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Survey of Vegetation in the Glen Canyon Reservoir Basin

By ANGUS M. WOODBURY, STEPHEN D. DURRANT, SEVILLE FLOWERS

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ANTHROPOLOGICAL PAPERS

The University of Utah Anthropological Papers are a medium for reporting to interested scholars and to the people of Utah research in anthropology and allied sciences bearing upon the peoples and cultures of the Great Basin and the West. They include, first, specialized and technical record reports on Great Basin archeology, ethnology, linguistics, and physical anthropology, and second, more general articles on anthropological discoveries, problems and interpretations bearing upon the western regions, from the High Plains to the Pacific Coast, insofar as they are relevant to human and cultural relations in the Great Basin and surrounding areas.

For the duration of the archeological salvage project for the upper Colorado River Basin which the University has undertaken by contract agreement with the National Park Service, reports relating to that research program are being published as a series within a series, bearing numbers in the general sequence of the papers as well as their own identifying numbers.

The Glen Canyon subseries will represent a wider range of the sciences and humanities than the parent series itself. The project provides for studies of the natural history of the Glen Canyon area and its inhabitants so that the relations of the prehistoric cultures and their settings will be understood in depth. As contact with Western peoples and cultures has had a varying effect upon the native Americans and the land, some papers will be concerned with the Colorado in the more recent past. Most of the Glen Canyon publications, however, will be archeological reports.

A SURVEY OF VEGETATION IN GLEN CANYON RESERVOIR BASIN

Angus M. Woodbury, Stephen D. Durrant, Seville Flowers

Division of Biological Sciences

University of Utah

Number 36 (Glen Canyon Series Number 5) January, 1959

A N T H R O P O L O G I C A L   P A P E R S

DEPARTMENT OF ANTHROPOLOGY
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Glen Canyon Reservoir

Upper Colorado River Basin

Survey of Vegetation in the Glen Canyon Reservoir Basin

as a part of the

Upper Colorado River Basin Salvage Program

in accordance with the

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between the

U.S. National Park Service and the University of Utah

by

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FOREWORD

This report is one of a series of papers dealing with investigations of the Colorado River arising out of the water storage program provided by Congress for the development of the Upper Colorado River Basin (Federal Public Law 485, 84th Congress, 2nd Session). Under this program, a dam is being constructed across a narrow gorge in Glen Canyon, fifteen miles above Lee's Ferry, Arizona, which will back water 186 miles up Glen and Cataract Canyons and 71 miles up the San Juan River to form the Glen Canyon Reservoir, most of which lies in Utah.

A by-product of this program is a plan of the National Park Service to salvage the archaeological remains that will be covered by the water of the reservoir. A part of this salvage program was undertaken by the University of Utah under an agreement with the National Park Service, dated July 23, 1957. This salvage project, of which Dr. Jesse D. Jennings is Director, includes in addition to the main archaeological salvage program, a historical study of the region and an ecological study of the aboriginal people of the Glen Canyon region.

At the request of Dr. Jennings, the Division of Biological Sciences undertook the ecological study. Dr. Don M. Rees, head of the Division called upon Angus M. Woodbury to organize the work. In doing so, he has had the willing cooperation of many staff members. During the course of these ecological studies, two reports have been prepared; one dated October, 1957, is a preliminary proposal titled "Working Plan for Ecological Studies", Glen Canyon Reservoir; the other, dated April, 1958, and titled "Preliminary Report on Biological Resources of the Glen Canyon Reservoir", was published in the University series of Anthropological Papers, No 31 (Glen Canyon Series Number 2).

When the Bureau of Reclamation found need for a program during the summer of 1958 to assess the vegetation in Glen Canyon before it is covered with water, an arrangement was made by Cecil B. Jacobson, chief of the Bureau's Upper Colorado River Office at Salt Lake City through the National Park Service, for the University to undertake the study. This report is the result of that study. A part of the background for the study was provided by a field trip through Glen Canyon from Hite to Lee's Ferry by a group that included three representatives of the Bureau: Herbert S.Riesbol, Denver; Don Barnett and Stanley Rasmussen, Salt Lake; and five representatives of the University; Angus M. Woodbury, Walter P. Cottam, Stephen D. Durrant, Albert W. Grundmann, and Seville Flowers. During the progress of the work and preparation of this report, we have had the genial cooperation of Don Barnett, liaison officer for the Bureau; H. R. McDonald of the Denver office; Albert M. DeGering and others of the Salt Lake office. The design for statistical analysis used in studying the field data was provided by Dr. Lowell A. Woodbury.

A SURVEY OF VEGETATION IN GLEN CANYON RESERVOIR BASIN

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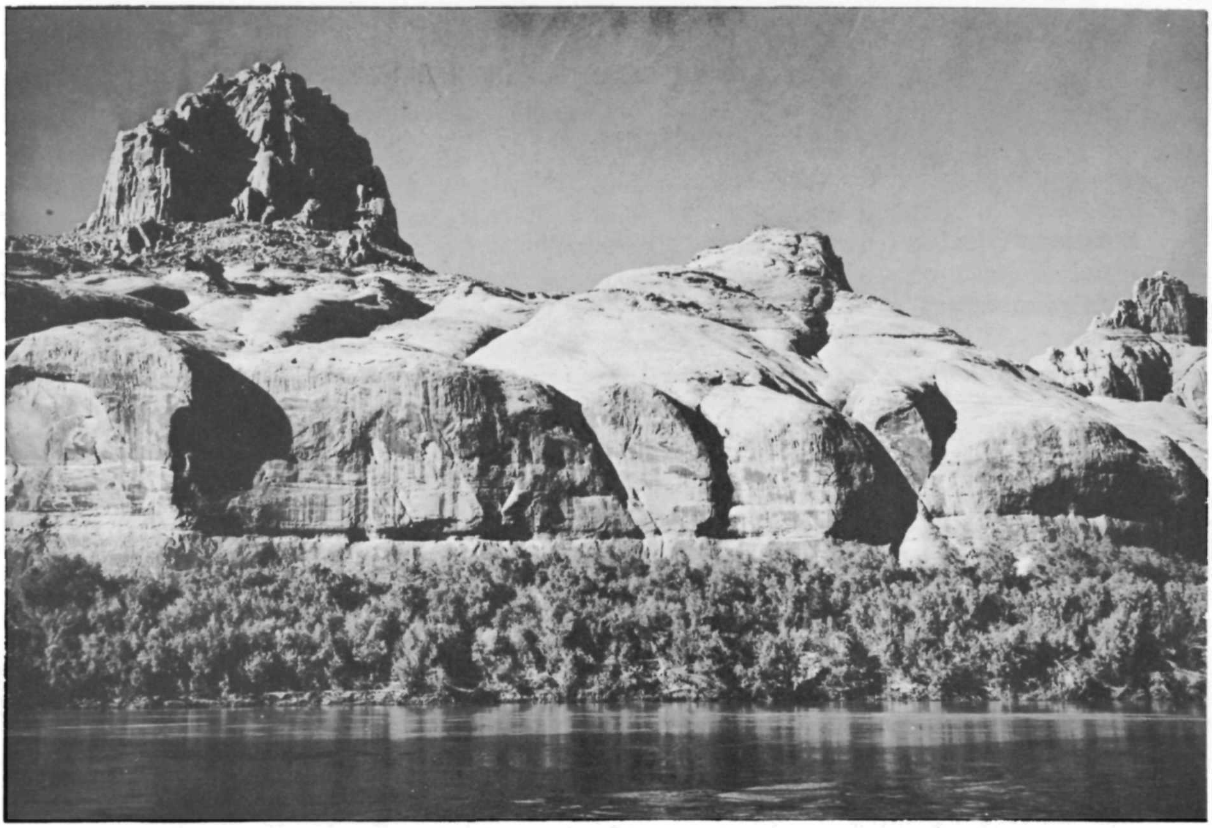

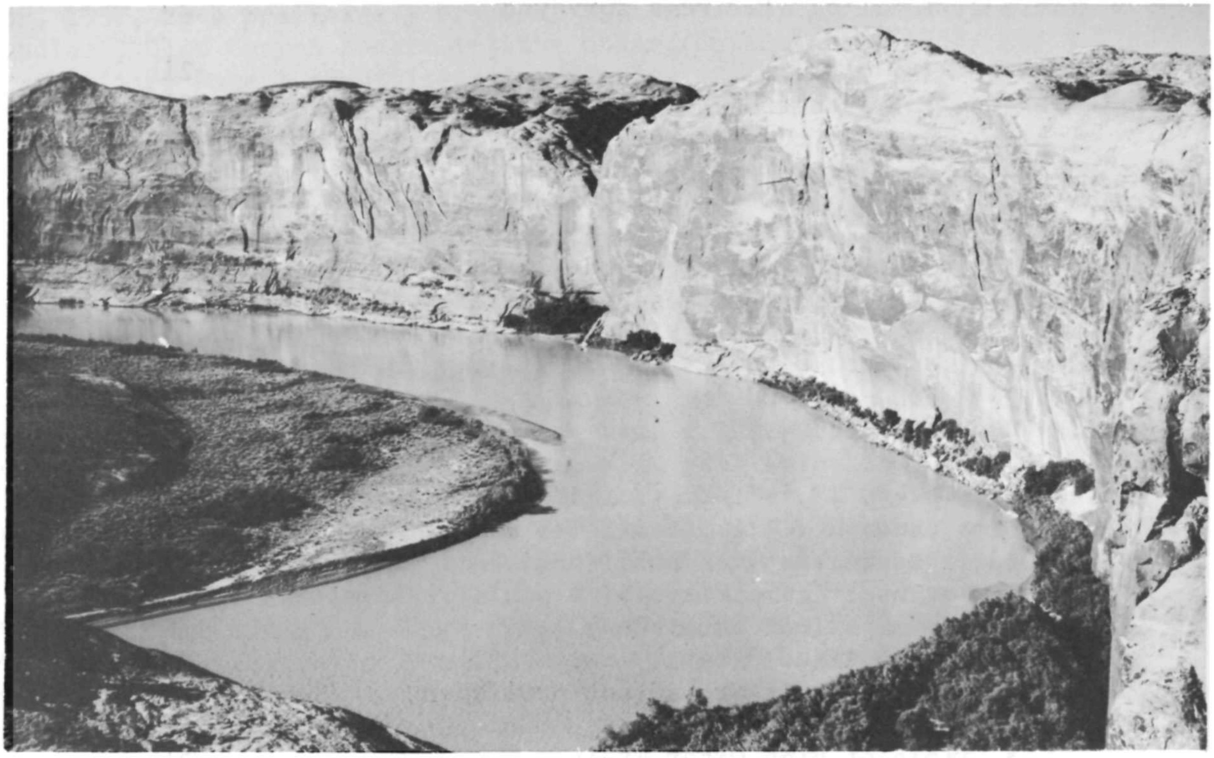

Figures 1 and 2. The Bureau of Reclamation found a need to assess the vegetation along the Colorado River in Glen Canyon that will be covered by water of the Reservoir. Photos of Castle Butte near Red Canyon (above) and bend in the river below Hall Creek, 1957. U.S. Bureau of Reclamation photos by Stanley Rasmussen.

A SURVEY OF VEGETATION IN GLEN CANYON RESERVOIR BASIN

INTRODUCTION

In cooperation with a study of the archaeological resources of the Glen Canyon Reservoir Basin being made by the Department of Anthropology, University of Utah, under an agreement with the National Park Service, dated July 23, 1957, an auxiliary study of the biological resources that may have been available to the aboriginal inhabitants of the basin was undertaken by the Division of Biological Sciences.

During the summer of 1958, an expedition was sent by the University through ruggedly isolated Glen Canyon to study the biological resources. This expedition had three main objectives: (1) to obtain information about the plants and animals of the region that may have affected the lives and distribution of the aborigines, (2) the limnology of the Colorado River and its tributaries, and (3) a survey of the vegetation in the reservoir basin to determine the kinds and quantities of plants that would be lost when the reservoir is filled, figures 1 and 2. This report deals with the last objective.

The survey of vegetation was made in cooperation with the Bureau of Reclamation through its Upper Colorado River Office at Salt Lake City. It was undertaken by University specialists under the leadership of Angus M.Woodbury of the University's Ecological Research Colorado River Project in consultation with the Bureau liaison officer, Don Barnett of the Upper Colorado River Office. Plans for the expedition developed through negotiation with the University of Utah Department of Anthropology, the Utah State Department of Fish and Game, and the Bureau of Reclamation Upper Colorado River Office, provided for a trip from Hite to Lee's Ferry beginning about July 1 after the high water season had passed. Plans for the vegetation survey included a preliminary trip to Hite during early June to establish detailed procedures for the later expedition.

PRELIMINARIES

In preliminary negotiations for this study, the Upper Colorado River Office supplied aerial photographs of Glen Canyon accessory supplies and certain other equipment. These photographs (18 x 18 inches) were provided with overlay sheets upon which to map the areas of vegetation in the field. The preliminary trip to Hite to plan methods and procedures was taken June 8 to 10, 1958. Personnel of the trip, figure 3, included Bureau representatives H. R. McDonald, Denver, and Albert M. DeGering, Salt Lake; University of Utah staff specialists Drs. Angus M. Woodbury, Stephen D. Durrant and Seville Flowers; graduate students Harold G. Higgins, Grant O. King and Delbert W. Lindsay; and Dr. Earl M. Christensen of the Brigham Young University.

On this preliminary trip, it was agreed that on the later expedition the University personnel would map the different types of vegetation on the

Fig. 3. Personnel of the preliminary trip to Hite, June 8 to 10, 1958. From left: Earl M. Christensen, Delbert W. Lindsay, Stephen D. Durrant, Harold G. Higgins, Seville Flowers, Angus M. Woodbury and Grant O. King (behind); Albert M. DeGering not shown. Mile 166. Photo by H. R. McDonald, U. S. Bureau of Reclamation.

Fig. 4. Part of personnel of the summer expedition of 1958 at mouth of Long Canyon, Mile 95.5, looking upstream, wet sand in foreground, July 18, 1958. Photo by Delbert W. Lindsay.

overlay sheets, make ocular estimates of the vegetation on each such area and record the data on tabulation sheets. The specialized personnel making these estimates were to receive an initial period of training in the field and also check their ocular estimates weekly by a series of measured transects.

THE SUMMER EXPEDITION OF 1958

The expedition was planned for midsummer after the high water season had passed and when faculty and students of the University would be free to participate. It was organized in May while many of the personnel were still otherwise uncommitted for summer work. Arrangements were made with the Hatch River Expeditions of Vernal, Utah to provide river transportation and a complete camp including boats, camp equipment and food supplies.

The technical personnel of the expedition assembled on June 29 at the University and left Salt Lake by bus next morning at 6 A.M. They arrived at Hite at 5 P.M., where they found the Hatch Camp established. They were also joined by a representative of the Utah State Department of Fish and Game.

The complete personnel of the expedition consisted of the following: Dr. Stephen D. Durrant, field director of expedition; Dr. Seville Flowers, chief of the vegetation survey; James Crook, Don P. Gaddis, Heber H. Hall, Gideon Herrmann, Harold G. Higgins, H. Wendell Hyde, Grant O. King, Delbert W. Lindsay, Merrill K. Ridd, and Bruce N. Smith, members of the vegetation survey crew; Donald D. McDonald, representative of the State Fish and Game Department, Guy Musser, and Gerald R. Smith, limnological study team; Nowlan K. Dean and Allen Lambert, animal study team; Bruce Lium, in charge of transportation on the river, and Dale Winward, cook, Hatch River Expeditions employees; a total of 19 men. The camp was supplied weekly by Woody Edgell from his White Canyon Grocery across the river from Hite, Figure 4.

After the preliminary period of training and work around Hite and White Canyon, the expedition left Hite at 8:30 A. M. July 4 and continued moving downstream as the vegetation survey progressed until the group passed the Glen Canyon dam site at 8 A.M., August 7 and floated on down to Lee's Ferry late that afternoon. They left Lee's Ferry about 5 P.M., next day by bus and arrived in Salt Lake City about 5:30 A. M. next morning, August 9.

Equipment on the river included two 26-foot rubber pontoons for hauling the crews, the scientific equipment and personal gear; one 10-man rubber raft manipulated by the cook for transporting camp and commissary supplies; two power boats, each with two motors, one supplied by Hatch and the other by the Department of Fish and Game. The latter was used primarily by the limnologists in their river studies. One pontoon was used on each side of the river in servicing the vegetation survey crews. The other power boat was used mainly in coordinating activities of the entire group. The river, which was flowing about 107,000 second feet on June 9, had dropped to about 22,000 by July 1 and to about 4,000 at Lee's Ferry on August 8.

SURVEY OF VEGETATION

LOG OF THE EXPEDITION

The log of the expedition from Hite to Lee's Ferry as abridged from the report of Dr. Durrant follows. All river miles indicate distance above Lee's Ferry.

July 1 to 3. In camp at Hite engaged in preliminary training of the vegetation survey crew and in work around Hite, White Canyon and mouth of Trachyte Canyon.

July 4. Left Hite at 8:30 A.M. river mile 162. Stopped at a big island while survey crew cruised the island and revised their scheme of mapping and tabulating data. Worked down river past Two and Four Mile Creeks and camped at mile 153, 9 miles.

July 5. One pontoon with its crew floats down each river bank, dropping off men at appropriate places and picking them up lower down. This leap-frogging continued downstream to Red Canyon, then on to the mouth of Ticaboo Canyon for camp at mile 148, 5 miles.

July 6. Sunday. No work. The men busied themselves in camp chores, writing letters and hiking 3 miles up Ticaboo Canyon where we found springs of good drinking water and pools for bathing. Temperature over 100° F. in daytime but dropped to 63° F. last night.

July 7. Continued leap-frogging the vegetation survey crews downstream and camped at mile 142, 6 miles. The first supply boat caught us at the first rincon. It had a broken propeller and we loaned the boatman one of our motors to return to White Canyon. At supper, we were pleasantly surprised to find fresh steaks, vegetables and even ice cream. Hot all night.

July 8. Before leaving camp, the supply boat arrived and returned our motor. We worked down river, stopping enroute to work.Seven and Nine Mile side canyons and then went on to Warm Spring Creek, mile 137 to camp, 5 miles.

July 9. Camp kept here today while we worked Warm Spring Creek up to the top.

July 10. Working downstream, we investigated Cedar and Knowles canyons about one-half mile upstream from mouths; continued on down river, stopping to investigate Smith and Hansen Creeks and camped on left bank of river at mile 129, 8 miles.

July 11. Continuing downstream, we stopped for lunch at the mouth of Moqui Creek but could not ascend its canyon because of high precipitous cliffs and quicksand in the stream bed. We camped on the left bank at Mile 121, 8 miles. Morale high. River still falling and difficult to put men ashore.

July 12. Working downstream, we encountered heavy upstream wind that nearly neutralized the pontoon drift with the current. Camped on left bank at mile 119, 2 miles. After camp was established, crews visited Bullfrog and Hall's Creek. Camp life made miserable by wind and drifting sand.

July 12. Sunday. Too miserable to stay in camp, so we decided to work. Worked downstream to mouth of Lake Canyon, mile 113, 6 miles, where we found a fine campsite. This is the area of Lake Canyon rapids and shallows where the river is flowing over a solid rock bottom of Kayenta sandstone.

July 14. Day off, in lieu of yesterday. The supply boat arrived at 1:30. The operator had knocked his motor out on the rocks in these rapids and could not go back upstream. He proceeded downstream to the rincon where he was building a road. He had a truck there and planned to go back overland and leave the boat at that point. The vegetation crews climbed to the top of Lake Fork Canyon and surveyed the vegetation. They also found many archaeological ruins. Good spring water was found about 300 yards above the mouth.

July 15. We did not move camp today, but continued our work in Lake Canyon and other places in the vicinity.

July 16. We worked downstream today, mostly between bare walls where vegetation was sparse. The winds were terrific, one gust blew the hatch cover off the power boat. It sailed 30 feet into the air, then fell into the river and was lost. We camped on a large sandbar at river mile 105, 8 miles.

July 17. Continued downstream today to mile 101, 4 miles. We surveyed two unnamed canyons on the left side of the river, each of which had a lake and permanent water in it.

July 18. We continued down the river today to mile 91, 10 miles. Much of the canyon had barren walls and sparse vegetation. At noon we stopped to work Long Canyon which is called Navajo Creek on some maps.

July 19. We made a short run today and camped at the mouth of Escalante River, mile 88, 3 miles. We sent two vegetation survey crews up Escalante River to make an overnight camp and then work as far up the river as possible the next morning.

July 20. Without the crew working up Escalante River, we moved downstream to Hole-in-the-Rock where we stopped for investigation and allowed the men to climb out on top. Later we moved downstream to mile 83, 5 miles. The power boat returned to the mouth of Escalante River and picked up the overnight camping party and brought them down to camp.

July 21. Day off in lieu of yesterday. The supply boat did not arrive today, hence we were very apprehensive about supplies and decided to send our power boat back upstream if it did not arrive by morning.

July 22. As we were striking camp this morning, the supply boat arrived. The supplies had been freighted overland to the Big Rincon and brought downstream from there by boat. We worked downstream to the mouth of the San Juan River, mile 78, 5 miles. The San Juan River was flowing about 1,000 second feet.

July 23. A dark and dismal morning with high winds and showers. We were unable to ascend the San Juan River by boat, hence the survey crews worked up on each side of the river as far as feasible. One crew reached the top at the base of the Great Bend in the river. They returned about 11 and we moved camp down to Music Temple, mile 76, 2 miles. The storm ceased in the evening, but we were pretty well soaked. Some of the boys carried their gear up to Music Temple to camp under the large overhang.

July 24. We worked downstream as far as the mouth of Aztec Canyon, mile 68.5, 7.5 miles.

July 25. Without moving camp, we worked up Aztec Creek and Bridge Canyon as far as the Rainbow Bridge. All but two of the men returned to camp.

July 26. The two men that stayed out last night had arrived by 7 A.M. Later we proceeded downstream until late afternoon and camped on a sandbar at river mile 63, 5.5 miles. Before leaving camp this morning the river, which had hitherto been clear, changed to a dark red color heavy with silt, brought down by a storm on the San Juan drainage.

July 27. Going downstream this morning we encountered the expedition of the Department of Anthropology, University of Utah, at mile 61. We visited their camp and some of their workings, carried on by a crew of seven men. Later we moved on downstream to the mouth of Rock Creek, river mile 56, 7 miles. The river dropped from 4 to 6 inches after the storm and the banks were left gooey with red mud.

July 28. Without moving camp, the vegetation survey crews mapped the three forks of Rock Creek. We found good drinking water about a mile upstream from the mouth. After lunch, Heber H. Hall and Donald McDonald left in the Department of Fish and Game boat for home expecting to leave the river at Kane Creek.

July 29. We worked downstream to the mouth of Last Chance Creek, river mile 49.5, 6.5 miles. We camped on a tremendous sandbar across the river from the mouth of the creek.

July 30. We surveyed the vegetation downstream to river mile 43, 6.5 miles. Enroute we surveyed two unnamed side canyons that were lush with vegetation. In both we found good drinking water a short distance upstream from the mouth. We camped on a large sandbar on the right side of the river.

July 31. We worked downstream to the mouth of Kane Creek, mile 40.5, 2.5 miles, where we made camp. We surveyed the embayment on Kane Creek.

LOG OF THE EXPEDITION

August 1. We laid over here today awaiting our last supplies. These arrived in early afternoon by truck brought in by Woody Edgell from White Canyon via Kanab and Wahweap. This is the point at which tourists coming down the river leave the canyon. In all, I counted 56 people landing on this bare rock.

August 2. We continued our work downstream and camped on a sandbar at river mile 34, 6.5 miles.

August 3. We worked downstream to the mouth of Cottonwood Canyon, river mile 28, 6 miles, where we camped on a wet sandbar across the river from the mouth of Warm Creek.

August 4. We continued the survey downstream as far as river mile 21, 7 miles where we found a fine spring at the water edge on the right bank of the river. We camped on a large sandbar across the stream from the spring.

August 5. A day off for the crew. With Bruce Lium and Dale Winward, I went downstream 5 miles to the dam site where I arranged for our passage through that area on the morning of August 7th. We found that there was little vegetation along this 5 mile strip.

August 6. We remained in camp and prepared for the trip through the dam site on the morrow.

August 7. We struck camp at 6 A.M. and mapped the sparse vegetation as we went downstream to the dam site, which we passed at 8 A. M. and floated on down to Lee's Ferry.

August 8. We were busy all morning beaching and cleaning the boats for loading. The Hatch Expedition Crew departed around noon. At 4 P. M. our bus arrived and we loaded it quickly and departed about 5 P. M. We stopped for dinner at Cliff Dwellers' Lodge and arrived at Kanab at about 10 P. M.

August 9. After traveling all night, we arrived in Salt Lake City at 5:30 A. M.

THE VEGETATION SURVEY

During the preliminary trip to Hite, June 8 to 10, problems of computing the kinds and quantities of vegetation in Glen Canyon were discussed with the Bureau representative, Mr. H. R. McDonald, using the pamphlet "A Guide to the Density Survey of Bottom Land and Streambank Vegetation" prepared by the Sub-committee on Phreatophytes, Pacific Southwest Inter-Agency Committee, as back-ground for the discussions. Mr. McDonald pointed out certain features of the vegetation along the river and outlined the kind of data desired by the Bureau, especially emphasizing kinds of data that the Bureau personnel could interpret most easily.

METHODS OF STUDY

Dr. Christensen discussed various methods of measuring vegetation and demonstrated types thought to be most suitable for the purpose of training and testing the judgment of observers in making ocular estimates of the density, height and width of specific areas of vegetation. Some areas above Hite were ocularly estimated and then tested by making line transects of the estimated vegetation. In the areas selected for sampling, several transects (usually about 6), each 50 feet in length, were selected at random and measured by the line transect method.

This line transect method was used by pacing off ten steps from any selected point and then arbitrarily stretching a 50-foot measuring tape taut in any random direction within the stand. The tape was anchored at each end with metal pins. A second pair of metal pins was used in measuring the linear distance in inches that the tape extends across the crown of a plant and across bare soil. A second observer recorded on specially prepared survey sheets the distances read from the tape for each plant and for each bare soil exposure. Dead plants and litter were recorded as bare soil since they were not drawing water from the soil. These distances were tabulated in columns for each kind of plant, Appendix A-2.

The total distance covered by the tape over or through each species of plant computed as a percentage of 50 feet was considered to be the density of that species on that line transect. The total of all species was used to indicate the density of vegetation along that line. The average of several such lines was used to indicate both the density of vegetation on the area being sampled and the percentage composition of each species. These figures were then compared with the densities provided by the ocular estimates and used as a guide for training purposes.

INITIAL TRAINING

Under supervision of the Bureau representative and University personnel, graduate students Higgins, King and Lindsay made ocular estimates of areas along the river from Hite to the mouth of the Dirty Devil River, in Trachyte Canyon and North Wash. In actual practice, it was soon found that the areas selected as units of vegetation were by no means fully uniform in composition and the areas sampled by the transects were not necessarily representative of the whole areas. Hence for training purposes, it was decided that comparison of ocular estimates and transects must be limited to specific local spots and judgment must be exercised in applying it to larger areas.

In the initial training later given to other men, emphasis was placed upon the use of judgment in:

1. Recognition of plants.
2. Size of individual plants with regard to volume of foliage on the shoot as estimated from height and crown diameter.
3. The cover provided by each species in a mixed population.
4. The total density of vegetation on an area with variable density of cover.
5. Height of individual plants and average height of stands of vegetation.
6. The average width of narrow strips of vegetation along the river bank too small for practical measurement on a map.

After the expedition arrived at Hite, most of the time of the first three days was devoted to training the vegetation survey crews and initial work in studying the dominant plants of the region. Typical plants were examined and such features as the habit of growth, size, color, and characteristics of stem and leaves were studied. Special stress was laid on the ecology of root systems in relation to soil moisture and to adaptations of stems and leaves to prevent water loss. Excursions were made into several different vegetation types to study variations in size, growth habit and leaf differences. Special practice was given the men in recognition and naming of the common dominant plants.

In addition, studies were made of the vegetation as background for dividing it into recognizable types. Emphasis was placed upon the distribution of species in reference to environmental conditions of soil, soil moisture, topography and slope exposure. Differences in the distribution of plants using percolating water of streamsides, capillary water of terraces and precipitation water of hillsides were emphasized.

After this part of the training, the men were divided into pairs and each pair was assigned to a separate area for training in making ocular estimates of the vegetation and then checking the results by means of measured transects. They practiced estimating the total density of vegetation on an area and the percentage composition of the dominant species representing as much as 5 or 10% of the cover. Other vegetation, representing less than 5% of the cover, was generally ignored in the ocular estimate of density.

THE FIELD SURVEY

This period of training was also used to initiate the field work. In practice, the men were usually sent out in two-man crews to areas preselected from the maps. Each crew cruised its area, estimated the total density of vegetation on it, the percentage composition of each major species of dominant vegetation, recorded the data on the tabulation sheet (Appendix A-1)

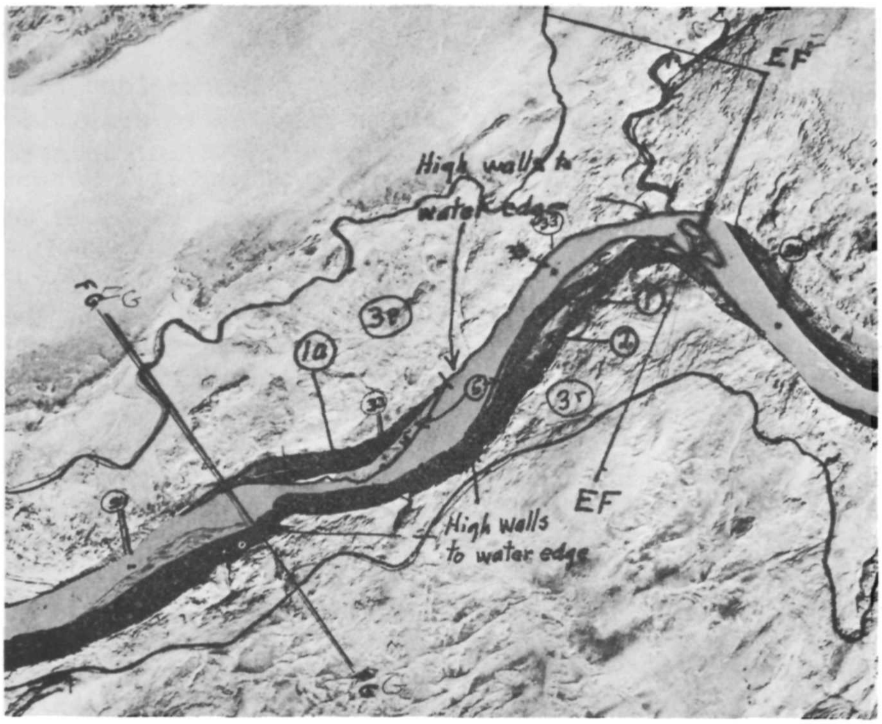

Fig. 5. Photo of an overlay map showing the method of mapping on the aerial photographs.

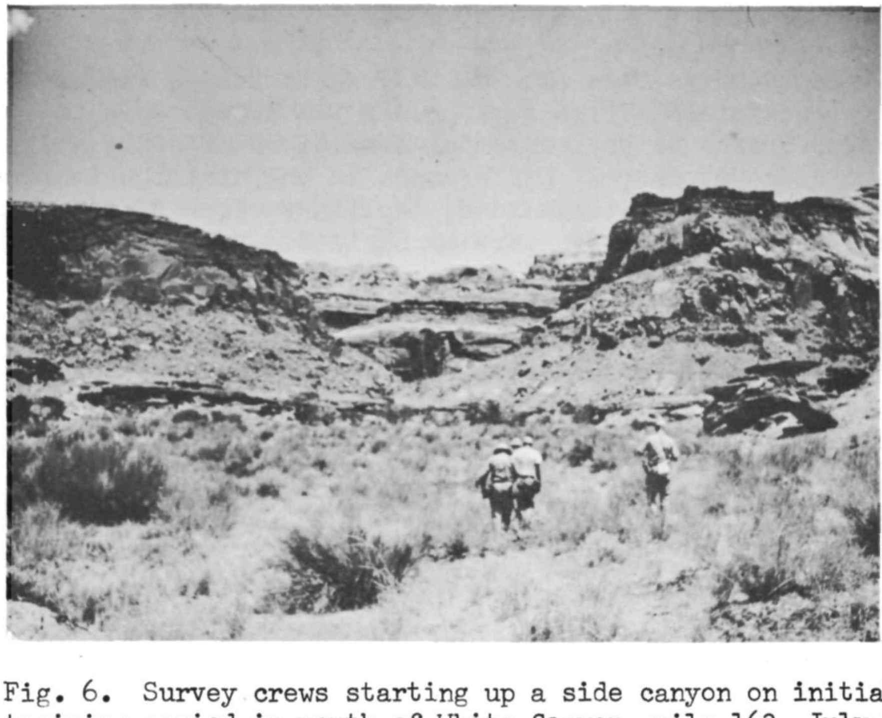

Fig. 6. Survey crews starting up a side canyon on initial training period in mouth of White Canyon, mile 163, July 1, 1958. Photo by Delbert W. Lindsay.

determined the boundaries of the unit areas for recording on the overlay maps, and numbered the unit areas. This information from each crew was brought to Dr. Flowers for incorporation on the composite control map that he personally handled.

On the first day of travel down the river, the expedition halted about two miles below Hite to cruise a big island. By the time this island was finished, it had become obvious that some alterations in the plans of recording data were in order. A careful re-evaluation in light of field experience was made and a modified plan was elaborated. Previous work was revised to fit the changes.

Under the changed procedure, unit areas were numbered consecutively on each map instead of the whole river. The areas were divided into five habitat types as follows:

1. Streamside vegetation presumably using percolating water from the river.
2. Terrace vegetation using capillary water.
3. Hillside vegetation using precipitation water.
4. Farm lands
5. Wet sand areas of the river bed.

Areas were always numbered on each map by using this type number. If more than one such area was found on a map, successive areas downstream were numbered by adding a letter to the type number, thus 1, 1a, 1b, 1c, ... or 2, 2a, 2b, 2c, ..., etc. This was necessary for field convenience to accomodate changes needed as the data from the various crews were incorporated on the maps and on the master tabulation sheets. In many, but not all cases, auxiliary maps were available to the survey crews for use in cruising the areas. These assisted in determining the units and drawing their boundaries on the overlay maps, Figure 5.

Since Glen Canyon is relatively narrow, it was found that a 2-man crew could easily cruise the area on one side of the river except in long side canyons. A policy was, therefore, adopted of sending a pontoon down each bank of the river to service the men on the respective sides of the stream. In practice, a pontoon would stop at the upper end of areas usually preselected from the map, land a crew at that point and then float on downstream to a point where a new crew was to be landed. At this point, the pontoon waited for the first crew to arrive and board the pontoon. It was then floated down to the next point where a similar exchange took place. When a side canyon was reached, either one or both of the pontoons were halted while crews were investigating the vegetation as far up the canyon as time and physical features permitted, Figure 6.

In many places, one or both sides of the canyon are very narrow and often the cliffs, the talus slopes or the hillsides extended down to the river bank. In such cases, the fringing vegetation was very narrow and all of the vegetation could be inspected and estimated by the parties as the pontoons floated by. In other cases, it was necessary to get behind the taller fringing vegetation to inspect the shorter terrace vegetation hidden behind it. Where

Fig. 7. A cliff and talus slope leading directly to river, mile 168, streamside vegetation narrow and interrupted; between Dirty Devil River and North Wash, June 10, 1958. Photo by H. R. McDonald, U. S. Bureau of Reclamation.

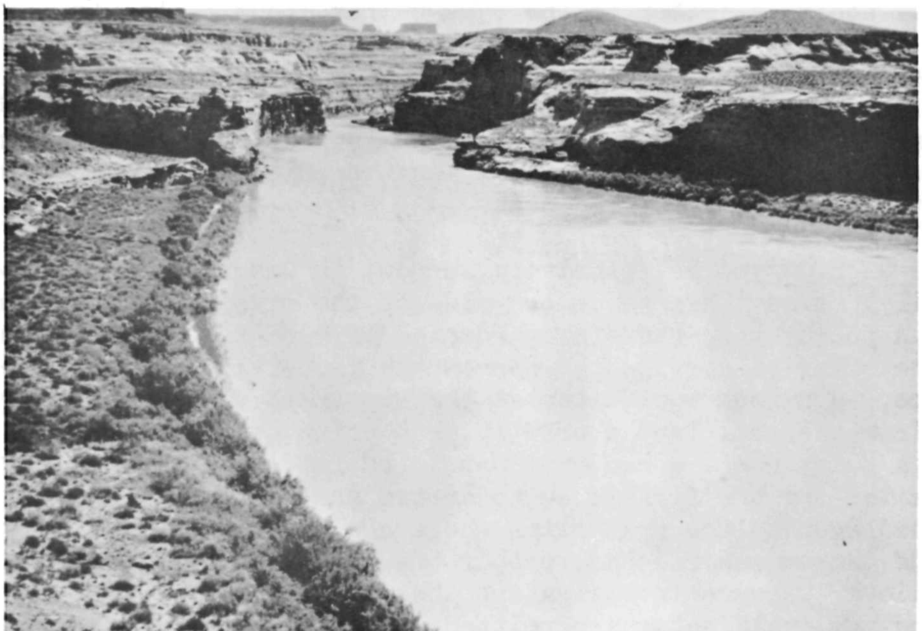

Fig. 8. View along Colorado River about mile 165, between Hite and North Wash, showing fringing streamside vegetation and terrace vegetation behind it, giving way to hillside vegetation. Photo by H. R. McDonald, U. S. Bureau of Reclamation.

vegetation was so dense it was difficult to cruise, the usual practice was to climb the hillside behind it and make the estimates while viewing it from a vantage point above, Figures 7 and 8.

Dr. Flowers occupied the pontoon that usually floated down the left bank of the river and superintended the cruising operations on that side. The pontoon on the other side of the river was managed under Dr. Flowers' direction. As soon as was convenient, usually at noon and at the end of the day's work, the parties on the two pontoons met and pooled the data that had been gathered. Dr. Flowers took personal charge of coordinating the information from the various parties, making the final outlines of the units of vegetation, numbering the areas and recording data on the overlay maps. Under his direction, Merrill K. Ridd compiled the data provided by the various crews on their field data sheets and made a master file of survey data compiled from the crew sheets. The original crew records, original compilation of the crew records, and typewritten copies of this file are transmitted with this report as Appendix B1, B2 and B3.

The overlay maps when taken into the field were firmly stapled to the underlying 18 x 18 inch aerial photographs which had a scale of approximately 2000 feet per map inch. Since the scale varied from this assumed standard, mainly in a radial direction outward from the center, the photographs had been so selected that a central portion of one map fit adjacent to the central portion of the next one. The Bureau of Reclamation had marked the specific portion of each map to be covered and had drawn lines across the river and the canyon at each end of the area to be so used.

Beginning at the upper end, these lines were designated A-A and B-B on the first map; B-B and C-C on the second map and so on through the 33 maps used to cover the area from the mouth of the Dirty Devil River, mile 170 to the dam site, river mile 15 above Lee's Ferry. In addition, the flowline of the expected reservoir was drawn on each map to indicate the extent of the reservoir basin. The mouth of the Dirty Devil River is shown in Figure 9.

In use, the crews estimating an area used the aerial photographs for determining the extent of their units and reported their determinations directly to Dr. Flowers who personally helped to determine divisions between units, drew the boundary lines on the overlays and gave them their consecutive numbers.

During the course of the expedition, the estimates of each crew were checked by weekly transects on the transect form, Appendix A-2. The usual practice was for each crew to select an area, make ocular estimates on it and then run 6 random line transects through it for comparison. There is, of course, little assurance that the transects were more representative of the overall area than the ocular estimates, but they were very helpful in sharpening the judgment of the crew members.

Fig. 9. View of the lower Fremont (Dirty Devil) River and its mouth where it enters the Colorado River, mile 169.5. American Exploration Society photo taken for Angus M. Woodbury.

Such transects were made as follows:

1. June 9, river mile 166, terrace, right bank, (2 men).
2. July 1, river mile 163, Farley Canyon, 3/4 mile from river.
3. July 7, river mile 148, Tickaboo, right bank.
4. July 15, river mile 113, Lake Canyon, left bank.
5. July 23, river mile 78, San Juan Junction, left and right banks of the San Juan River (8 men).

5a. July 25, river mile 67, Aztec Canyon, left bank (2 men).

6. July 29, river mile 48, Last Chance Creek, right and left banks.

The usual procedure in making such transects was to make ocular estimates of the vegetation on the area selected and record these estimates before making the transects. A tabulation of these estimates and transect results is given in Appendix C. In a few cases, the observer failed to record the ocular estimate so the overall comparison is not quite complete but is generally useful as background information. It is ordinarily expected that overestimation and underestimation will nearly balance one another. The totals in the chart indicate that there is a slight excess of underestimation from the transect figures.

RESULTS OF THE VEGETATION SURVEY

As the work on each map was finished, it was transferred to an aluminum waterproof case which was guarded personally by the field director of the expedition, Dr. Durrant. At the end of the expedition, the 33 maps were all finished and stored in the waterproof case. On these maps were the outlines of the 249 units of streamside vegetation, 158 units of terrace vegetation and 35 units of hillside vegetation that had been analyzed by the survey crews. These maps are transmitted as Appendix D.

In addition, the tabulated data for these units was carefully guarded in separate containers.

These data consisted of the following:

1. Field sheets with records of the tabulations made by each crew in making their ocular estimates of the units they investigated, Appendix B-1.
2. A master file of the data immediately compiled from the field sheets by Merrill K. Ridd under the personal direction of Dr. Flowers, Appendix B-2.
3. Field sheets of the line transects made by the crews on their weekly checks of the ocular estimates, Appendix C-1.

STATISTICAL ANALYSIS

After returning from the field, the overlay maps and the tabular data were scrutinized in the laboratory by Delbert W. Lindsay assisted in part by H. Wendell Hyde and Merrill K. Ridd under supervision of Seville Flowers and Angus M. Woodbury. During this scrutiny, minor inconsistencies between the maps and the tabulated data were brought into harmony. The maps were cleaned and boundaries of vegetation units carefully checked for accurate delineation.

When this checking was completed, the area of each unit was calculated in the laboratory from field data recorded on the overlay maps and data sheets. In most cases, areas were obtained by planimeter measurements translated into acres. By measuring the area of one square mile on a map with the planimeter, it was found by the average of three trials that it measured 670 planimeter units. A slide rule was set with 670 over 640 (acres per square mile) and the area of each unit in acres read directly under the planimeter readings for that area (average of three readings). This direct proportion result is equivalent to multiplying the planimeter reading by 0.955.

In other cases where the units were too narrow to be planimetered realistically on the map, estimates of the average width of the units were made in the field and tabulated on the data sheets. In the laboratory, the length of each such area was measured on the overlay map by a lineameter or map measuring device. This device measured 2.6 inches (lineameter units) per map mile. As with the planimeter, the average of three consistent measurements of the length of each unit was used in translation by slide rule to equivalent map distance in feet. This distance multiplied by the width gave an area which was translated into acres.

PREPARATION OF DATA FOR ANALYSIS

The data thus checked and computed were then prepared for statistical analysis. Those data pertaining to the vegetation were transferred to analysis sheets. These were used later as copy for punch cards, designed for analysis by the electronic computing machine, the University Datatron. This required the use of three form sheets in order to accomodate all of the data. Sheet No. I (Appendix A-3) contained data of the riverbank or streamside vegetation; No. II (Appendix A-4), the terrace vegetation; and No. III (Appendix A-5), the hillside vegetation.

The first 20 columns are identical on all three sheets but the balance up to 80 columns are different on each sheet to provide for analysis of the data pertaining to different species of plants in the different habitats. The first 20 columns are arranged as follows:

1 and 2. The overlay map numbers ranging from 01 to 33.
3, 4, and 5. The unit area numbers on each map beginning with figures 1, 2 or 3 in column 3, which may be followed by letters of the alphabet translated into figures as a-01, b-02, c-03, . . k-11 in columns 4 and 5.

PREPARATION OF DATA

6. Canyon type using 1 for the main Glen Canyon or San Juan Canyon and 2 for side canyons.

7 and 8. Crew members listed below:

Column 7	Column 8
1. Christensen, Dr. Earl C.	1. Flowers, Dr. Seville
2. Crook, James R.	2. Gaddis, Don
3. Hall, Heber H.	3. Herrmann, Gideon
4. Higgins, Harold G.	4. Higgins, Harold G.
5. King, Grant O.	5. Hyde, H. Wendell
6. Lindsay, Delbert W.	6. Lindsay, Delbert W.
7. Ridd, Merrill K.	7. Ridd, Merrill K.
	8. Smith, Bruce N.

9. Indicates altitude according to the code listed below:

1 - 3100 to 3199 feet	6 - 3600 to 3699 feet
2 - 3200 to 3299 feet	7 - 3700 to 3799 feet
3 - 3300 to 3399 feet	8 - 3800 to 3899 feet
4 - 3400 to 3499 feet	9 - 3900 to 3999 feet
5 - 3500 to 3599 feet	

10. Indicates the habitat type:

1. Streambanks where vegetation uses percolating water from the river.
2. Terraces where vegetation uses capillary water from the river.
3. Hillsides where vegetation uses precipitation water only.

11, 12 and 13. The average height of vegetation on the unit area, being used respectively for tens, digits and tenths of feet.

14, 15 and 16. The density of vegetation given as per cent of ground covered by projection of the crowns (delimited by the perimeters) downward, using the columns respectively for hundreds, tens and digits of percentage.

17, 18, 19 and 20. The area of each unit in acres, using the columns respectively for hundreds, tens, digits and tenths for sheets I and II, and for thousands, hundreds, tens and digits on sheet III.

All other columns from 21 to 80 represent given species of plants as listed in the following tabular keys:

SURVEY OF VEGETATION

KEY FOR SHEET NUMBER I

Columns	Scientific names	common names
21, 22, 23	*Salix exigua*	sandbar willow
24, 25, 26	*Tamarix pentandra*	tamarix or salt cedar
27, 28	*Baccharis emoryi*	baccharis
29, 30	*Salix goodingi*	Gooding tree willow
31, 32	*Rhus trilobata*	three-lobed squawbush
33, 34	*Quercus gambelii*	Gambel oak
35, 36	*Pluchea sericea*	arrowweed
37, 38	*Phragmites communis* . . .	reed cane
39, 40	*Rhus toxicodendron* . . .	poison sumach
41, 42	*Distichlis spicata* . . .	salt grass
43, 44	*Populus fremonti*	Fremont cottonwood
45, 46	*Carex* spp.	sedge
47, 48	*Juncus* spp.	rush
49, 50	*Equisetum* spp.	horsetail
51, 52	*Chrysothamnus nauseosus* .	rabbit brush
53, 54	*Atriplex confertifolia* .	shadscale
55, 56	*Atriplex canescens* . . .	4-winged saltbush
57, 58	*Suaeda intermedia* . . .	seepweed
59, 60	*Salsola kali*	Russian thistle
61, 62	*Datura meteloides* . . .	sacred datura
63, 64	*Celtis douglasii*	hackberry
65, 66	*Scirpus* spp.	bulrush
67, 68	*Typha latifolia*	cattail
69, 70	*Artemisia filifolia* . . .	sand sagebrush
71, 72	*Oryzopsis hymenoides* . .	Indian rice grass
73, 74	*Aster spinosus*	aster
75, 76	*Cercis occidentalis* . . .	redbud
77, 78	*Bromus tectorum*	cheat grass
79, 80	Miscellaneous	other species

KEY FOR SHEET NUMBER II

21, 22	*Atriplex canescens* . . .	4-winged saltbush
23, 24	*Chrysothamnus nauseosus* .	rabbit brush
25, 26	*Suaeda intermedia*	seepweed
27, 28	*Artemisia filifolia* . . .	sand sagebrush
29, 30	*Sarcobatus vermiculatus* .	greasewood
31, 32	*Celtis douglasii*	hackberry
33, 34	*Rhus utahensis*	Utah squawbush
35, 36	*Sporobolus airoides* . . .	drop-seed grass
37, 38	*Chrysothamnus viscidiflorus* .	rabbitbrush
39, 40	*Ephedra* spp.	ephedra
41, 42	*Oryzopsis hymenoides* . .	Indian rice grass
43, 44	*Gutierrezia microcephala* .	matchweed
45, 46	*Pluchea sericea*	arrowweed
47, 48	*Rhus trilobata*	three-lobed squawbush
49, 50	*Quercus gambelii*	Gambel oak

KEY FOR SHEET NO. II (continued)

Columns	Scientific names	common names
51, 52	Rhus toxicodendron	poison sumach
53, 54	Baccharis emoryi	baccharis
55, 56	Lepidium spp.	peppergrass
57, 58	Atriplex confertifolia . . .	shadscale
59, 60	Cercis occidentalis	redbud
61, 62	Opuntia spp.	cactus
63, 64	Atriplex garrettii.	saltbush
65, 66	Tamarix pentandra	tamarix or salt cedar
67, 68	Salix goodingi	Gooding tree willow
69, 70	Salix exigua	sandbar willow
71, 72	Phragmites communis	reed cane
73, 74	Distichlis spicata	salt grass
75, 76	Dalea fremonti	Fremont indigo bush
77, 78	Populus fremonti	Fremont cottonwood
79, 80	Miscellaneous	other species

KEY FOR SHEET NO. III

21, 22	Atriplex confertifolia . . .	shadscale
23, 24	Atriplex garrettii.	saltbush
25, 26	Shepherdia rotundifolia . . .	silver buffaloberry
27, 28	Rhamnus betulaefolia	buckthorn
29, 30	Dalea thompsoni	Thompson indigo bush
31, 32	Lycium andersoni	wolf-berry
33, 34	Ephedra spp.	ephedra
35, 36	Oryzopsis hymenoides	Indian rice grass
37, 38	Gutierrezia microcephala . .	matchweed
39, 40	Bromus tectorum	cheat grass
41, 42	Opuntia spp.	cactus
43, 44	Yucca angustissima	narrow-leaved yucca
45, 46	Chrysothamnus nauseosus . . .	rabbit brush
47, 48	Hilaria jamesii	galeta or curly-top grass
49, 50	Mixed grasses	mixed grasses
51, 52	Coleogyne ramosissima	black brush
53, 54	Celtis douglasii	hackberry
55, 56	Quercus gambelii	Gambel oak
57, 58	Artemisia filifolia	sand sagebrush
59, 60	Dalea fremonti	Fremont indigo bush
61, 62	Lepidium montanun	peppergrass
63, 64	Juniperus osteosperma	Utah juniper
65, 66	Grindelia fastigiata	gum weed
67, 68	Eriogonum inflatum	bottle-stopper
69, 70	Populus fremonti	Fremont cottonwood
71, 72	Atriplex cuneata	saltbush
73, 74	Miscellaneous	other species

SURVEY OF VEGETATION

TABULATION OF DATA

After these form sheets were prepared and checked, the data on each sheet was transferred to a punch card. The card records were then printed in tabular form and checked back to the field data for each of the vegetation units on the overlay maps. This tabulation is appended to this report as Appendix E-1. It is divided into 6 parts. Each of the three types of cards, streamside, terrace and hillside, were divided into two parts, one showing vegetation in the main canyon, the other in side canyons. The total acreage in each of these six parts is given in the following tabulation:

AREAS OF VEGETATION UNITS

Table 1. The total areas of vegetation surveyed and plotted on the overlay maps.

	Streamside	Terrace	Hillside
Main canyon	1918.6	3585.6	13802
Side canyons	643.6	3001.7	4620
Totals	2562.2	6587.3	18422.0

Grand total . . . . 27,571.5 acres

During the progress of the expedition survey, an area of farm land at Hite and numerous areas of wet sand were encountered. These were plotted on the overlay maps but were not included in the tabulation of vegetated areas. The area of the farm lands, now mostly abandoned was planimetered as 84 acres. The wet sand areas were planimetered and tabulated on sheets attached hereto as Appendix E-2. In addition to these wet sand areas plotted on the overlay maps, it was estimated that a strip averaging at least 6 feet wide on each side of the river at the time of year when the survey was made represented wet unvegetated banks between the river and the edge of the vegetation that was exposed to evaporation equivalent to that of wet sand. This is calculated as 0.73 acres per mile on each side of the river.

The total of all areas surveyed is shown in the following tabulation:

TOTAL OF ALL AREAS SURVEYED

Table 2. The total of all areas included in the survey and plotted on the overlay maps.

Vegetated areas	27,571.5 acres
Farm lands	84.0 acres
Wet sand	2,890.5 acres
Wet banks	248.0 acres
TOTAL	30,794.0 acres

ANALYSIS OF DATA

From the data included in the preceding tabulations, analyses of the data for each of the vegetation units were made on the Datatron to provide the following information:

1. The total acreage covered by vegetation on each vegetation unit (cover acreage) with totals for each of the 6 major subdivisions.

2. The total acreage of bare ground exposed in each unit (bare ground acreage) with similar totals.

3. The cover acreage of each species of plant listed in the tabulations (species cover) with similar totals.

The tabulation of these calculations made by the Datatron is transmitted herewith as Appendix F. A general summary of the tabulation is given in the following table:

TOTAL COVERAGE OF VEGETATION

Table 3. The percentage of vegetation cover in each of the three habitat types surveyed in main and in side canyons.

Vegetation	Canyon type	Total acreage	Cover acreage	Bare ground	% coverage
Streamside	Main	1918.6	1706.5	212.1	89
	Side	643.6	409.7	233.9	63
Terrace	Main	3585.6	1690.5	1895.1	47
	Side	3001.7	1646.0	1355.7	55
Hillside	Main	13802.0	2519.0	11283.0	20
	Side	4620.0	788.0	3832.0	15
TOTALS		27,571.5	8,759.7	18,811.8	36

For more convenience in analyzing the vegetation, the cover for each species is given in Table 4, Species Cover Acreage. In order to compute an estimated volume of foliage, the totals from the chart, Table 4, have been used to compile the data given in the chart, Table 5, Species Volume of Foliage. In this case, the cover acreage is multiplied by the estimated average height in feet of the foliage of each species to provide a volumetric estimate of the total foliage in the surveyed portion of the reservoir. The result is given in units of acre-feet (an acre covered one foot deep with foliage). There is a small difference between the total of cover acreage given in tables 3 and 4, probably due to rounding off fractions in tabulating the species cover.

SPECIES COVER ACREAGE

Table 4. The cover acreage (100% cover) of dominant species in each of the three habitat types and in the main and side canyons.

Name	Streamside main	Streamside side	Terrace main	Terrace side	Hillside main	Hillside side	Totals
Equisetum spp.	1.2	.2	- -	- -	- -	- -	1.4
Ephedra spp.	- -	- -	94.3	.9	321	7	423.2
Typha latifolia	- -	18.4	- -	- -	- -	- -	18.4
Bromus tectorum	3.3	- -	- -	- -	16	- -	19.3
Distichlis spicata	.9	- -	36.7	- -	- -	- -	37.6
Phragmites communis	14.6	7.0	.2	- -	- -	- -	21.8
Sporobolus airoides	- -	- -	26.3	- -	- -	- -	26.3
Oryzopsis hymenoides	.7	- -	36.3	- -	90	131	258.0
Hilaria jamesii	- -	- -	- -	- -	13	- -	13.0
Mixed grasses	- -	- -	- -	- -	635	14	649.0
Carex spp.	- -	42.3	- -	- -	- -	- -	42.3
Scirpus spp.	10.8	.2	- -	- -	- -	- -	11.0
Juncus spp.	- -	44.4	- -	- -	- -	- -	44.4
Populus fremonti	3.7	20.1	3.7	15.1	- -	18	60.6
Salix exigua	845.9	152.2	20.5	12.3	- -	- -	1030.9
Salix goodingi	79.1	1.1	6.3	3.1	- -	- -	89.6
Quercus gambelii	44.9	4.0	84.1	439.3	2	25	599.3
Celtis douglasii	17.8	3.1	13.1	145.7	- -	20	199.7
Eriogonum inflatum	- -	- -	- -	- -	- -	66	66.0
Atriplex canescens	3.8	1.3	262.1	296.3	- -	- -	563.5
Atriplex confertifolia	1.3	- -	96.0	3.5	845	131	1076.8
Atriplex cuneata	- -	- -	- -	- -	47	- -	47.0
Atriplex garrettii	- -	- -	.5	- -	81	- -	81.5
Sarcobatus vermiculatus	- -	- -	64.1	- -	- -	- -	64.1
Suaeda intermedia	.4	.4	212.9	3.7	- -	- -	217.4
Salsola kali	.4	- -	- -	- -	- -	- -	.4
Lepidium montanum	- -	- -	- -	- -	23	- -	23.0
Lepidium spp.	- -	- -	5.0	- -	- -	- -	5.0
Coleogyne ramosissima	- -	- -	- -	- -	207	- -	207.0
Cercis occidentalis	.2	- -	- -	.7	- -	- -	.9
Dalea fremonti	- -	- -	.3	5.5	21	- -	26.8
Dalea thompsoni	- -	- -	- -	- -	135	66	201.0
Rhus toxicodendron	6.1	1.1	- -	- -	- -	- -	7.2
Rhus trilobata	42.1	2.3	29.3	3.5	- -	- -	77.2
Rhus utahensis	- -	- -	2.4	- -	- -	- -	2.4
Rhamnus betulaefolia	- -	- -	- -	- -	- -	18	18.0
Tamarix pentandra	329.7	74.5	10.2	7.7	- -	- -	422.1
Opuntia spp.	- -	- -	22.5	- -	3	- -	25.5
Lycium andersoni	- -	- -	- -	- -	25	131	156.0
Datura meteloides	2.0	- -	- -	- -	- -	- -	2.0
Gutierrezia microcephala	- -	- -	10.7	3.5	3	- -	17.2
Chrysothamnus nauseosus	10.9	1.0	295.8	23.1	24	79	433.8
Aster spinosus	.3	- -	- -	- -	- -	- -	.3
Baccharis emoryi	155.5	32.2	22.6	.2	- -	- -	210.5
Pluchea sericea	121.4	1.2	136.5	3.4	- -	- -	262.5
Artemisia filifolia	4.6	.4	57.8	7.4	- -	70	140.2
Others	7.7	.5	143.7	671.6	42	15	880.5
TOTALS	1709.3	407.9	1693.9	1646.5	2533	791	8,781.6

SPECIES VOLUME OF FOLIAGE

Table 5, showing the estimated volume of foliage obtained by multiplying the cover acreage by the estimated foliage height (feet) for each species.

Scientific name	Common name	Cover acreage	Height ave.	Height climax	Foliage acre-feet
Equisetum spp.	horsetail	1.4	1.4	2.3	2.0
Ephedra spp.	ephedra	423.2	1.4	2.5	592.5
Typha latifolia	cattail	18.4	5.0	7.0	92.0
Bromus tectorum	cheat grass	19.3	0.6	0.9	11.6
Distichlis spicata	salt grass	37.6	0.5	1.0	18.8
Phragmites communis	reed cane	21.8	5.0	8.0	109.0
Sporobolus airoides	drop-seed grass	26.3	0.5	0.6	13.2
Oryzopsis hymenoides	Indian rice grass	258.0	1.2	1.7	309.6
Hilaria jamesii	galeta grass	13.0	0.4	0.5	5.2
Mixed grasses	mixed grass	649.0	0.8	1.0	519.2
Carex spp.	sedge	42.3	1.2	1.5	50.8
Scirpus spp.	bulrush	11.0	1.2	5.0	13.2
Juncus spp.	rush	44.4	1.0	1.5	44.4
Populus fremonti	Fremont cottonwood	60.6	20.0	30.0	1,212.0
Salix exigua	sandbar willow	1,030.9	7.0	15.0	7,216.3
Salix goodingi	Gooding tree willow	89.6	15.0	20.0	1,344.0
Quercus gambelii	Gambel oak	599.3	8.0	18.0	4,794.4
Celtis douglasii	hackberry	199.7	8.0	20.0	1,597.6
Eriogonum inflatum	bottle-stopper	66.0	0.1	0.1	6.6
Atriplex canescens	4-winged saltbush	563.5	2.7	4.5	1,521.5
Atriplex confertifolia	shadscale	1,076.8	0.8	1.4	861.4
Atriplex cuneata	saltbush	47.0	0.5	0.8	23.5
Atriplex garrettii	saltbush	81.5	0.7	1.0	57.1
Sarcobatus vermiculatus	greasewood	64.1	2.0	3.5	128.2
Suaeda intermedia	seepweed	217.4	1.5	2.4	326.1
Salsola kali	Russian thistle	.4	0.6	1.0	.2
Lepidium montanum	peppergrass	23.0	1.0	1.3	23.0
Lepidium spp.	peppergrass	5.0	3.0	3.0	15.0
Coleogyne ramosissima	black brush	207.0	1.0	1.5	207.0
Cercis occidentalis	redbud	.9	8.0	12.0	7.2
Dalea fremonti	Fremont indigo bush	26.8	1.2	1.7	32.2
Dalea thompsoni	Thompson indigo bush	201.0	1.2	1.7	241.2
Rhus toxicodendron	poison sumach	7.2	2.5	5.0	18.0
Rhus trilobata	three-lobed squawbush	77.2	5.0	7.0	386.0
Rhus utahensis	Utah squawbush	2.4	4.5	7.0	10.8
Rhamnus betulaefolia	buckthorn	18.0	5.8	8.0	104.4
Tamarix pentandra	tamarix or salt cedar	422.1	8.0	15.0	3,376.8
Opuntia spp.	cactus	25.5	0.4	0.5	10.2
Lycium andersoni	wolf-berry	156.0	1.5	2.3	234.0
Datura meteloides	sacred datura	2.0	2.0	2.3	4.0
Gutierrezia microcephala	matchweed	17.2	0.8	1.4	13.8
Chrysothamnus nauseosus	rabbit brush	433.8	3.0	3.3	1,301.4
Aster spinosus	aster	.3	0.6	1.0	.2
Baccharis emoryi	baccharis	210.5	5.5	8.0	1,157.8
Artemisia filifolia	sand sagebrush	140.2	2.0	2.5	280.4
Pluchea sericea	arrowweed	262.5	2.5	4.0	656.3
Others	others	880.5	1.0	1.0	880.5
	TOTAL	8,781.6			29,830.6

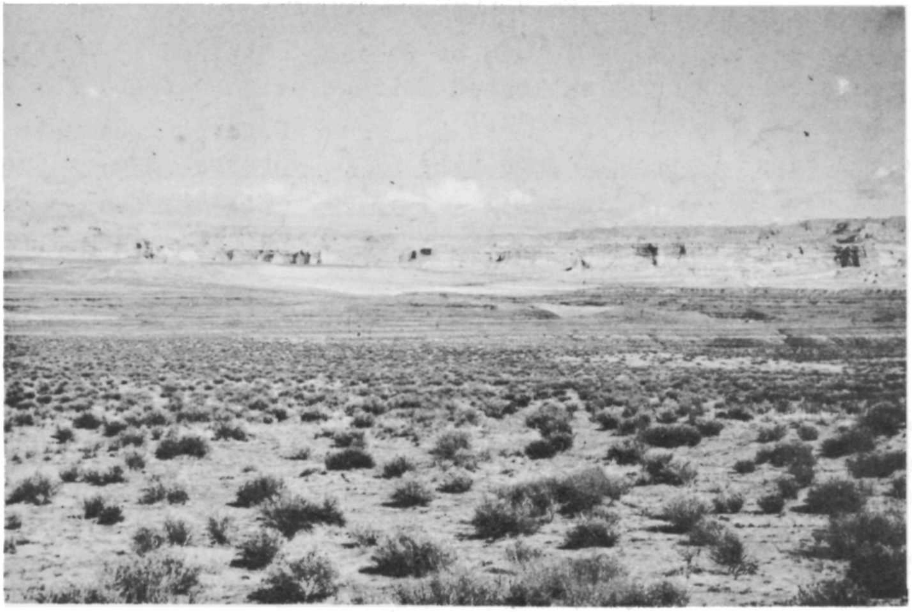

Fig. 10. Looking NW down slope from sandy highland that will be an island in Glen Canyon Reservoir; (one mile W from mouth of Warm Creek) March 25, 1958, showing typical black brush vegetation, Coleogyne ramosissimum. Photo by Lewis T. Nielson, University of Utah.

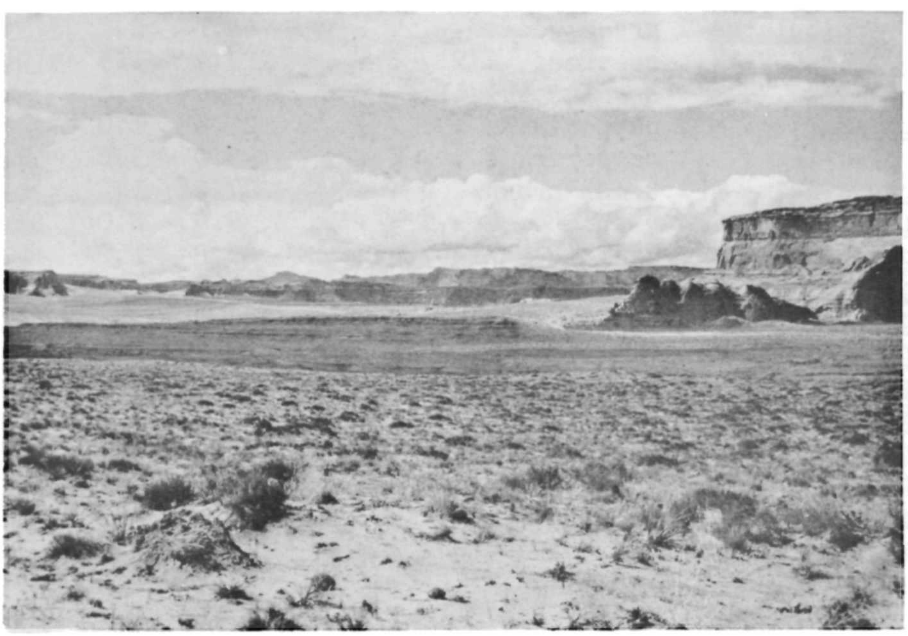

Fig. 11. Looking south over plateau toward Glen Canyon (in distance) from road between Wahweap and Kane Creek, March 24, 1958. Photo by Lewis T. Nielson, University of Utah.

VEGETATION BY EXTRAPOLATION

The detailed survey by the expedition during the summer of 1958 provided background data from which estimates of the balance of the vegetation in the reservoir basin can be made with a reasonable degree of confidence. The expedition covered the main canyon from the mouth of the Dirty Devil River, Figure 9, to Lee's Ferry and extended its investigations up the side canyons as far as physical conditions and time permitted. In doing so, members of the personnel penetrated Escalante River upward to the mouth of Fifty-Mile Creek, about two thirds of the distance to the flow line of the reservoir and about four miles up the San Juan River.

Additional background for interpretation of the vegetation upon the aerial photographs is provided by the personal acquaintance of other parts of the basin by the writers or the personnel of the expedition. Dr. Woodbury has made two boat trips down the San Juan River to the Colorado, has twice examined it by aerial flight, and has covered on the ground much of the area from Rock Creek to Wahweap, Figures 10 and 11. Drs. Woodbury and Durrant have examined practically all of the reservoir basin from the air and all three writers are well acquainted with surrounding areas. Heber Hall, a member of the expedition who was personally acquainted with the Escalante River basin, stated that in general there is little difference between the portions examined and those that were unexamined by crew members.

The area of the basin not covered by members of the expedition includes, in addition to portions of the canyons of the Escalante and San Juan rivers, Cataract, Navajo and Narrow canyons, the canyon of the Dirty Devil River, the heads of a few side canyons, and the embayments on Bullfrog, Hall, Last Chance and Wahweap creeks. Of these, Cataract, Narrow, Dirty Devil and Navajo are exceedingly narrow canyons with high cliffs and talus slopes that leave little room for any vegetation. The embayments, however, not only cover large areas of rough ground consisting of sheer cliffs and rocks, but also include some plateaus which possess a normal cover of desert vegetation, mainly black brush and its associates.

Along the edges of the main canyon, especially where the Navajo Sandstone is exposed, vast areas of the so-called "slick rock" exist, which appear to have little vegetation, Figure 12. Upon close examination, however, it is found that there are small islands of lichens and mosses interspersed over the otherwise bare rock and on some north exposures, this cover becomes so extensive that it helps to give a dark appearance to the otherwise lighter colored sandstone, Figure 13. In many places this dark appearance is enhanced by the coating of "desert varnish" which accumulates on the surface where water absorbed in the rock evaporates and leaves a dark chemical deposit that usually contains manganese.

In planning these extrapolation studies, it was deemed advisable to make estimates from planimeter measurements of all areas within the flowline of the reservoir not covered by the vegetation survey. A tabulation of the measurements of the high-water areas of the Colorado and San Juan rivers is attached as Appendix E-3. The tabulation of the balance of the areas is given in Appendix E-4.

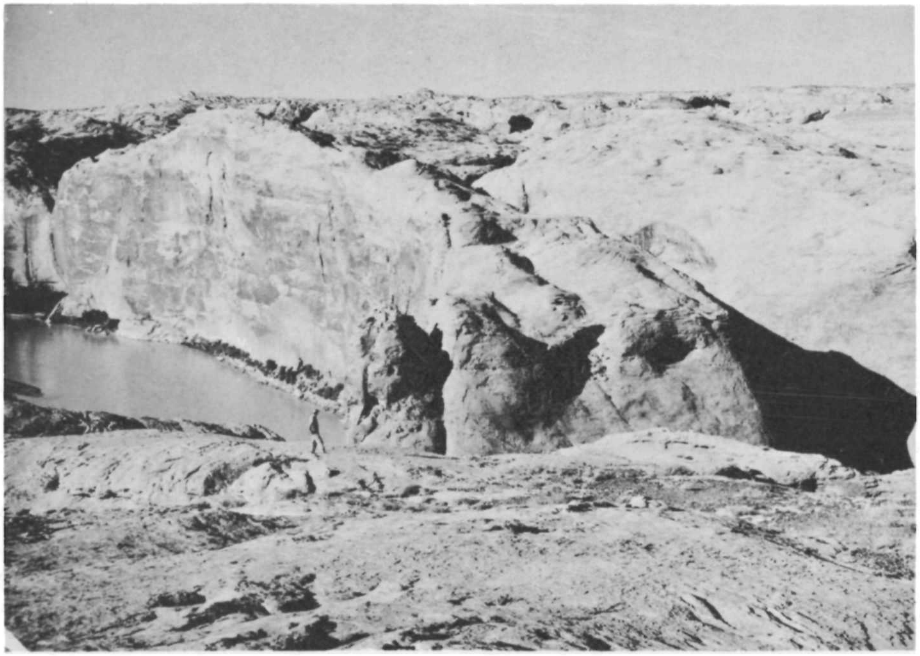

Fig. 12. View of great masses of "slick rock" along the river below the mouth of Hall Creek, mile 118. U. S. Bureau of Reclamation photo by Stanley Rasmussen.

Fig. 13. North facing cliffs above mouth of Wahweap Creek with dark coating of desert varnish, mosses and lichens covering much of the lighter colored sandstone, mile 18. Photo by Delbert W. Lindsay.

VEGETATION BY EXTRAPOLATION

Examination of available maps and aerial photographs has enabled us to classify the habitats on each of the extrapolated areas except in those areas where aerial photo-maps were not available. The latter which included areas along the Fremont and Escalante rivers and the Bullfrog-Hall Creek embayment, were calculated from the older U.S.G.S. Plan and Profile sheets of the Colorado River. For these, no overlay maps were made. The balance of the extrapolated areas were plotted on the overlay maps of the survey numbered in Arabic or upon new overlays prepared for that purpose which were given Roman numerals for contrast. For convenience in orientation, the numbers in Roman numerals given to these new overlays were the same as the Arabic numerals on adjacent survey overlays. For further convenience, the maps of San Juan River, beginning at the upper end of the reservoir, were indicated by capital letters, A to P, except for the letters I and O which might be mistaken for Arabic figures.

A summary of the extrapolated calculations is given in Table 6. An item of miscellaneous areas is introduced to indicate the difference between our totals from calculations and the official estimated coverage of the reservoir at the 3700 foot level. This difference has probably arisen largely from three difficulties, namely: (1) distortion in fringe areas of the aerial photographs, (2) inaccuracies in plotting the flowline on them, and (3) conservative measurements in planimetering photo-map areas. The total area of extrapolations amounts to more than 116,000 acres. A tabular summary of all the investigations in the basin is given in Table 7.

SUMMARY OF EXTRAPOLATED AREAS

Table 6. A summary showing the estimated areas and cover of the extrapolations in different portions of the reservoir.

Drainage System	Streamside Area acres	Streamside Cover acres	Terrace Area acres	Terrace Cover acres	Hillside Area acres	Hillside Cover acres	Total Area acres	Total Cover acres
Fremont River	200	40			827	124	1,027	164
Bullfrog-Hall Creek embayment					12,764	1,915	12,764	1,915
Escalante River	75	45			3,189	478	3,264	523
San Juan River	468	279	102	29	13,726	2,015	14,296	2,323
Colorado River	116	29			69,653	9,387	69,769	9,416
Miscellaneous areas					15,000	2,000	15,000	2,000
TOTALS	859	393	102	29	115,159	15,919	116,120	16,341

SURVEY OF VEGETATION

TOTALS FOR THE RESERVOIR BASIN

Table 7. A summary showing the totals derived from the vegetation survey, the extrapolations and planimetered areas of water surface.

	Streamside		Terrace		Hillside		Total	
	Area acres	Cover acres	Area acres	Cover acres	Area acres	Cover acres	Area Acres	Cover acres
Surveyed	2,562	2,116	6,587	3,337	18,422	3,307	27,571	8,760
Farm land			84				84	
Extrapolated	859	393	102	29	115,159	15,919	116,120	16,341
TOTALS	3,421	2,509	6,773	3,366	133,581	19,226	143,775	25,101

Water surface* of rivers 18,971

Total area of reservoir included in computations . . 162,746

*The water surface of the Colorado and San Juan rivers was calculated from planimeter measurements on each map. The measurements included the total areas within the high water lines of the rivers and thus include all of the wet sand areas as part of the totals.

DISCUSSION

The principal objective of this study has been to assess the vegetation that will be lost when inundated by the water of the Glen Canyon reservoir. Specifically, it has been designed to estimate the kinds and quantities of plants that will be covered and roughly calculate the estimated quantity of foliage. It is well known that the kinds and distribution of plants depends largely upon the availability of water. In this desert basin, the principal sources of water are, in addition to precipitation, the springs and streams that enter it from elsewhere, mainly from the mountains around the headwaters. It is also well known that the water from streams is stored in stream banks during high water and drained out during low water.

Primary phreatophytes growing along the banks of streams, Figure 8, generally have their roots immersed in the water stored in the banks and use the water freely in metabolism and in evaporation. These plants maintain low temperatures during hot weather by re-radiation and by the cooling effect of evaporation from the leaves. In sharp contrast to this are the desert plants that depend solely upon precipitation for their water supply. They are more parsimonius in their use of water. For example, the cactuses of this region, Figure 14, do not use the principle of cooling by evaporation hence when the sun shines upon them, they become heated to the degree provided by the sunshine. Temperatures reported by Woodbury (p. 14, Comfort for Survival, 1956, Vantage Press, N.Y.) ranged as high as 130° to 135° F. in the cactus body.

Between these two extremes, are many intermediate plants that show various stages of adaptation to prevent water loss without entirely losing the principle of cooling by evaporation. Some of these adaptations that reduce water loss include:

1. A coat of waterproof wax on the surface of the leaves.
2. A coat of hairs that cover the leaves and especially the stomatal openings.
3. Reduction in the size of the leaves.
4. Transforming leaves into thorns.
5. Transferring photosynthetic functions ordinarily performed by the leaves to the plant stems, as in the cactuses.

Plants that have these intermediate adaptations doubtless use intermediate quantities of water. All plants use water in growth. It is incorporated in the chemical compounds that help to form the substance of the plant body. The quantity used in this process varies largely in proportion to the amount of growth and is usually much greater in the vicinity of streams where plenty of water is available. In some of the cactuses that do not use water for cooling, there are ridges and grooves along the plant body which stretch like an accordion when the body is full of water and collapse when water is used, Figure 15. At least part of this consumptive use is lost by leaf-fall in deciduous plants.

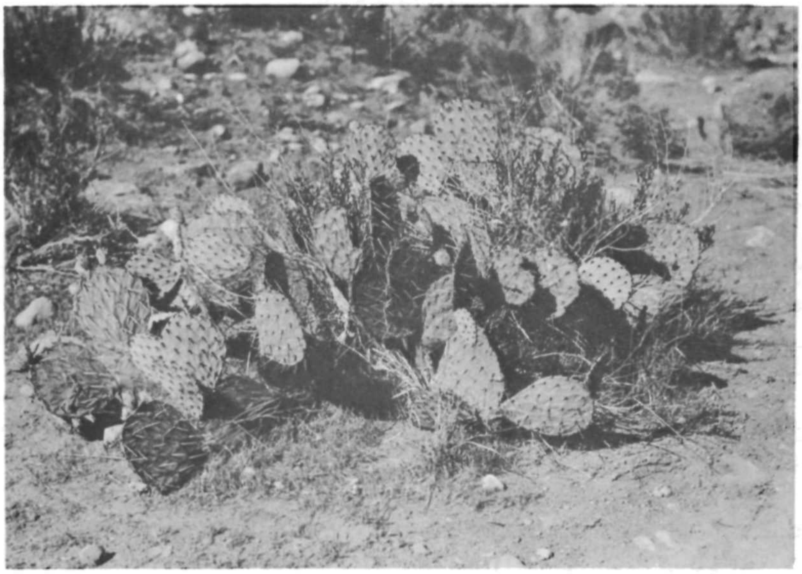

Fig. 14. A cactus plant that does not use the principle of cooling by water evaporation and takes high temperatures imparted by the sunshine. U. S. National Park Service photo.

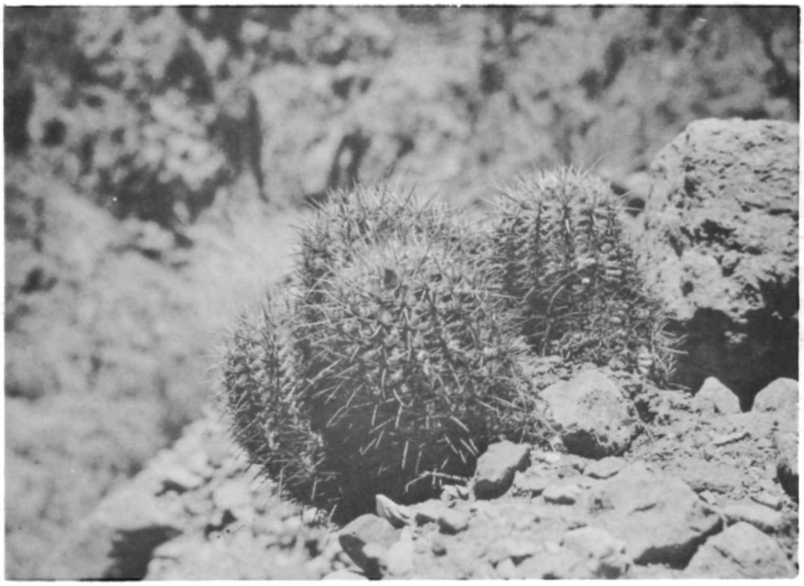

Fig. 15. A cactus plant with ridges and grooves that expands and contracts as it gains and uses water. U. S. National Park Service photo.

DISCUSSION

In general, a typical cross-section of the canyon presents a distribution of the vegetation such that the greatest users of water, the phreatophytes, are nearest the water edge and those adapted to using less and less water are spread over the terraces and up the hillsides. Our concept of this spread is given in the sketch shown in Figure 16.

This arrangement helps to interpret the distribution of the vegetation in the canyon. In making the maps, it was necessary to draw boundary lines of the units where differences in composition of the vegetation warranted. It is well known that in general one type of vegetation gradually intergrades into another type. The studies in Glen Canyon confirm the fact that the vegetation there is not an exception to the general rule although in many places the divisions appear to be relatively sharp, Figures 17 and 18.

From the tabulation of areas, Appendix E-1, it is obvious that the willows, tamarix and baccharis are the most important of the primary phreatophytes but that several other plants including the arrowweed, reed cane and salt grass usually occupy intermediate positions between the water-edge phreatophytes and the terrace vegetation. In the tabulation, these intermediates are shown to occur in both the streamside and terrace areas. These relations are summarized on the transfer sheets shown in Appendix A-3.

Similarly, the secondary phreatophytes of the terraces that depend mainly upon capillary water have intergradation with both the streamside and hillside vegetation. These relations are shown on the transfer sheets in Appendices A-4 and A-5. Even some of the primary phreatophytes, as well as many of the hillside plants, are shown to occur on the terraces.

No matter where a line is drawn between the streamside and terrace vegetation, or between the terrace and hillside, Figure 19, there is almost certain to be overlapping between any two types of vegetation and the line will leave some of each kind on the other side. This leaves room for differences in judgment between different crew members but it is expected that these differences will normally tend to counterbalance one another as was indicated in the summary analysis of the line transects.

Despite these invasions of plants from one community into another, the general character of each community is quite distinct from that of the others. The reasons for these invasions can generally be found in the nature of the physical environment or in competition with other plants. For example, where a point of terrace extends down toward the river bank, its vegetation may enter an area otherwise classified as streamside, or similarly hillside vegetation may extend down a talus slope and form a local indentation in an area otherwise occupied by terrace or even streamside vegetation, Figure 20. In such cases, the invaders may be included in the area they enter but would be placed in their proper category if it were feasible to draw lines accurately enough to exclude them.

In side canyons, terraces are usually small or absent but secondary phreatophytes often occur along the edge of the canyon bottom mixed with either the streamside or hillside vegetation or both. This telescoping

TYPICAL TRANSECT OF VEGETATION IN GLEN CANYON

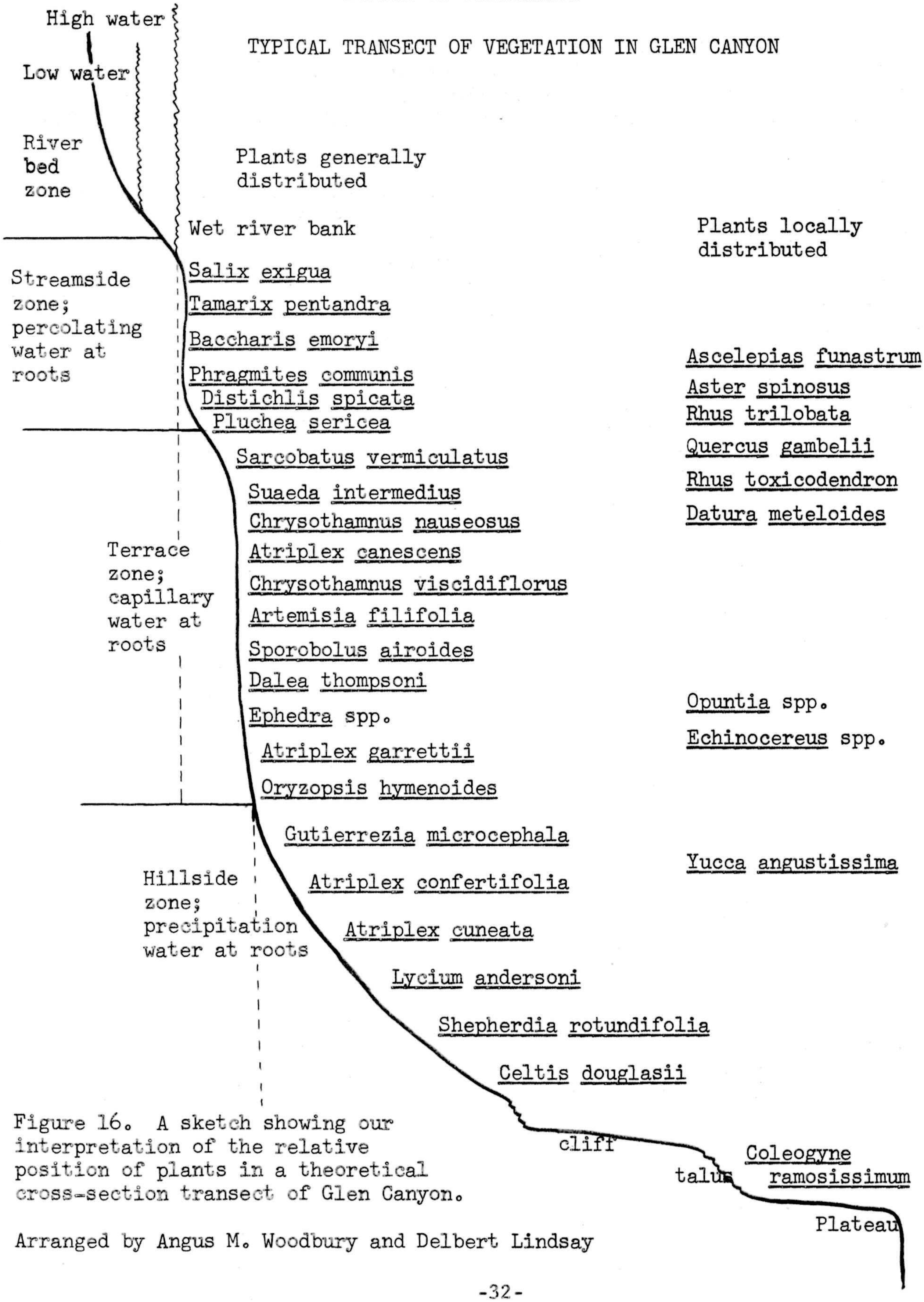

Figure 16. A sketch showing our interpretation of the relative position of plants in a theoretical cross-section transect of Glen Canyon.

Arranged by Angus M. Woodbury and Delbert Lindsay or intermingling of the types of vegetation, normally found segregated in the main canyon, makes the types still more difficult to segregate accurately.

Competition among species doubtless plays an important role in determining the composition of the vegetation of a unit and competition between groups of species intergrading between two units doubtless affects the position of the line between them. For example, the native sandbar willow has been invaded by the old world Tamarix probably within the last two or three centuries. Within that time, it has occupied an estimated 422 cover acres in Glen Canyon compared with 1030 cover acres still occupied by the willow. There are many areas with heavy cover of willow in which the tamarix has not so far established a foothold but there are many other areas in which the willow cover has been broken and the tamarix has occupied sites that are normal habitat of the willow.

Where the two grow together, the willows usually occupy the muddier parts and the tamarix the sandy areas, Figure 21. Tamarix seedlings are sometimes abundant on wet sand but willow seedlings are not mixed with them. There is no evidence to indicate that willows will displace tamarix in sandy soils. It is probable that competition between the two will tend to restrict the willows more and more to the muddy banks and yield sandy areas to the tamarix although without competition either one alone might spread more widely into both types of soil.

Willows are a favorite food of beavers along the river banks and there was considerable cutting, especially in the vicinity of the beaver slides which averaged about ten per mile. Only one case of tamarix being cut by beavers was observed and there was no evidence that feeding on the willows favored the entrace of tamarix among them.

In areas beyond the reach of subterranean water supplied by the river, tributary streams, springs or aquifers, the vegetation must depend upon precipitation water for its existence. Within the reservoir basin, the quantity of water available from this source is small, probably ranging annually between five and nine inches with an average around seven. This is not enough water to support a dense cover of foliage and in many places, a vast amount of bare ground or bare rock is exposed.

Where vegetation occurs, the leaf litter under the plants usually forms a spongy mat that absorbs precipitation water faster than does bare ground or bare rock. With light storms, the water may all be absorbed readily in rock, soil and litter but with an increasing rate of precipitation, some of the water may be lost by run-off. If water falls so fast that one drop is not absorbed before the next drop arrives, it will pile up and begin to run off. This will usually occur first on bare rock, next on compact soils and last on sand or soils with a leaf litter sponge.

Even light rains may bring run-off from rocks but this may soak into the talus slopes or soil and thus concentrate water in certain places that will give plants more water than precipitation would normally provide. If

Fig. 17. A wide strip of streamside phreatophytes of bar at mile 51, opposite the mouth of West Canyon, showing sharp boundaries at foot of hillside (left foreground). Photo by Delbert W. Lindsay.

Fig. 18. Streamside willows in bottom of narrow Kane Creek box canyon. Photo by Delbert W. Lindsay.

precipitation is heavy enough to bring run-off from soil as well as rocks, floods may occur and much of the precipitation will be lost and plants may not get the expected quota. Sand usually absorbs all the water that falls on it and in addition, it yields a larger proportion of the precipitation for plant use than do finer soils.

Steep slopes usually lose more water by run-off than do more level areas of the plateaus. Here, plants dominated by the black brush and associates are generally widely spaced in a more or less regular pattern that exposes much bare ground to rain and sunshine. The wide spacing is regulated largely by root competition since the roots occupy all of the soil space available and more or less determine how much foliage can be maintained by the water they get. Except for unusually heavy storms, these plants usually hold all of the precipitation. Some is lost by evaporation from the exposed soil but the deeper moisture is usually used by the plant for consumptive needs or for water-cooling purposes. This precipitation water, except for the small amount lost by run-off will practically all be evaporated from the soil or rocks, or else used by the plants.

Upon close inspection, what appears from a distance to be bare rock, may be found to have irregular patches, islands or even coats of lichens or mosses which affect the permeability and absorption of water in the rock. These lichens possess relatively small water-holding capacity as compared with that of the tufts of mosses that often get a foothold where the lichens pave the way. On south exposures, the extra water absorbed by these plants may soon be lost by evaporation but on the north exposures, sufficient moisture may be retained to maintain extensive areas of moss intermixed with the lichens.

On north-facing cliffs such as those in the canyon between the mouths of Aztec and Wahweap creeks, the moss covering becomes so dense and extensive on well protected faces that it practically covers the rock. During dry weather, the moss has a blackish or reddish brown color but when it rains, it immediately turns bright green. The moss usually holds all the water that falls on it and continues green while it is available. Such areas usually consume or transpire nearly all of the precipitation water and little, if any, is lost to run-off, except in heavy downpours. Wherever desert moss occurs elsewhere in the basin, it usually functions in a similar manner, but is usually much less dense.

The deep canyons that are so common in the basin cut the sedimentary rock layers so that aquifers find outlets on canyon walls, talus slopes or canyon bottoms and provide extra water in the form of seeps or springs. Some of these seeps occur high up on the faces of cliffs but most of them are near the bases. Many of the seeps harbor maidenhair ferns, columbines, monkey flowers, lobelias, grasses, mosses and other semi-aquatic plants that use water profusely, Figure 22. The extent of these seepage areas has not been estimated.

Fig. 19. A view in Glen Canyon showing terrace vegetation Gambel oak, creeping up the hillside above the willows. U. S. Bureau of Reclamation photo by Stanley Rasmussen.

Fig. 20. Looking downstream at Colorado River from about mile 165.6 showing hillside vegetation extending down to riverbank, June 9, 1958. Photo by H. R. McDonald.

DISCUSSION

There are many factors that affect the use of water by plants which must be considered in explaining their distribution. Among these, some of the more important ones include the following:

1. The amount of solar energy reaching the plants. In Glen Canyon, this quantity must be very high because of the relatively high intensity of sunshine reaching the ground in the basin.
2. The amount of water available at plant roots; percolating water, capillary water, precipitation water.
3. The adaptations that plants possess for suppression of water loss.
4. The amount of air movement (wind) around the plants. This factor is exceedingly variable in the rough topography of the basin.
5. The time of exposure to the sunshine. Plants on ridge tops have much longer exposure than those in canyon bottoms.
6. The share of solar energy that plants get. Plants on south-facing slopes may get at noon 100% of the energy available; those on north-facing slopes get a much smaller percentage because a similar quantity of sunshine is spread over a much larger area of ground surface.
7. The altitude at which the plants occur. At higher altitudes, there is less air for the sunshine to penetrate and hence a larger proportion reaches the plants, but this is probably offset by the thinner air failing to trap and hold as much of the solar energy as the denser air at lower altitudes.
8. The density of the foliage. In general, more open foliage allows greater penetration of sunshine and easier escape of evaporated moisture; denser vegetation absorbs more of the sunshine but tends to prevent escape of moisture by holding humidity at a higher level among the foliage. A density factor applied to the foliage of different species would help to make them more nearly comparable.

It is quite obvious from these considerations that the distribution of the vegetation in this desert region, although affected by many factors is ultimately more or less regulated by the availability of water and the adaptations of plants that fit them to make use of the quantity available at any particular site. Those adapted to profuse use of water will be found along the streamsides, at ponds, at seeps or at springs. Those adapted to parsimonius use of water will be found in the desert and will ordinarily use all of the water that precipitation provides. Those that require intermediate quantities of water will usually be found on terraces where extra water beyond that provided directly by precipitation is available, usually capillary water from some subterranean water source.

Fig. 21. Sparse tamarix vegetation in sand behind tamarix of streamside, above Hite, June 9, 1958. Photo by H. R. McDonald, U. S. Bureau of Reclamation.

Fig. 22. A hillside glen of semi-aquatic vegetation below Lake Canyon, about mile 111. Photo by Delbert W. Lindsay.

SUMMARY

During the summer of 1958, the University of Utah Ecological Research Colorado Project, made a survey of the vegetation in Glen Canyon Reservoir Basin as a part of a larger program of studies of the biological resources of the region in cooperation with the U. S. National Park Service and the Bureau of Reclamation Upper Colorado River Office. This survey was made to assess the kinds and quantities of vegetation that will be inundated by the Glen Canyon Reservoir.

The survey was made in the field by a crew of ten advanced students under the personal direction of Dr. Seville Flowers. They made ocular estimates of the vegetation on each of 249 units of streamside phreatophytes, 158 units of terrace vegetation mainly secondary phreatophytes that use capillary water, and 35 units of hillside vegetation that depend upon precipitation water. The ocular estimates were checked by measured line transects. Both the estimates and the transects were tabulated on special forms and the units were plotted on overlay maps attached to aerial photographs with a scale of approximately 2000 feet per inch. These maps were numbered consecutively downstream from 1 to 33 between the mouth of the Dirty Devil River, Figure 9, and the Glen Canyon dam site.

In making the ocular estimates, the field crews estimated the density and average height of the vegetation on each unit area and estimated the percentage composition of the dominant species that occupied as much or more than 5 or 10% of the cover.

In the laboratory, the areas of the units were determined by planimeter or linear measurements on the overlay maps.

The field data were tabulated to show the area of each unit, the density of vegetation, its height and the percentage composition of the species of plants listed in the field. The units were sorted into streamside, terrace and hillside types.

From these data, by computations and analyses on an electronic machine, the following analysis of the vegetation was established: 2562 acres bore stands of streamside vegetation of a density that would completely cover 2116 acres; 6587 acres of terrace vegetation had a cover area of 3337 acres; 18,422 acres of hillside vegetation had a cover area of 3307 acres; making a total of 27,571 acres with a cover area of 8760 acres, which when multiplied by the foliage heights of the species of plants yielded a product of nearly 30,000 acre feet of foliage.

Using these data as background, the balance of the vegetation in the reservoir basin was estimated by extrapolation. By adding the figures derived by these calculations to the preceding, the totals for the reservoir basin stand as follows: streamside vegetation, 3421 acres, 2509 cover acres; terrace vegetation, 6773 acres, 3366 cover acres; hillside vegetation, 133,581 acres, 19,226 cover acres; total 143,775 acres, 25,101 cover acres. Adding 18,971 acres of water surface of rivers and 84 acres of farm land makes a total of 162,746 acres included in the calculations for the reservoir basin.

SURVEY OF VEGETATION

APPENDICES

APPENDIX A-1

SURVEY OF VEGETATION

_______________________________ Reservoir Basin

General Locality _______________________ Overlay No. ________

River Section ____________ to ____________ Sheet ____of____

Observed by _______________________ Date __________

MAP IDENTIFICATION			PLANT COMMUNITY				REMARKS
Aerial Photo & Overlay Number	River Mile	Area No. on Overlay	COMPOSITION (botanical)	Width feet	Height feet	Density %	

APPENDIX A-2

QUANTITATIVE ESTIMATION OF VEGETATION

LINE TRANSECT METHOD

Plant Community ______________________________ Area ________

Observers ______________________________ Date ________

______________________________ Map No. _____

VEGETATION SURVEY OF GLEN CANYON

APPENDIX A-3

KEY TO I.B.M. PUNCH CARD MASTER SHEETS

MASTER SHEET I

Map number	Area number	Canyon type	Crew member	Alt. Code	Habitat type	Height ft.	Density %	Area Acres
1 2	3 4 5	6	7 8	9	10	11 12 13	14 15 16	17 18 19 20

TYPICAL RIVER BANK FORMS

Salix exigua	*Tamarix pentandra*	*Baccharis emoryi*	*Salix goodingi*
21 23 23	24 25 26	27 28	29 30

FORMS SHOWING INTERGRADATION INTO TERRACES

Rhus trilobata	*Quercus gambelii*	*Pluchea sericea*	*Phragmites communis*	*Rhus toxicodendron*	*Distichlis spicata*
31 32	33 34	35 36	37 38	39 40	41 42

OTHER STREAMSIDE FORMS OCCURING MOSTLY IN SIDE CANYONS

Populus fremonti	*Carex* spp.	*Juncus* spp.	*Equisetum* spp.
43 44	45 46	47 48	49 50

TERRACE FORMS REPORTED WITH RIVER BANK FORMS

Chrysothamnus nauseosus	*Atriplex confertifolia*	*Atriplex canescens*	*Suaeda intermedia*	*Salsola kali*	*Datura meteloides*
51 52	53 54	55 56	57 58	59 60	61 62

Celtis douglasii	*Scirpus* spp.	*Typha latifolia*	*Artemisia filifolia*
63 64	65 66	67 68	69 70

Oryzopsis hymenoides	*Aster spinosus*	*Cercis occidentalis*	*Bromus tectorum*	Other
71 72	73 74	75 76	77 78	79 80

VEGETATION SURVEY OF GLEN CANYON

APPENDIX A-4

KEY TO I.B.M. PUNCH CARD MASTER SHEETS

MASTER SHEET II

Map number	Area number	Canyon type	Crew member	Alt. Code	Habitat type	Height ft.	Density %	Area acres
1 2	3 4 5	6	7 8	9	10	11 12 13	14 15 16	17 18 19 20

DOMINANTS PECULIAR TO TERRACES

Atriplex canescens	Chrysothamnus nauseosus	Suaeda intermedia	Artemisia filifolia	Sarcobatus vermiculatus	Celtis douglasii	Rhus utahensis
21 22	23 24	25 26	27 28	29 30	31 32	33 34

Sporobolus airoides	Chrysothamnus viscidiflorus
35 36	37 38

DOMINANTS GRADING INTO HILLSIDES

Ephedra spp.	Oryzopsis hymenoides	Gutierrezia microcephala
39 40	41 42	43 44

DOMINANTS GRADING INTO RIVER BANK

Pluchea sericea	Rhus trilobata	Quercus gambelii	Rhus toxicodendron	Baccharis emoryi
45 46	47 48	49 50	51 52	53 54

MINOR TERRACE PLANTS

Lepidium spp.	Atriplex confertifolia	Cercis occidentalis	Opuntia spp.	Atriplex garretti
55 56	57 58	59 60	61 62	63 64

RIVER BANK FORMS REPORTED FROM TERRACES

Tamarix pentandra	Salix goodingi	Salix exigua	Phragmites communis
65 66	67 68	69 70	71 72

UNCLASSIFIED

Distichlis spicata	Dalea fremonti	Populus fremonti	Other
73 74	75 76	77 78	79 80

VEGETATION SURVEY OF GLEN CANYON

APPENDIX A-5

KEY TO I.B.M. PUNCH CARD MASTER SHEETS

MASTER SHEET III

Map number	Area number	Canyon type	Crew member	Alt. code	Habitat type	Height ft.	Density %	Area acres
1 2	3 4 5	6	7 8	9	10	11 12 13	14 15 16	17 18 19 20

TYPICAL HILLSIDE FORMS

Atriplex confertifolia	Atriplex garrettii	Shepherdia rotundifolia	Rhamnus betulaefolia	Dalea thompsoni	Lycium andersoni
21 22	23 24	25 26	27 28	29 30	31 32

HILLSIDE PLANTS WHICH GRADE INTO TERRACES

Ephedra spp.	Oryzopsis hymenoides	Gutierrezia microcephala	Bromus tectorum	Opuntia spp.
33 34	35 36	37 38	39 40	41 42

Yucca angustissima	Chrysothamnus nauseosus	Hilaria jamesii
43 44	45 46	47 48

OTHER

Mixed grasses	Coleogyne ramosissima	Celtis douglasii	Quercus gambelii	Artemisia filifolia	Dalea fremonti
49 50	51 52	53 54	55 56	57 58	59 60

Lepidium montanun	Juniperus osteosperma	Grindelia fastigiata	Eriogonum inflatum	Populus fremonti	Atriplex cuneata	Other
61 62	63 64	65 66	67 68	69 70	71 72	73 74

APPENDIX C-2

A Table Showing Comparison of Ocular Estimates (E) and Transects (T)

Observer	Transect number	River mile	Habitat	E %	T %	E-T %	Totals
Crook, James R.	2	163	River terrace	50	51.6	- 1.6	
	3	148	River terrace	40	28.8	+11.2	+ 19.4
	4	113	Hillside	30	36.5	- 6.5	- 8.1
	5	78	River terrace	40	39.8	+ 0.2	+ 11.3
	6	48	River terrace	60	52.0	+ 8.0	
Gaddis, Don	2	163	River terrace	50	51.6	- 1.6	
	3	148	River terrace	35	28.8	+ 6.2	+ 14.4
	4	113	Hillside	30	36.5	- 6.5	- 8.1
	5	78	River terrace	40	39.8	+ 0.2	+ 6.3
	6	48	River terrace	60	52.0	+ 8.0	
Hall, Heber H.	2	163	River terrace		35.0		
	3	148	River terrace	31	35.5	- 4.5	
	4	113	River bank	90	95.0	- 5.0	
	4	113	River terrace	31	35.25	- 4.25	- 19.05
	5	78	Hillside	28	33.3	- 5.3	
Herrmann, Gideon	2	163	River terrace		32		
	3	148	River terrace		40		
	4	113	River terrace	37.7	36.7	+ 1.0	+ 1.0
	5a	67	River terrace		38.3		
	6	48	River terrace		42		
Higgins Harold G.	1	166	River terrace	40	30	+10.0	
	2	163	River terrace		29		
	3	148	River terrace	35	33.5	+ 1.5	+ 32.1
	3	148	Hillside	18	24.7	- 6.7	- 21.9
	4	113	River bank	70	60.5	+ 9.5	+ 10.2
	4	113	River terrace	30	36.3	- 6.3	
	5	78	River bank	95	83.9	+11.1	
	5	78	River terrace	55	56.7	- 1.7	
	6	48	River terrace	60	67.2	- 7.2	
Hyde, Wendell H.	2	163	River terrace	35	39	- 4.0	
	3	148	Hillside	20	25.7	- 5.7	
	4	113	River terrace	35	35.5	- 0.5	
	5	78	Hillside	25	30	- 5.0	- 22.2
	6	48	River terrace	35	43	- 7.0	

APPENDIX C-2 (continued)

Observer	Transect number	River mile	Habitat	E %	T %	E-T %	Totals
King, Grant O.	2	163	River terrace		32		
	3	148	River terrace		40		+ 1.0
	4	113	River terrace	37.7	36.7	+ 1.0	- 2.0
	5a	67	River terrace		38.3		- 1.0
	6	48	River terrace	40.0	42	- 2.0	
Lindsay, Delbert W.	1	166	River terrace	45	30	+15.0	
	2	163	River terrace	40	30	+10.0	
	3	148	Hillside	30	25.7	+ 4.3	+39.3
	4	113	River terrace	35	35.5	- 0.5	-13.5
	5	78	Hillside	40	30	+10.0	+25.8
	6	48	River terrace	30	43	-13.0	
Ridd, Merrill K.	2	163	River terrace		35		
	3	148	River terrace	34	35.5	- 1.5	
	4	113	River bank	91	95	- 4.0	
	4	113	River terrace	30.3	35.25	- 4.95	-13.75
	5	78	Hillside	30	33.3	- 3.3	
Smith, Bruce N.	2	163	River terrace		29		
	3	148	River terrace	35	33.5	+ 1.5	
	3	148	Hillside	18	24.7	- 6.7	
	4	113	River bank	70	60.5	+ 9.5	+22.1
	4	113	River terrace	30	36.3	- 6.3	-21.9
	5	78	River bank	95	83.9	+11.1	+ 0.2
	5	78	River terrace	55	56.7	- 1.7	
	6	48	River terrace	60	67.2	- 7.2	

TOTALS

+54.8
-56.0

Differences . . . . - 1.2

APPENDIX E-2

TABULATION OF WET SAND AREAS

The areas indicated on the overlay maps by the number 5 represent unvegetated areas of wet sand at the time the survey was made. The acreage of these areas was obtained by planimeter measurements where feasible but where the areas were too narrow for reasonable planimeter accuracy, a map measure or lineameter was used to measure the length of the areas on the map. On the map, the planimeter measured 839 planimeter units per square mile and the map measure 2.64 units per linear mile. A slide rule was set with 839 over 640 (acres per square mile) and the acreage for each map was read directly from the total planimeter units on that map. Areas not measured by planimeter were calculated from the linear measure and the field-estimated width.

PLANIMETERED AREAS

Date 1958	Map No.	Sand area	Planim. reading	Acreage
6/10	1	1	0011	
		2	0045	
		3	0050	
		4	0013	
		total	0119	91.0
7/4	2	1	0003	
		2	0007	
		3	0060	
		4	0012	
		total	0082	62.5
7/4	3	1	0014	
		2	0007	
		3	0034	
		4	0011	
		total	0066	50.4
7/4	4	1	0005	
		2	0028	
		3	0008	
		total	0041	31.3
7/4	5	1	0012	
		2	0013	
		3	0024	
		4	0004	
		5	0011	
		6	0003	
		7	0019	
		total	0086	65.6

Date 1958	Map No.	Sand area	Planim. reading	Acreage
7/5	6	1	0023	
		2	0049	
		3	0009	
		total	0081	61.8
7/7	7	1	0022	
		2	0002	
		3	0014	
		4	0042	
		5	0007	
		total	0087	66.5
7/7	8	None		
7/8	9	1	0011	
		2	0023	
		3	0007	
		4	0021	
		total	0062	47.3
7/10	10	1	0007	
		2	0006	
		total	0013	9.9
7/10	11	1	0008	
		2	0032	
		3	0009	
		total	0049	37.2

PLANIMETERED AREAS OF WET SAND (continued)

Date 1958	Map No.	Sand area	Planim. reading	Acreage
7/11	12	1	0003	
		2	0084	
		3	0007	
		4	0006	
		5	0006	
		6	0031	
		7	0005	
		8	0020	
		9	0003	
		10	0003	
		11	0004	
		12	0002	
		13	0004	
		14	0005	
		total	0183	140.0
7/12	13	1	0003	
		2	0011	
		3	0016	
		4	0052	
		5	0030	
		6	0004	
		7	0031	
		total	0147	112.0
7/13	14	1	0008	
		2	0016	
		3	0015	
		4	0003	
		5	0008	
		6	0010	
		7	0014	
		8	0002	
		total	0076	58.0
7/16	15	1	0061	
		2	0006	
		3	0007	
		4	0004	
		5	0012	
		total	0090	68.7
7/17	16	1	0005	3.8
7/18	17	1	0008	
		2	0004	
		total	0012	8.2
7/18	18	None		
7/19	19	1	0005	
		2	0007	
		total	0012	8.2
7/22	20	None		
7/22	21	1	0010	
		2	0016	
		3	0003	
		4	0020	
		5	0025	
		total	0074	56.5
7/24	22	1	0020	
		2	0012	
		3	0027	
		4	0028	
		5	0014	
		total	0101	77.2
7/24	23	1	0039	
		2	0030	
		3	0034	
		4	0024	
		5	0025	
		6	0038	
		7	0035	
		8	0042	
		9	0012	
		total	0279	213.0
7/26	24	1	0002	
		2	0018	
		3	0009	
		4	0039	
		5	0015	
		total	0083	63.4
7/27	25	1	0018	
		2	0006	
		3	0007	
		total	0033	25.2

PLANIMETERED AREAS OF WET SAND (continued)

Date 1958	Map No.	Sand area	Planim. reading	Acreage
7/27	26	1	0015	
		2	0014	
		3	0017	
		4	0002	
		5	0015	
		6	0021	
		7	0052	
		8	0025	
		9	0008	
		total	0169	129.0
7/27	27	1	0042	
		2	0027	
		3	0014	
		4	0017	
		5	0018	
		6	0018	
		7	0041	
		total	0177	135.0
7/29	28	1	0009	
		2	0017	
		3	0007	
		4	0008	
		5	0008	
		6	0009	
		7	0027	
		8	0009	
		9	0039	
		10	0068	
		11	0049	
		12	0039	
		13	0027	
		total	0316	243.0
7/31	29	1	0065	
		2	0030	
		3	0021	
		4	0004	
		5	0034	
		6	0072	

(continued next column)

Date 1958	Map No.	Sand area	Planim. reading	Acreage
7/31	29	(cont.)		
		7	0028	
		8	0022	
		9	0007	
		10	0035	
		11	0021	
		12	0031	
		13	0005	
		14	0004	
		15	0017	
		16	0010	
		17	0012	
		total	0418	319.0
8/3	30	1	0018	
		2	0011	
		3	0020	
		total	0049	37.4
8/3	31	1	0042	
		2	0012	
		3	0031	
		4	0025	
		5	0017	
		6	0020	
		7	0011	
		total	0158	121.0
8/4	32	1	0008	
		2	0024	
		3	0045	
		4	0023	
		5	0020	
		6	0003	
		7	0007	
		total	0130	99.0
8/7	33	1	0014	
		2	0010	
		3	0014	
		4	0015	
		total	0053	41.0
		TOTAL AREAS		2,482.1

UNPLANIMETERED AREAS OF WET SAND

Date 1958	Map No.	Sand area	Map measure inches	Width feet	Acreage
6/10	1	North Wash, mile 167.5	13	50	30.4
7/4	2	Trachyte Creek, mile 161.5	3.5	25	4.1
7/5	6	Red Canyon, mile 151	4.5	25	5.2
7/7	7	Ticaboo Creek, mile 148.5	3.5	10	1.6
7/8	9	Seven-mile canyon, mile 139	4.5		2.5
7/10	10	Warm Spring Canyon, mile 136.5	3	10	1.4
7/10	11	Little Ball Canyon, mile 130	3.5	10	1.6
7/12	13	Bullfrog Creek, mile 120	7	50	16.3
		Hall Creek, mile 118.5	3.5	50	8.2
7/13	14	Lake Canyon, mile 113	13	10	6.1
7/17	16	Main Canyon, mile 101	12	10	5.6
7/19	19	Escalante River, mile 88	30	75	104.8
7/22	21	San Juan River, mile 78			120.0
7/24	23	Aztec Creek, mile 68.5	12.5	10	5.8
7/27	25	Dangling Rope Canyon, mile 61	6	10	2.8
7/27	26	Side Canyon, mile 60	5	8	0.2
7/27	27	Dungeon Canyon, mile 56.5	2	6	0.6
		Rock Creek, mile 55.5	11	33	15.4
7/29	28	Side Canyon, mile 51.5	1.5	15	1.1
		West Canyon, mile 51	9	40	16.8
		Side Canyon, mile 44.5	8	10	3.7
7/31	29	Kane Creek, mile 40.5	1.5	8	0.6
		Padre Creek, mile 40	5.5	6	1.5
		Side Canyon at mile 34.5	6	6	1.7
8/3	31	Warm Creek, mile 28	14	40	26.1
8/4	32	Navajo Creek, mile 25.5	6	75	21.0
8/7	33	Antelope Creek, mile 19.5	0.5	20	0.5
		Wahweap Creek, mile 16.5	1.5	40	2.8
		Total unplanimetered areas			408.4
		Total planimetered areas			2,482.1
		TOTAL WET SAND AREAS			2,890.5

APPENDIX E-3

TABLE OF HIGH WATER AREAS

Colorado River

Map	Acres	Map	Acres
Cataract	531	18	402
1	235	19	603
2	312	20	248
3	65	21	662
4	180	22	338
5	190	23	520
6	280	24	328
7	263	25	116
8	200	26	348
9	480	27	523
10	210	28	888
11	502	29	1,448
12	507	30	410
13	463	31	146
14	308	32	390
15	701	33	480
16	235		
17	166	Total	13,678

San Juan River

Map	Acres
A	48
B	290
C	301
D	1,240
E	240
F	412
G	528
H	322
J	438
K	358
L	190
M	312
N	96
P	518
San Juan total	5,293
Colorado total	13,678
TOTAL	18,971

APPENDIX E-4

EXTRAPOLATED AREAS

A table of computations showing the values assigned to unsurveyed areas by extrapolation from similar areas included in the survey. The areas along the Fremont and Escalante rivers and the Bullfrog-Hall Creek embayment were calculated from the U.S.G.S. Plan and Profile sheets; the balance from aerial photo-maps. The areas were calculated from planimeter measurements except in Cataract Canyon, and along the Fremont and Escalante rivers where extrapolation was made by linear extension from comparison with known areas.

Map No.	Streamside Area Acres	Streamside Density	Streamside Cover Acres	Terrace Area Acres	Terrace Density	Terrace Cover Acres	Hillside Area Acres	Hillside Density	Hillside Cover Acres	Total Area Acres	Total Cover Acres
Fremont River											
USGS	200.2	20	40.0	. . .	. . .	. . .	827	15	124.0	1027	164
Bullfrog - Hall Creek embayment											
USGS	. . .	. . .	. . .	. . .	. . .	. . .	12764	15	1914.6	12764	1915
Escalante River											
USGS	75.0	60	45.0	. . .	. . .	. . .	3189	15	478.0	3264	523

APPENDIX E-4

EXTRAPOLATED AREAS (continued)

Map No.	Streamside Area Acres	Streamside Density	Streamside Cover Acres	Terrace Area Acres	Terrace Density	Terrace Cover Acres	Hillside Area Acres	Hillside Density	Hillside Cover Acres	Total Area Acres	Total Cover Acres
Colorado River											
I-3p	116.0	25	29.0				381	20	76.2	497	105.2
3-3p							107	15	16.1	107	16.1
4-3p							319	15	47.9	319	47.9
5-3p							201	8	16.1	201	16.1
6-3p							853	5	42.7	853	42.7
3r							216	20	43.2	216	43.2
7-3p							438	8	35.0	438	35.0
8-3p							770	20	154.0	770	154.0
3r							237	8	19.0	237	19.0
9-3p							448	10	44.8	448	44.8
3r							444	5	22.2	444	22.2
10-3p							229	10	22.9	229	22.9
11-3p							605	20	121.0	605	121.0
3r							562	15	84.3	362	84.3
3s							153	10	15.3	153	15.3
12-3p							657	15	98.6	657	98.6
3r							183	15	27.5	183	27.5
3s							1067	20	213.4	1067	213.4
14-3p							433	15	65.0	433	65.0
3r							444	10	44.4	444	44.4
15-3p							694	5	34.7	694	34.7
3r							368	5	18.4	368	18.4
3s							96	15	14.4	96	14.4
16-3pr							881	15	132.2	881	132.2
17-3pr							1468	20	293.6	1468	293.6
18-3p							622	10	62.0	622	62.0
20-3pr							896	15	134.4	896	134.4
21-3prt							539	5	27.0	539	27.0
3s							612	10	61.2	612	61.2
22-3pr							713	10	71.3	713	71.3
23-3pr							1267	15	190.0	1267	190.0
3s							948	10	94.8	948	94.8
24-3pr							2013	10	201.3	2013	201.3
25-3pr							1116	5	55.8	1116	55.8
26-3pr							2413	10	241.3	2413	241.3
27-3pr							6693	15	1004.0	6693	1004.0
XXVII-3pr							1674	15	251.1	1674	251.1
XXVIII-3prs							6035	15	905.3	6035	905.3
29-3p							1572	15	235.8	1572	235.8
XXVIX-3rs							3750	15	562.5	3750	362.5
30-3p							816	10	81.6	816	81.6
3r							252	5	12.6	252	12.6

APPENDIX E-4

EXTRAPOLATED AREAS (continued)

Map No.	Streamside Area Acres	Streamside Density	Streamside Cover Acres	Terrace Area Acres	Terrace Density	Terrace Cover Acres	Hillside Area Acres	Hillside Density	Hillside Cover Acres	Total Area Acres	Total Cover Acres
Colorado River continued											
31-3p							556	15	83.4	556	83.4
3r							930	5	46.5	930	46.5
XXXI-3t							1912	15	286.8	1912	286.8
XXXIa-3s							8852	15	1327.8	8852	1327.8
32-3pr							1729	5	86.5	1729	86.5
XXXII-3p							1061	15	159.2	1061	159.2
33-3p							1648	15	247.2	1648	247.2
3tu							1256	10	125.6	1256	125.6
XXXIII-3r							5020	15	753.0	5020	753.0
XXXIIIa-3s							2504	15	375.6	2504	375.6
Total	116.0		29.0				69,653		9,387.0	69,769	9,416.0
San Juan River											
A	2.6	10	.3							2.6	.3
B	7.6	10	.8							7.6	.8
C	7.2	10	.7							7.2	.7
D	7.7	10	.8	86	30	25.8	2155	15	323.3	2248.7	349.9
D-1a	115.0	70	80.5							115.0	80.5
E	4.9	10	.5				350	10	35.0	354.9	35.5
E-1a	28.0	80	22.4							28.0	22.4
F	9.1	40	3.6							9.1	3.6
F-1a	40.0	80	32.0				1258	15	188.7	1298.0	220.7
G	14.7	30	4.4				1302	15	195.3	1316.7	199.7
G-1a	54.0	80	43.2							54.0	43.2
H	17.3	30	5.2				679	15	101.9	696.3	107.1
H-1a	53.0	70	37.1							53.0	37.1
J	16.9	10	1.7				743	10	7.4	759.9	9.1
J-1a	13.0	80	10.4							13.0	10.4
K	8.7	10	.9				1849	15	277.4	1857.9	278.3
K-1a	20.0	80	16.0							20.0	16.0
L	5.1	30	1.5	16	20	3.2	1544	20	308.8	1565.1	313.5
L-1a	9.0	80	7.2							9.0	7.2
M	15.5	40	6.2				1190	15	178.5	1205.5	184.7
N	5.7	25	1.4				722	15	108.3	727.7	109.7
P	13.2	15	2.0				1934	15	290.1	1947.2	292.1
Total	468		279	102		29	13726		2015	14296	2323
Miscellaneous areas							15000		2000	15000	2000
GRAND TOTAL	859		393	102		29	115,159		15,919	116,120	16,341

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