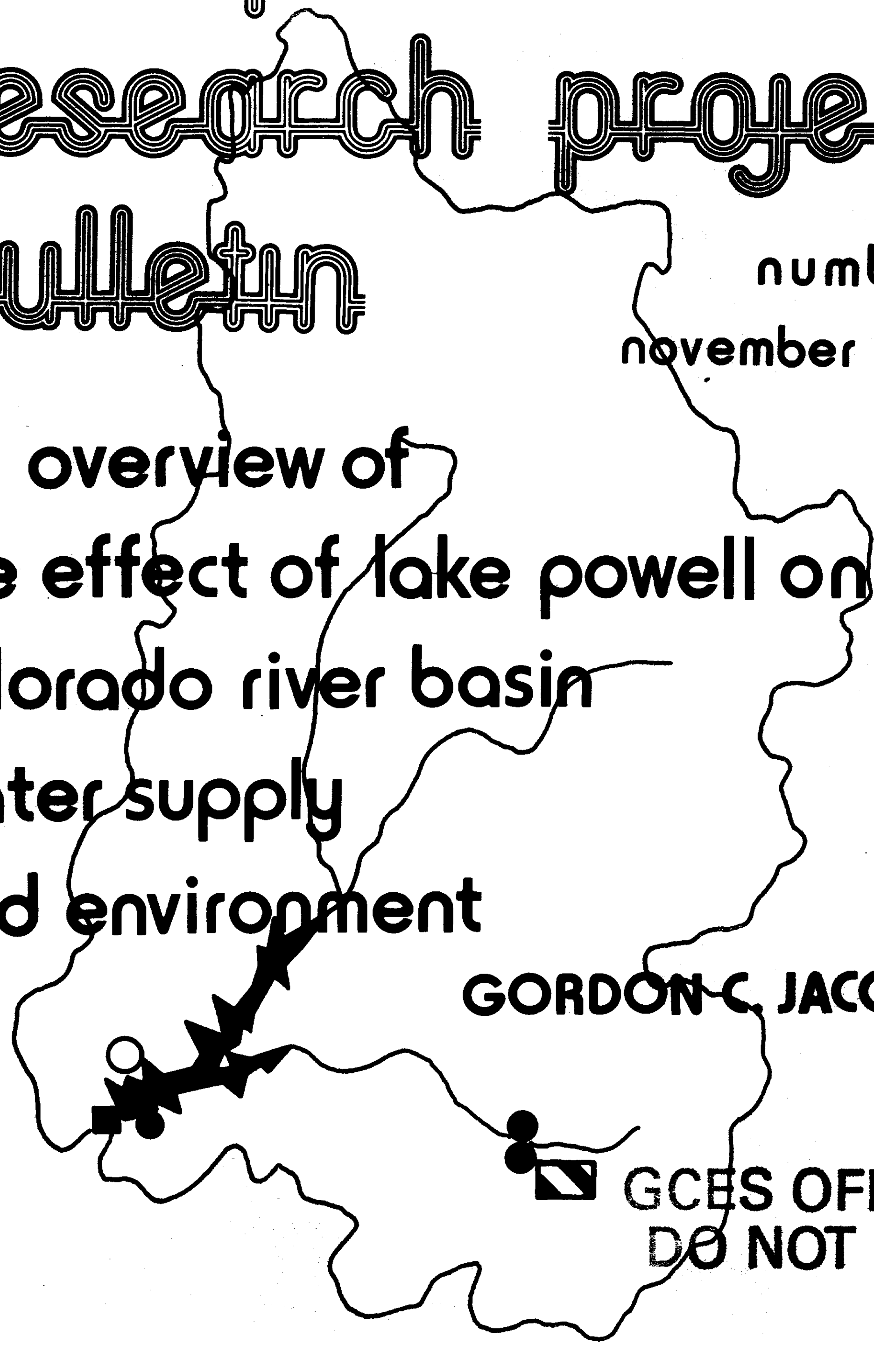
lake powell research project bulletin

number 14
november 1975



an overview of the effect of lake powell on colorado river basin water supply and environment

GORDON C. JACOBY, JR.

National Science Foundation
Research Applied to National Needs

LAKE POWELL RESEARCH PROJECT BULLETIN

BULLETIN EDITORS
Priscilla C. Grew and Orson L. Anderson

Managing Editor
Jeni M. Varady

a publication of the research project

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

funded by

Research Applied to National Needs
National Science Foundation

<u>Funded Institutions</u>

Dartmouth College
John Muir Institute
Northern Arizona Society of Science and Art, Inc.
University of Arizona
University of California, Los Angeles
University of California, Santa Barbara
University of New Mexico
University of Rochester
Utah State University

Copies obtainable from:

Jeni M. Varady
Institute of Geophysics and Planetary Physics
University of California
Los Angeles, California 90024

Price: $1.50, Payable to the Regents of the University
of California

AN OVERVIEW OF THE EFFECT OF LAKE POWELL ON COLORADO RIVER BASIN WATER SUPPLY AND ENVIRONMENT

Gordon C. Jacoby, Jr.[1]
Institute of Geophysics and Planetary Physics
University of California
Los Angeles, California 90024

November 1975

[1]Now at Lamont-Doherty Geological Observatory of Columbia University, Palisades, New York 10964.

LAKE POWELL RESEARCH PROJECT

The Lake Powell Research Project (formally known as Collaborative Research on Assessment of Man's Activities in the Lake Powell Region) is a consortium of university groups funded by the Division of Advanced Environmental Research and Technology in RANN (Research Applied to National Needs) in the National Science Foundation.

Researchers in the consortium bring a wide range of expertise in natural and social sciences to bear on the general problem of the effects and ramifications of water resource management in the Lake Powell region. The region currently is experiencing converging demands for water and energy resource development, preservation of nationally unique scenic features, expansion of recreation facilities, and economic growth and modernization in previously isolated rural areas.

The Project comprises interdisciplinary studies centered on the following topics: (1) level and distribution of income and wealth generated by resources development; (2) institutional framework for environmental assessment and planning; (3) institutional decision-making and resource allocation; (4) implications for federal Indian policies of accelerated economic development of the Navajo Indian Reservation; (5) impact of development on demographic structure; (6) consumptive water use in the Upper Colorado River Basin; (7) prediction of future significant changes in the Lake Powell ecosystem; (8) recreational carrying capacity and utilization of the Glen Canyon National Recreational Area; (9) impact of energy development around Lake Powell; and (10) consequences of variability in the lake level of Lake Powell.

One of the major missions of RANN projects is to communicate research results directly to user groups of the region, which include government agencies, Native American Tribes, legislative bodies, and interested civic groups. The Lake Powell Research Project Bulletins are intended to make timely research results readily accessible to user groups. The Bulletins supplement technical articles published by Project members in scholarly journals.

TABLE OF CONTENTS

LIST OF FIGURES

AN OVERVIEW OF THE EFFECT OF LAKE POWELL ON COLORADO RIVER BASIN WATER SUPPLY AND ENVIRONMENT

by

Gordon C. Jacoby, Jr.
Institute of Geophysics and Planetary Physics
University of California
Los Angeles, California 90024

Abstract

Lake Powell is a multi-purpose reservoir, creating water storage, generating hydroelectric power, and furnishing recreation in the southeastern part of Utah. Although Glen Canyon was one of the most scenic of the Colorado River canyons, access was limited and human impact was minimal. Creation of the lake inundated much of the canyon and increased access to the remaining portions. Storage in Lake Powell gives major control over the Upper Basin surface-water resources. Development of the Upper Basin and extra-basinal pressures for exportable water, food and fiber, and energy will increase consumptive use. Control coupled with increased consumptive use will have significantly greater water supply and environmental consequences throughout the entire Colorado River Basin than in the local Lake Powell area. Within the next two decades or earlier, Upper Basin estimated surface water supply and projected water-use curves will intersect. Sustained operation of the consumptive use developments will be possible during dry periods by using water stored in Glen Canyon to meet downstream obligations. After about a decade of rapid

development in the Upper Basin, the surface water resource will be "spent" and growth may be sharply curtailed. Ground water resource development could alleviate the situation somewhat. Upper Basin consumptive use and flow control will reduce the releases to the Lower Basin to the legal minimum. Lower Basin consumptive use already exceeds renewable annual supply of both surface and ground water. Any continued growth should involve increased efficiencies in use of present supplies. New or augmented supplies could also permit continued growth, but they present serious attendant difficulties.

I. INTRODUCTION

Much of the information in this paper is generally known but it is considered worthwhile to assemble it in this overview to provide a composite picture of regional effects.

The Colorado River Basin lies in the water-deficient southwestern United States. It has been legally divided into an upper and a lower basin by the Colorado River Compact of 1922. The Upper Basin lies within the States of Colorado, Utah, Wyoming, New Mexico, and a small part of Arizona. The Lower Basin lies within the States of Arizona, California, and Nevada, with small portions in Utah and New Mexico (see Figure 1).

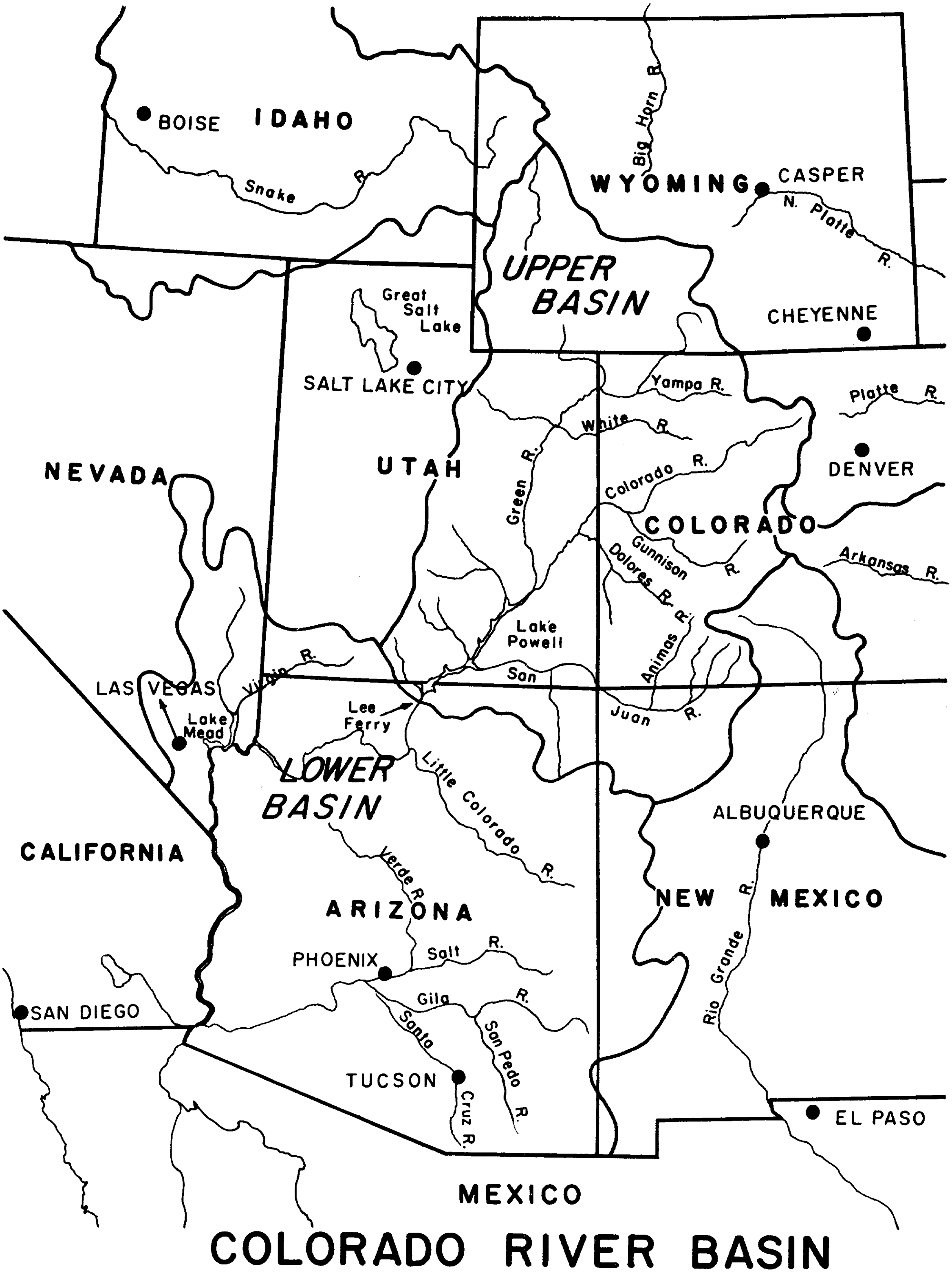
In this paper the term "environment" refers to the total environment as it is affected by industrial, agricultural, or population growth. Development and growth in the Southwest are extremely dependent on water supply. In this semi-arid to arid region with its highly variable precipitation, a key factor in water supply is storage. Lake Powell, a large man-made lake filling Glen Canyon in southeastern Utah (Figure 2), is by far the largest storage reservoir in the Upper Colorado River Basin. It is capable of containing about 80 percent of the total Upper Basin active storage of 33.6 million acre-feet (Upper Colorado River Commission, 1970, p. 28). It started filling in 1963, and in July of 1974 contained 20 million acre-feet of water in active storage (Bureau of Reclamation, 1974).

In considering the environmental impact of the creation of Lake Powell, it is useful to recognize three distinct zones. The first is the local region around Lake Powell itself; the second is the Upper Colorado River Basin, above Lee Ferry;

Figure 1: Colorado River Basin

The Upper and Lower Basins are indicated and the Lee Ferry accounting point for the division of waters according to the Colorado River Compact is shown near the center of the map.

(North is toward the top of the page and the scale is approximately 112 miles to the inch.)



BOISE
IDAHO
Snake R.
WYOMING
CASPER
Big Horn R.
N. Platte R.
UPPER BASIN
CHEYENNE
Great Salt Lake
SALT LAKE CITY
Yampa R.
White R.
Platte R.
DENVER
NEVADA
UTAH
Green R.
Colorado R.
COLORADO
Gunnison R.
Dolores R.
Arkansas R.
Lake Powell
Animas R.
LAS VEGAS
Virgin R.
Lake Mead
Lee Ferry
San Juan R.
LOWER BASIN
Little Colorado R.
ALBUQUERQUE
CALIFORNIA
Verde R.
ARIZONA
NEW MEXICO
Rio Grande R.
PHOENIX
Salt R.
Gila R.
SAN DIEGO
Santa Cruz R.
San Pedro R.
TUCSON
EL PASO
MEXICO
COLORADO RIVER BASIN

Figure 1

Figure 2: Lake Powell Region

(North is toward the top of the page and the scale is approximately 4 miles to the inch.)

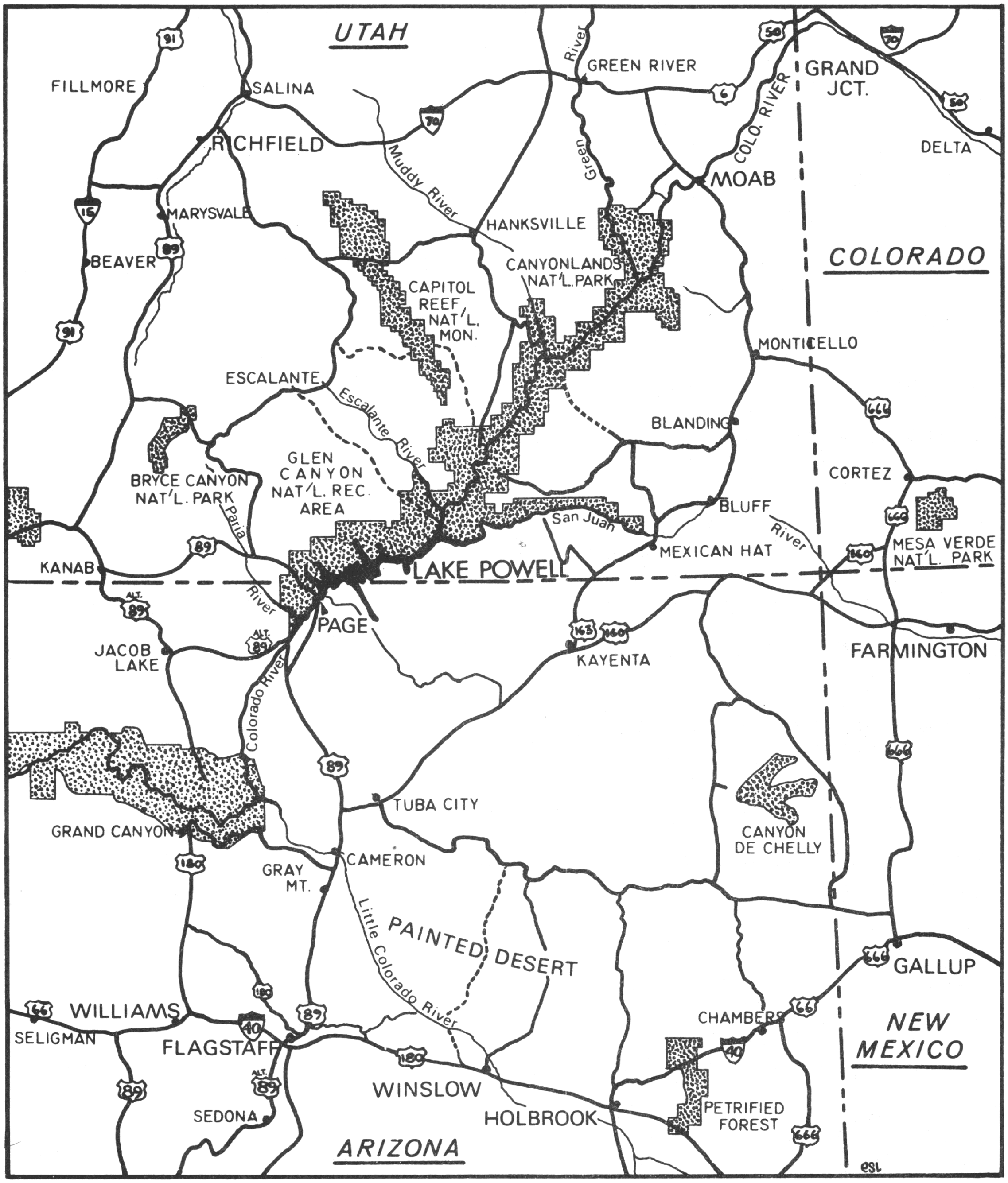

UTAH
FILLMORE
SALINA
RICHFIELD
MARYSVALE
BEAVER
GREEN RIVER
GRAND JCT.
DELTA
MOAB
COLO. RIVER
Green
River
Muddy River
HANKSVILLE
CANYONLANDS NAT'L. PARK
CAPITOL REEF NAT'L. MON.
COLORADO
MONTICELLO
ESCALANTE
Escalante River
BLANDING
BRYCE CANYON NAT'L. PARK
GLEN CANYON NAT'L. REC. AREA
CORTEZ
BLUFF
San Juan
River
MEXICAN HAT
MESA VERDE NAT'L. PARK
KANAB
Paria
River
LAKE POWELL
PAGE
JACOB LAKE
Colorado River
KAYENTA
FARMINGTON
TUBA CITY
GRAND CANYON
CANYON DE CHELLY
CAMERON
GRAY MT.
PAINTED DESERT
Little Colorado River
GALLUP
WILLIAMS
SELIGMAN
FLAGSTAFF
CHAMBERS
NEW MEXICO
WINSLOW
HOLBROOK
SEDONA
PETRIFIED FOREST
ARIZONA

Figure 2

and the third is the Lower Colorado River Basin, below Lee Ferry. The Colorado River Compact water accounting point is Lee Ferry, below Lake Powell. One might expect that the local region is the area of greatest impact. The impacts in this area have indeed been very great and tremendous changes have occurred locally as the result of the creation of Lake Powell. However, within the next few decades, or even in a few years, the most significant impacts of the damming of Glen Canyon to create Lake Powell will turn out to be the impacts on the entire Colorado River Basin. Developments that are ultimately predicated on the water storage capabilities of Lake Powell will affect regional and local economies, air quality, land use, overall environmental quality, and various other large-scale phenomena in the entire Basin region. Also, there will be effects on external metropolitan areas which are utilizing the water resources of the Colorado River Basin.

II. LAKE POWELL VICINITY

During the planning and construction of Glen Canyon Dam, there was considerable negative publicity about the fact that unusual scenic areas were to be inundated (e.g., Griffen, 1966). Several publications, notably the Sierra Club book The Place No One Knew (Porter, 1963), depict the scenic grandeur of Glen Canyon before the creation of Lake Powell and the almost unique ecological zones of various surrounding glens. These publications and observations were correct in that there was a certain unique beauty in areas throughout Glen Canyon, and these areas were irretrievably lost with the creation of Lake Powell.

However, there is another suite of publications extolling the virtures of Lake Powell, the attractiveness of this new lake created in a desert area, and the recreation available to boaters and fishermen so that more people can now view many of the different scenic areas bordering Lake Powell (e.g., U.S. Department of the Interior, 1965; and Edwards, 1967). There is easier access to these places, and larger numbers of people are now enjoying them. Observations about this recreational benefit are also correct.

Due to the ease of access, large numbers of individuals have entered the Lake Powell area by various motorized means of transport, either land transport in the vicinity of the lake and/or water transport for travel around the lake surface itself. These visitors and their mechanized transport introduce noise pollution, degradation of air quality, litter, and various other factors which unfortunately seem to accompany any increase in human activity. Along with the positive and negative aspects mentioned above, there has also been concern about Rainbow Bridge National Monument. The intrusion of lake water into the Monument has provoked sharp controversy and has resulted in expensive legal battles.

There is a non-quantitative, environmental cost-benefit effect at Lake Powell. It is difficult to come to a specific ultimate conclusion as to what the result of a "cost-benefit" evaluation of these environmental effects might be. It is a subjective evaluation as to whether what has been lost was greater than what has been gained, and this relative evaluation has been, and will continue to be, the topic of many debates. There probably is no way to determine whether Lake Powell or Glen Canyon in its pristine state had greater aesthetic value.

III. COLORADO RIVER BASIN

As stated previously, the major environmental impacts of Lake Powell will eventually affect the entire Colorado River Basin and its service area. These effects will turn out to be of much greater significance than those in the immediate vicinity of Glen Canyon and Lake Powell. The service area of the Basin comprises those localities receiving extrabasin transfers of water. These transfers include water transported across the Rocky Mountain Divide into Eastern Colorado; water exported westward out of the Basin into the Great Basin for the greater Salt Lake City metropolitan area and into some irrigation areas in central Utah; water exported into the Rio Grande Basin in New Mexico; and water transferred westward by the State of California, which carries water all the way to coastal cities for municipal water supplies in addition to using large quantities in irrigation areas. In fact, more water is exported from the Colorado River Basin than from any other river basin in the United States (National Research Council, 1968, p. 5).

In 1922 the Colorado River Compact was drafted in an attempt to divide the waters of the Colorado River Basin between the Upper Basin and the Lower Basin. At that time utilization of these waters was nowhere near the estimated streamflow, and there was no crisis other than the usual regional rivalry for resources of an area. In this case, the regional rivalry was somewhat heightened since it concerned water resources in what was largely a semi-arid to arid region. Since that time, the estimates of virgin flow from the Colorado River Basin have been, in general, declining, as various new studies, engineering estimates, and evaluations are made (U.S. Department of the Interior, 1974). In contrast, the water utilization has been increasing. It is the author's opinion that the curves for annually renewable supply and use will probably meet within the next 10 to 15 years (see Figure 3). Development toward full utilization in the Upper Basin will produce profound environmental changes there and will affect water supply and growth in the Lower Basin. The possible role which Lake Powell will play in this situation is considered here.

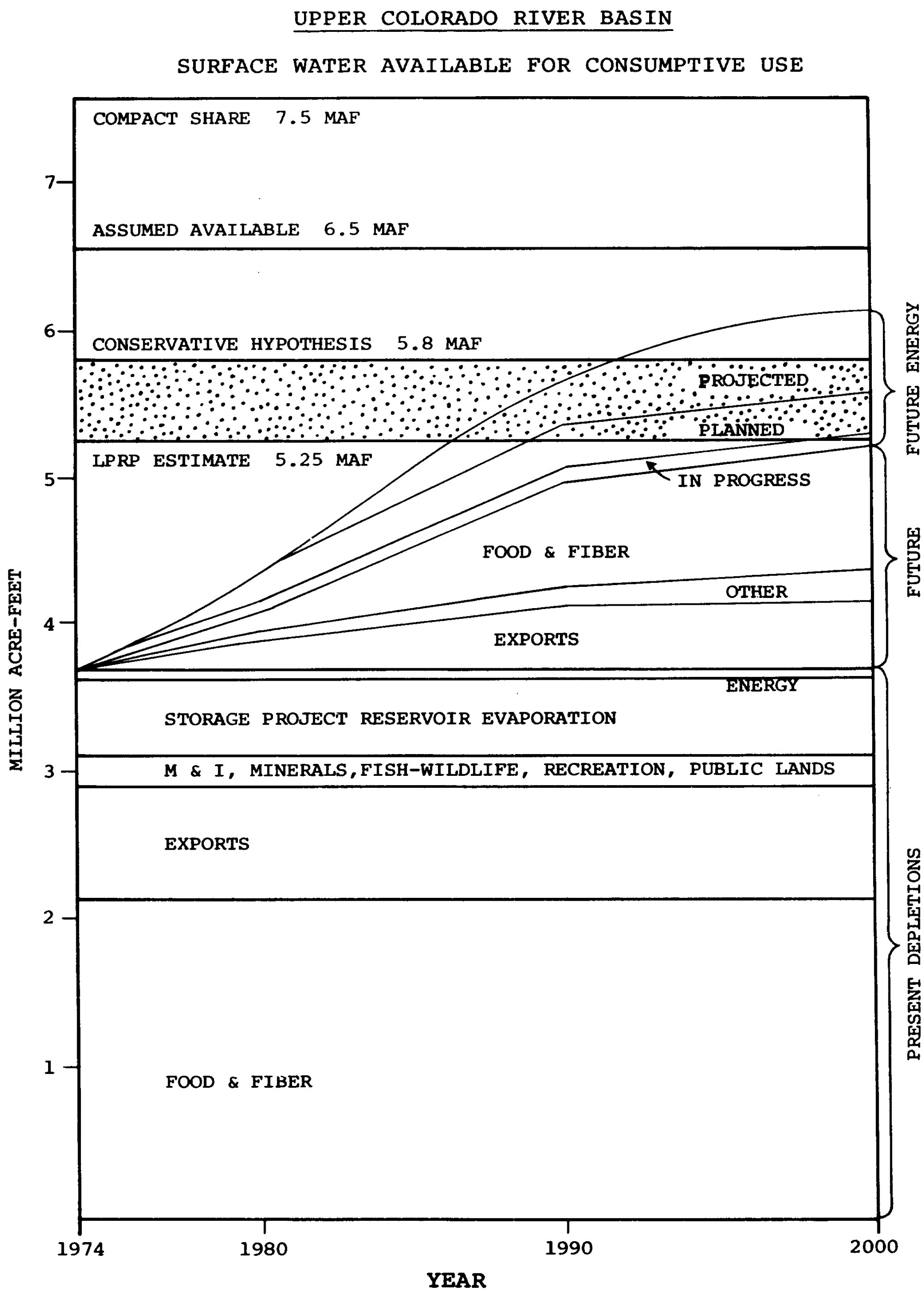
IV. UPPER COLORADO RIVER BASIN

Prior to the creation of Lake Powell, the policies in the Upper Basin had been to develop certain projects which consumptively used water from the Colorado River system. However, these projects did not appreciably interfere with the deliveries of water to the Lower Basin to meet and exceed the Colorado River Compact requirement that "The States of the upper division will not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of 10 consecutive years reckoned in continuing progressive series..." (Colorado River Compact, 1922, III, (d); Water Resources Council, 1971, appendix V). Thus, until the initiation of storage in Lake Powell, the primary reasons that the downstream obligations were met and exceeded were a lack of facilities to control the flow and to reserve water for Upper Basin use, and a *de facto* policy of low consumptive utilization which resulted in availability of water over and above the legal downstream obligations.

Then two trends were set in motion. First, the Colorado River Storage Project started building facilities so

Figure 3: Supply and Demand Curves for the Upper Colorado River Basin Surface Water

Consumptive use estimates for energy developments in progress, planned, or projected are the largest category for additional water uses.



Stippled zone represents the most likely level of surface-water supply. (Modified after Dept. of Interior, Report on Water for Energy in the Upper Colorado River Basin, 1974)

Figure 3

that the Upper Basin could store large amounts of water for its own use, and also so that it would be able to release that stored water in dryer periods to meet downstream obligations, while still conducting or supporting projects within the Upper Basin itself. Second, projects were built and/or planned to use more of the Upper Basin's share of the water. The term "project," in this sense, refers to irrigation projects, recreational facilities, water for industry, and any type of consumptive water use in the Upper Basin, including extrabasin transfers.

In recent years there have been rapid changes in the Upper Basin, and, with the increasing stress for energy production, food and fiber production, and water exports, there will be even greater acceleration in the construction of water-using projects in the Upper Basin. The Upper Basin contains extensive deposits of coal and oil shale. If exploited, according to certain plans, these developments to facilitate the utilization of those resources will become tremendous users of water (U.S. Department of the Interior, 1974, p. 42). At present there is also a potential food and fiber crisis. In the Upper Basin are potentially productive agricultural areas which, if irrigated, can contribute food and fiber supplies to the region and to the rest of the nation (U.S. Department of the Interior, 1974, p. 45). Increases in both the production of energy and production of food and fiber will be stressed more in the near future than they have been in past years. Along with these increases will be the demand for water to support such endeavors. Extrabasin exports will also increase in the next decades (U.S. Department of the Interior, 1974, p. 44).

Each new consumptive use of water erodes the cushion or reserve of excess streamflow which could be released to the Lower Basin states. As this utilization increases, the time will come when the Upper Basin will be using almost all, or all, of the water that is available to it for consumptive use. The Upper Basin projects through their own existence will create a dependency on the part of their users. These projects will be obligated to continue production, and they will not be able to curtail their uses without serious consequences. It will be necessary to have a storage system whereby the projects can continue to function during a dryer period. The alternative, if there were not some sort of storage mechanism, would be to shut down irrigation projects or to curtail energy production in order to meet the legal downstream water obligations.

These are the projects with great environmental consequences. There will be disturbance of large surface areas due to mining of coal and oil shale and potential degradation of air quality caused by powerplants and urbanization. New workers and associated populations will come to the region to build and operate the new projects and installations. These new populations will change existing land use and environmental quality. There also may be deterioration of water quality associated with irrigation for increased food and fiber production.

V. LOWER COLORADO RIVER BASIN

The Colorado River Compact and subsequent legislative acts have divided the water in the Upper and Lower Basins. As noted above, the effect of the Compact was to guarantee a minimum specific amount of 75 million acre-feet every 10 years to the Lower Basin and remaining amounts to the Upper

Basin. In the monumental case of Arizona v. California, a ruling was made on the division of the waters of the Lower Colorado River Basin. This division of the waters of the Lower Basin quantitatively assigned to each of the user states a specific amount of water that they are able to draw. If there is water available over and above this amount, they may draw on it in amounts exceeding these legal allocations. (For a recent discussion of development and the Law of the River, see Weatherford and Jacoby, 1975.)

Until the creation of large storage reservoirs in the Upper Basin, there was only one major storage reservoir, Lake Mead, in the Lower Basin, and many smaller storage reservoirs. Because of the Upper Basin's low consumptive use and inability to store large quantities of runoff, more water has been available to the Lower Basin than the law required. In the Lower Basin, the State of Nevada has a relatively small amount of water from the Colorado River system reserved for its use. The State of Arizona has a much larger amount of water reserved for its use, but until some major project, such as the Central Arizona Project, is constructed, Arizona is not using as much Colorado River water as its legal allocation. The State of California, however, has facilities to divert more than its legal minimum share of water and has been doing so (State of California, 1972, p. 60). Therefore, in California the utilization and consumptive use of water has not been restricted to certain legal minimums.

However, as Upper Basin use continues to increase and a viable storage system does exist, it is entirely probable that the Upper Basin will restrict its transfers, or allowed flows, to the Lower Basin down to the legal minimum requirement. When that happens, users who are now exceeding their allocations will have to cut back because surplus water will no longer be available.

The control is, again, Lake Powell. It furnishes the Upper Basin users the ability to reserve water, so they could limit the flow to the legal minimum to satisfy the obligations to the Lower Basin and the international treaty with Mexico. As the flow to the Lower Basin is cut down to this legal minimum, the water available will not only reach a certain stable level, it will actually decrease for the State of California. The Lower Basin states and service areas will have to adjust to a decrease in flow down to the legal minimum to which they are entitled.

The increase in developments in the Upper Basin for production of energy and food and fiber, and the stress which these will place on utilization of water supplies, have been discussed. The same stresses for energy production and food and fiber production exist in the Lower Basin. The fossil-fuel resources of the Lower Basin are nowhere near as great as they are in the Upper Basin; therefore the stress for _in situ_ power production, except perhaps in nuclear or other types of facilities, is not as great as it is in the Upper Basin.

Ground water supplies in the Lower Basin should not be used to supplement surface water supply because the present utilization already results in an estimated annual overdraft of about 2,500,000 acre-feet (Water Resources Council, 1970, p. V-29). Most of this overdraft occurs in central Arizona, and even with the most optimistic projections for the Colorado River waters available through the Central Arizona Project, the area will still be using water faster than the renewable annual supply.

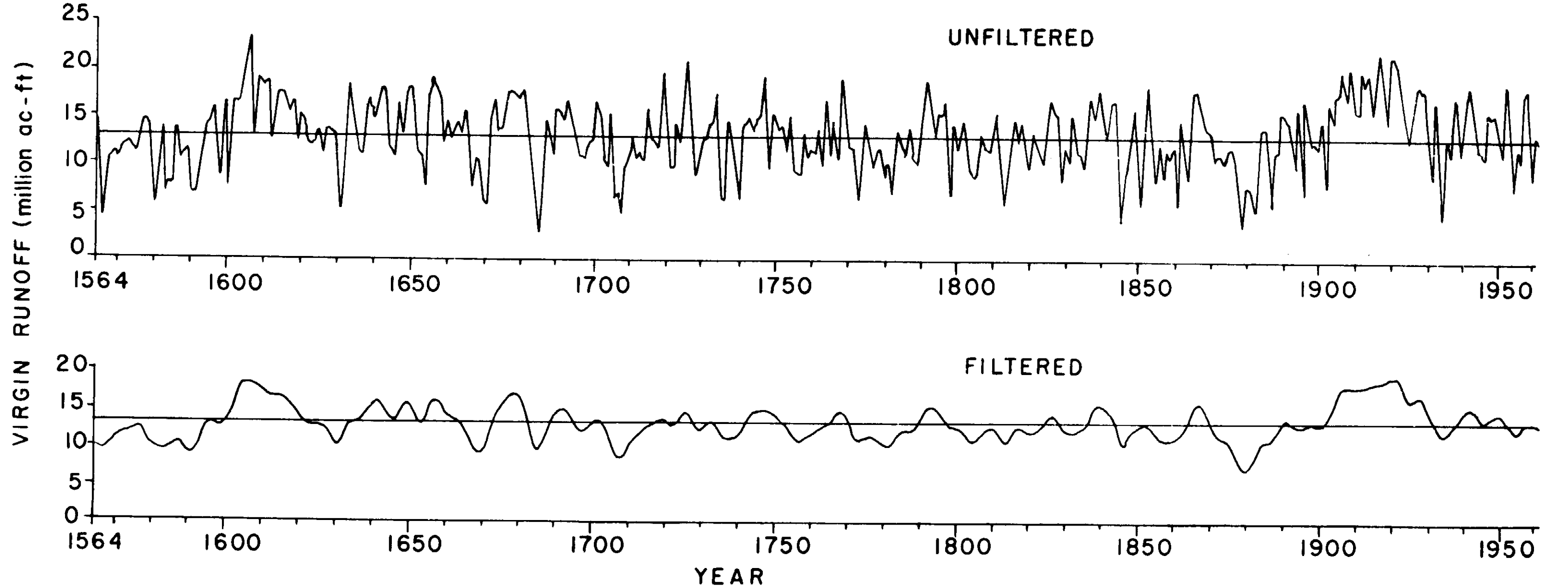
Therefore, the combination of increased Upper Basin consumptive use and water storage in Lake Powell will bring the supply to the Lower Basin to a fixed level, which in the case of California is lower than the current level of use. Any continued agricultural, industrial, or population growth in the Lower Basin will be affected by the fixed supply level of the Colorado River resources. In reality, the Lower Basin does not now have a renewable annual supply of water sufficient to support its present population, industry, and agriculture.

VI. SUPPLY OVERVIEW

One must also consider, as was mentioned before, the decline in estimated supply. The earliest and highest estimate is the Colorado River Compact share which envisioned the Upper Basin having 7.5 million acre-feet per year available for consumptive use. Another estimate is that produced by a consulting organization in 1965 which stated that the Upper Basin had available for annual consumptive use 6.5 million acre-feet (U.S. Department of the Interior, 1974, p. 12). In a 1974 report by the Water for Energy Management Team of the U.S. Department of the Interior, it was stated that the Bureau of Reclamation is using what is termed a conservative hypothesis of 5.8 million acre-feet available for consumptive use in the Upper Basin. In a study in which the author is currently involved, dendrochronology has been used to try to determine what the climatic environment has been in the Upper Basin in the past few centuries and, based on that, what one might expect assuming the climate to be fairly uniform over blocks of time on the order of several centuries. The dendrochronologic analyses and runoff reconstructions were done under the direction of Dr. Charles W. Stockton at the Laboratory of Tree-Ring Research in Tucson, Arizona. This study shows that since about 1930 we have been in a normal climatic period in the context of the past few centuries (see Figure 4). Streamflow measurements and estimates during this period, 1930 to the present, are more likely to give an accurate picture of the real surface water resources available in the Colorado River Basin than are some of the measurements and estimates made for the decades prior to 1930. These earlier decades were perhaps one of the wettest periods in several centuries (Stockton and Jacoby, 1975). The estimate for mean-annual virgin runoff based on the tree-ring growth and runoff studies gives a value of about 5.25 million acre-feet available for consumptive use in the Upper Basin while still meeting the downstream obligations (Weatherford and Jacoby, 1975). According to the 1974 report by the Water for Energy Management Team, U.S. Department of the Interior, if the conservative hypothesis estimate of 5.8 million acre-feet is used, the planned uses and projected uses of water in the Upper Basin will exceed this amount in the mid-1990s. Using the estimate of 5.25 million acre-feet based on tree-ring studies, the planned and projected uses could exceed this amount in the Upper Basin in little more than a decade (see Figure 3). When utilization approaches the available supply, the Upper Basin authorities can be expected to curtail releases to

Figure 4: Reconstructed Runoff for the Colorado River at Lee Ferry

These curves represent values for virgin runoff from the Upper Colorado River Basin.



Tentative 400-year reconstruction of annual runoff at Lee Ferry, Arizona. This reconstruction is based on tree-ring chronologies within the Upper Colorado River Basin collected as part of the Lake Powell Research Project and on chronologies which were in the files of the Laboratory of Tree-Ring Research. A future reconstruction will include additional chronologies and more definitive streamflow data.

The filtered series is shown so that the low-frequency tendencies can be revealed. The digital filter process separates out the variance with a frequency of greater than once every 10 years.

Figure 4

the Lower Basin to meet only their legal minimum obligations, and efforts will be made to prevent unnecessary spills over and above those amounts to the Lower Basin. Again, the primary mechanism to prevent those spills will be storage systems, primarily Lake Powell.

Most of the water produced in the entire Colorado River Basin comes from the Upper Colorado River Basin, specifically the high mountainous areas in Wyoming, Utah, and Colorado. Approximately 83 percent of the flow of the entire Colorado River system comes from the Upper Basin, and only a smaller percentage is contributed by the Lower Basin (Water Resources Council, 1970). Most of the inflow in the Lower Basin originates in the State of Arizona, primarily the Gila River and the Little Colorado River. Utilization in the Gila River area is already large enough to use or to control almost the entire flow of that river. Therefore, the primary source of Colorado River water for the users in the Lower Colorado River Basin is the Upper Basin above the Compact point. The impact of the existence of Lake Powell on users below this controlling point is that their growth based on utilization of unaugmented Colorado River water is essentially, or will be very quickly, stopped. There will have to be increased efficiencies in use or alternative supplies for any further growth based on water resources in these areas. In fact, as mentioned above, there may be a decrease in the amount of water available to the California service area as the flow is cut back to the legal minimum obligation at the Colorado River Compact point and as Arizona uses its full allotment.

VII. SUPPLY AUGMENTATION

The quests for increasing the usable water supply can be grouped in two categories: increased efficiencies in use of present supplies, and new or augmented supply. Increased efficiencies involve reduction of conveyance and reservoir losses, improved irrigation practices, improved efficiency on the part of industrial and municipal users, and demand management through revised statutes or pricing structures. These policies should be followed with or without any supply augmentation.

New supplies could involve desalination, vegetation management, importation, or weather modification. Rudel et al. (1973) reviewed various aspects of these approaches. Desalination, in addition to being expensive, also uses substantial amounts of energy: the same energy that is in increasingly short supply and that consumptively uses water in its creation. Vegetation management and eradication can increase water yield in a drainage basin (Ffolliott and Thorud, 1974) at the cost of the obvious substantial disturbance of the basin flora and the concurrent disturbance of the whole ecosystem. Due to the nature of growing things, it is an approach requiring repeated operations. Another problem is that increased flow can also cause increased sediment and soluble nutrient flux through the same system (Hibbert et al., 1974). Importation requires expensive capital construction projects and relies upon the relinquishment of water by the exporting region. The obvious choice for imported water, the Columbia River Basin, experienced a shortage of streamflow in 1973 and had to curtail certain operations (Boyer, 1974, p. 840).

It can be reasonably assumed that the various interested parties in that river basin wish to reserve their resources for their own use (Lane, 1975).

Weather modification, specifically cloud-seeding for snowpack augmentation, is another alternative to produce additional supplies. Such modification may be technologically feasible (Weisbecker, 1974). However, more knowledge about target area ecological effects and costs may also be needed. And, there is need for further information about downwind effects (National Research Council, 1973). Another factor is the question of water rights to augmented flow. The Lower Basin especially may be in a weak legal position in regard to rights to federally produced augmented flow (Weatherford and Jacoby, 1975). There is also a potential for ground water development in the Upper Basin. Judicious development of this resource could contribute significantly to the Upper Basin supply. Ground water and surface water interdependencies and low recharge rates must be considered carefully in this development.

The discussion above is obviously not a comprehensive review of all supply alternatives and consequences. It emphasizes, however, that each alternative for new supply does involve serious attendant problems. The blithe assumption that there will be a readily obtainable, additional, low-cost water supply for the Colorado River Basin and its service areas is not a sound operational hypothesis.

VIII. SUMMARY

The major environmental impact resulting from Lake Powell will be, in addition to the local effects, the effect on growth in the Upper and Lower Colorado River Basins due to the reservoir's influence on the water supply in both areas. There will be a slight decrease in water available for growth, new industry, and agricultural expansion in the Lower Basin. Unless there is more efficient management of current supplies or alternative sources of water are developed, a non-growth, static situation could ensue in the Lower Basin and service areas dependent on Colorado River water.

In the Upper Basin, the major environmental impact will be the construction of various facilities for food and fiber production and energy production, resulting in more human activity. There will be more pollution, largely from the energy-producing facilities, salination problems resulting from agricultural use, and various other problems which accompany increased industrial and agricultural expansion in the Upper Basin. These increases will be allowed by the fact that the users can develop and exploit the local water resources with the knowledge that they will not have to curtail their activities in times of drought. They have a large downstream reservoir to meet the Lower Basin obligations in times of stress.

Therefore, the environmental effects of Lake Powell reach far beyond the shores of the lake or even the immediately surrounding region, and will be felt throughout the entire Upper and Lower Colorado River Basins, even into the service areas surrounding the Colorado River Basin.

ACKNOWLEDGMENT

The research leading to this report was supported by the RANN Division of the National Science Foundation, Grant GI-34840, part of the Lake Powell Research Project.

LITERATURE CITED

Boyers, David S., 1974. The Columbia River. National Geographic, 146, no. 6, pp. 821-847.

Bureau of Reclamation, 1974. Hydrometeorological Data - Lake Powell for July 1974, 1 p.

Colorado River Compact, 1922. Printed in U.S. Department of the Interior, 1956. Documents on the Use and Control of the Waters of Interstate and International Streams, 39.

Edwards, Walter M., 1967. Lake Powell, Waterway to Wonders. National Geographic, 132, no. 1, pp. 44-75.

Ffolliott, P. F., and D. B. Thorud, 1974. Vegetation Management for Increased Water Yield in Arizona. University of Arizona Technical Bulletin 215, 38 pp.

Griffen, Frank L., 1966. Visit to a Drowning Canyon. Audubon, 68, no. 1, pp. 27-33

Hibbert, A. R., E. A. Davis, and D. G. Sholl, 1974. Chaparral Conversion Potential in Arizona: Part I, Water Yield Response and Effects on Other Resources, U. S. Department of Agriculture (USDA) Forest Service Research Paper RM-126. USDA, Fort Collins, Colorado, 36 p.

Lane, Donel J., Chairman, Pacific Northwest River Basin Commission, personal communication, 5 February 1975.

National Research Council, 1968. Water and Choice in the Colorado River Basin. National Academy of Sciences, 107 p.

National Research Council, 1973. Weather and Climate Modification: Problems and Progress. National Academy of Sciences.

Porter, Eliot, 1963. The Place No One Knew: Glen Canyon on the Colorado. Sierra Club, 170 p.

Rudel, R. K., H. J. Stockwell, and R. G. Walsh, 1973. Weather Modification: An Economic Alternative for Augmenting Water Supplies, Water Resources Bulletin, 9, no. 1, pp. 116-128.

State of California, 1972. Hydrologic Data: 1970 Department of Water Resources Bulletin 130-70, V, p. 60.

Stockton, C.W., and G. C. Jacoby, Jr., 1975. Streamflow Trends and Surface Water Supply in the Upper Colorado River Basin: A Preliminary Report Based on Tree-Ring Analysis, Lake Powell Research Project Bulletin, in press.

U.S. Department of the Interior, 1965. Lake Powell - Jewel of the Colorado. U.S. Government Printing Office, 28 p.

U.S. Department of the Interior, 1974. Report on Water for Energy in the Upper Colorado River Basin, 71 p.

Upper Colorado River Commission, 1970. Twenty-Second Annual Report, 120 p.

Water Resources Council, 1970. Lower Colorado Region Comprehensive Framework Study, Appendix V, Water Resources. Draft Copy, 113 p.

Water Resources Council, 1971. Upper Colorado Region Comprehensive Framework Study, Appendix V, Water Resources, 66 p.

Weatherford, G. W., and G. C. Jacoby, Jr., 1975. Impact of Energy Development on the Law of the Colorado River, Natural Resources Journal, 15, 171-213.

Weisbecker, Leo W., 1974. The Impacts of Snow Enhancement: Technology Assessment of Winter Orographic Snowpack Augmentation in the Upper Colorado River Basin. University of Oklahoma Press, Norman, Oklahoma, 624 p.

THE AUTHOR

Gordon C. Jacoby, Jr., has been a member of the Lake Powell Research Project since its founding in 1971. Prior to that time he participated in some of the preliminary workshops and studies about Lake Powell which led to the creation of the Project. He is presently Principal Investigator of the Hyrdrology Subproject.

Jacoby received his doctoral degree in Hydrology from Columbia University. He is presently (1) Assistant Research Geologist in the Institute of Geophysics and Planetary Physics at the University of California at Los Angeles, through which the Hydrology Subproject is funded, and (2) Research Assistant at Lamont-Doherty Geological Observatory of Columbia University. In addition, Dr. Jacoby is a Research Associate of the Museum of Northern Arizona, in Flagstaff.

LAKE POWELL RESEARCH PROJECT BULLETINS

No. 1 Mercury in the Lake Powell Ecosystem, by D. R. Standiford, L. D. Potter, and D. E. Kidd. ($1.50)

No. 2 Demographic Change among the Hopi and Navajo Indians, by S. J. Kunitz. ($1.50)

No. 3 Air Quality in the Lake Powell Region, by E. G. Walther, M. D. Williams, R. Cudney, and W. Malm. ($1.50)

No. 4 Legal-Political History of Water Resource Development in the Upper Colorado River Basin, by D. Mann, G. Weatherford, and P. Nichols. ($1.50)

No. 5 Major Element Geochemistry of Lake Powell, by R. C. Reynolds, Jr., and N. M. Johnson. ($1.00)

No. 6 Survey of Navajo Community Studies, 1936-1974, by E. B. Henderson and J. E. Levy. ($3.00)

No. 7 The Impact of Power Development on the Navajo Nation, by L. A. Robbins. ($1.50)

No. 8 Theoretical Analysis of Air Quality: Impacts on the Lake Powell Region, by M. D. Williams and E. G. Walther. ($1.50)

No. 9 Scientific Information in the Decision to Dam Glen Canyon, by P. C. Perkins. ($1.50)

No. 10 A Case Analysis of Policy Implementation: The National Environmental Policy Act of 1969, by Hanna J. Cortner. ($1.50)

No. 11 The Macroeconomic Impact of Energy Development in the Lake Powell Area, by W. Schulze, S. Ben-David, D. Brookshire, and R. Whitworth. ($1.50)

No. 12 Management of Scientific Collaboration in the Lake Powell Research Project, by O. L. Anderson. ($1.50)

No. 13 Utah Coal for Southern California Power: The General Issues, by O. L. Anderson ($2.00)

No. 14 An Overview of the Effect of Lake Powell on Colorado River Basin Water Supply and Environment, by G. C. Jacoby, Jr. ($1.50)

No. 15 Navajo Participation in Labor Unions, by L. A. Robbins. (in press)

No. 16 Bacterial Contamination of Lake Powell Waters: An Assessment of the Problem, by D. E. Kidd (in press)

No. 17 Survey Estimates of Visitation and Expenditures for the Lake Powell Area, by J. Baxter, S. Ben-David, F. L. Brown, and J. Knight. (in press)

No. 18 Long-term Surface-water Supply and Streamflow Trends in the Upper Colorado River Basin Based on Tree-Ring Analysis, by C. W. Stockton and G. C. Jacoby, Jr. (in press)

No. 19 A Dynamic View of Tribal Jurisdiction to Tax Non-Indians, by C. E. Goldberg (in press)

No. 20 The Relationship of Economic Variations to Mortality and Fertility Patterns on the Navajo Reservation, by S. J. Kunitz (in press)

No. 21 A Survey of Fertility Histories and Contraceptive Use Among a Group of Navajo Women, by S. J. Kunitz (in press)

No. 22 The Effects of Power Production and Strip Mining on Local Navajo Populations, by D. G. Callaway, J. E. Levy, and E. B. Henderson (in press)

No. 23 Utah Coal for Southern California Power: Historical Background, by P. C. Grew (in press)