-X
X
X


DESERT PROBLEM
STRIP 4
STRIP 5
STRIP 6
STRIP 7
STRIP 8
STRIP 10
POWELL
AREA 2
SHORT
COURSE
N


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