

CARRIER  
Return to EK

UPPER COLORADO RIVER COMMISSION

**WATER SUPPLIES OF THE  
COLORADO RIVER**

AVAILABLE FOR USE BY THE STATES OF THE UPPER DIVISION  
AND FOR USE FROM THE MAIN STEM BY THE STATES OF  
ARIZONA, CALIFORNIA AND NEVADA IN THE LOWER BASIN

PART I—TEXT

TIPTON AND KALMBACH, INC.

DENVER, COLORADO

JULY 1965

**UPPER COLORADO RIVER COMMISSION**

**WATER SUPPLIES OF THE  
COLORADO RIVER**

**AVAILABLE FOR USE BY THE STATES OF THE UPPER DIVISION  
AND FOR USE FROM THE MAIN STEM BY THE STATES OF  
ARIZONA, CALIFORNIA AND NEVADA IN THE LOWER BASIN**

**PART I—TEXT**

**TIPTON AND KALMBACH, INC.**

**DENVER, COLORADO**

**JULY 1965**

TIPTON AND KALMBACH, INC.

300 INSURANCE BUILDING  
831-14TH STREET

DENVER 2, COLORADO

PHONE CHERRY 4-2944

L. J. TIPTON, PRESIDENT  
W. L. KALMBACH, VICE-PRES.  
M. H. HUNT, TREASURER  
L. KIRGIS, SECRETARY

CABLES:

ARTIP - DENVER  
TIPCOL - BOGOTA  
TIPVEN - CARACAS  
TIPERU - LIMA  
ARTDOR - QUITO  
TIPAK - LAHORE

July 30, 1965

Upper Colorado River Commission  
355 South 4th East Street  
Salt Lake City, Utah 84111

Gentlemen:

During the latter part of May 1965 the firm of Tipton and Kalmbach, Inc., was retained by the Colorado Water Conservation Board to make a study of the water supplies available from the Colorado River for use in the Lower Colorado River Basin, and to determine whether such supplies would be available at all times to satisfy uses by the states of Arizona, California, and Nevada as defined in the decision of the U. S. Supreme Court in the case of Arizona vs. California, et al, 373 U. S. 546. Subsequently, at a meeting with three of the Commissioners and some of their engineering advisors, together with the U. S. representative on the Commission, and the Executive Director of the Commission, and its Chief Engineer, held in the office of the Colorado Water Conservation Board on June 3, 1965, the scope of the studies was discussed and it was concluded that the studies would be sponsored by the Upper Colorado River Commission rather than by the Colorado Water Conservation Board. The studies have been made and a report prepared which embodies the results of the studies.

Drafts of the report were reviewed from time to time by the Commission's Engineering Advisors and by some of the members of the Commission. [The suggestions of all of the interested parties have all been considered, and those believed to be consistent with the purpose of the report and the thinking of the author have been adopted.]

The report consists of two parts: Volume I - Text, and Volume II - Appendices. The text describes the manner in which the studies were made and gives the results of the most pertinent studies and final conclusions based on those results, and the reasons therefor. The Appendices consist of copies of all the detailed river and reservoir operation studies that were considered directly pertinent to the report. The Appendices also contain tables indicating the estimated present depletions on the river by the States of the Upper Division of the Colorado River Basin, and the prognostication by projects of increased depletion in the future, as made by various entities. A master table is included which indicates all known potentials in the Upper Basin and estimates of others which might come into being.

The report is submitted herewith for your consideration.

Sincerely yours,



R. J. Tipton

# Contents

## Part I—Text

	Page
FOREWORD .....	1
SUMMARY .....	5
STUDIES MADE	
Study Period .....	9
Increased Depletions on the Upper Colorado River Basin .....	10
Colorado River Operation Studies .....	12
Future Uses in the Lower Basin .....	13
Depletion Factor .....	15
River Losses Below Hoover Dam .....	15
Storage in the Basin Reservoirs .....	17
Results of the Studies .....	18
CONCLUSIONS .....	21

## Tables

(At end of Text)

Number	Title
1	Shortages to California, Arizona and Nevada based on Study Period 1914-1964, Depletion Factor = 1.0 and Maximum Upper Basin Reservoir Contents—32 maf
2	Shortages to California, Arizona and Nevada Based on 1921-1964 Period

## Figures

(Following Tables)

1	Colorado River 1921-1964, Upper Basin Depletion vs. Required Reservoir Capacity, 7.500 maf Delivery at Lee Ferry
2	Colorado River 1921-1964, Upper Basin Depletion vs. Required Reservoir Capacity, 8.250 maf Delivery at Lee Ferry
3	Estimates of Upper Basin Depletions

## Part II—Appendices (Separately Bound)

### Appendix

A	UPPER BASIN DEPLETION ESTIMATES
B	COMBINED OPERATION STUDIES
C	UPPER BASIN STUDIES

## Foreword

The reasons for making studies at this time of the available water supplies on the main stem of the Colorado River in the Lower Basin is because of the situation described below.

There are before Congress at the present time a number of bills which would authorize a part of the Southwest Water Plan proposed by the Secretary of Interior. The plan originally contemplated the importation of substantial quantities of surplus water from the streams of the Northwest; this part of the plan has been dropped and is no longer being included in the request for authorization for construction. However, authorization for a study of the contemplated importation is included in the proposed legislation. The principal physical works sought to be authorized are those comprising the Central Arizona Project.

The decision of the United States Supreme Court in the case of *Arizona vs. California et al.*, 373 U.S. 546, considered that the contracts with the Secretary of Interior and the three states of the Lower Basin, Arizona, Nevada and California, and individual entities thereof, constituting an apportionment of 2.8 million acre-feet (maf) of water to Arizona, an apportionment of 0.3 maf to Nevada, and a limitation of 4.4 maf to California effect a valid apportionment of the first 7.5 maf of mainstream water in the Lower Basin. All apportionments by the terms of the contracts are subject to the availability of water. The Master hearing the case recommended that in case of shortage the shortage be divided among the states in proportion to their allocation of water. The Supreme Court in its decree did not follow the recommendation of the Master in respect to the allocation of shortages, but left the matter in the hands of the Secretary of Interior subject to further consideration by the Court or consideration by Congress.

It is understood that the states of Arizona and California have entered into an agreement whereby Arizona will guarantee that her uses will be such as to insure the availability of 4.4 maf of water per year from the main stem to California at all times. The substance of this agreement is spelled out in Bill S 1019 which provides, in essence, a priority to existing consumptive uses by

California of Colorado River water on the main stem up to the amount of 4.4 maf annually, and to existing main stem Colorado River consumptive uses and entitlements in Arizona and Nevada by limiting diversions from the main stem for the Central Arizona Project in any year in which the Secretary of Interior determines there is insufficient main stem Colorado River water available to satisfy the total annual consumptive use of 7.5 maf by the states of Arizona, California and Nevada. This, in itself, would implement one of the suggestions made by the Supreme Court that the matter of allocating shortages among users of the Lower Colorado River Basin be subject to further consideration by Congress. If the Central Arizona Project is authorized and goes into operation, the relevant provisions of Bill S 1019 as now proposed would cause the burden of any shortage in water supplies to be on the Central Arizona Project.

This entire situation poses a problem to the States of the upper division of the Colorado River Basin. Uses in the Upper Basin may not have progressed to the point that all waters apportioned to it by the Colorado River Compact, or to the limit imposed by nature, are being used at the time the Central Arizona Project goes into operation if it is authorized and goes to construction. In other words, there might be some unused water destined for use in the Upper Basin passing Lee Ferry which, if used in the Lower Basin, would pose a problem when those waters subsequently were needed by projects in the Upper Basin. Actually, at the present time some of the uses in the Lower Colorado River Basin on the main stem are being made only because of unused flows in the Upper Basin passing Lee Ferry.

The present studies therefore appeared desirable to enable the Commission to take stock and see what problems might arise because of the situation, and in order that policies and procedures may be developed.

At the meeting of June 3, 1965 of certain members of the Commission and its Engineering Advisors, these studies were authorized and their scope discussed. As the studies progressed, two other meetings were held with the Engineering Advisory Committee to the Commission, at which time the Commissioners from

some of the states were also present. Frequent conferences were held with Mr. Ival Goslin, Executive Director of the Commission; some were had with Mr. Felix Sparks, Director of the Colorado Water Conservation Board, and his technical staff. Mr. Cecil Jacobson, Chief Engineer of the Commission, spent some time in the office of Tipton and Kalmbach, Inc., assisting the studies.

The studies were made under the direction of R. J. Tipton. He is solely responsible for the conclusions derived from the studies contained in the report. During the time the studies were being made and drafts of the report were being prepared, the drafts of the report were reviewed by the groups at the meetings mentioned above. Editorial changes suggested by representatives of the Commission for clarification purposes were accepted; other suggestions more substantive in character were not accepted if they were not concurred in by the author of the report.

The author wishes to express his appreciation for the constructive advice afforded by various representatives of the Commission and its Engineering Advisors during the course of the studies and preparation of this report.

## Summary

Based upon the recorded historic flow of the Colorado River, it appears that nature has decreed that the river will not supply enough water to support the apportionment made by the Colorado River Compact to the Upper Basin; an amount of 7.5 maf for consumptive use from the main river to the states of Arizona, California and Nevada; and the allocation to Mexico by the Mexican Water Treaty of 1944. The U.S. Supreme Court in *Arizona vs. California, et al.*, 373 U.S. 546, agreed with the Special Master that the Secretary's (of Interior) contracts with Arizona for 2.8 maf and with Nevada for 0.30 maf of water, together with the limitation of California to 4.4 maf effect a valid apportionment of the first 7.5 maf of main stem water in the Lower Basin. All those contracts provide for the stipulated deliveries of water subject to the availability thereof. The Court recognized that shortages might occur. Where the words "apportionment" or "apportion" appear hereinafter relating to the beneficial consumptive-use values of the states of Arizona, California and Nevada, the word or words mean what the Supreme Court decision said as cited above. The use of the words does not imply an absolute amount of water but rather a limitation of use subject at all times to the availability of water.

With the active storage capacity available to the Upper Basin, including reservoirs of the Upper Colorado River Storage Project now operating or under construction, beneficial consumptive use (depletion at Lee Ferry) in the Upper Colorado River Basin, including reservoir evaporation, is limited to 6.3 million af (maf) per annum, because of the required delivery in successive 10-year periods of 75 maf in accordance with the terms of the Compact. The net depletion, excluding reservoir evaporation, would be 5.6 maf.

If deliveries at Lee Ferry were greater than 7.5 maf per year (75 maf in successive 10-year periods) to insure more power generation and financial support for the Upper Basin development, the net depletion at Lee Ferry by Upper Basin development would be less than the amounts indicated above. These depletions are

less than the 7.5 maf apportioned to the Upper Basin which, in turn, are less than the ultimate total requirements of the Upper Basin.

The relation between Upper Basin depletion and the reservoir storage capacity required to insure its availability is shown in Figures 1 and 2, the first of which is based on deliveries at Lee Ferry of 7.5 maf per year, and the second on an arbitrarily assumed delivery at Lee Ferry of 8.25 maf per year.

The principal studies described herein are based on study periods 1914 through 1964 and 1921 through 1964. The period 1930 to date has been used by the Department of Interior and by the Colorado River Board of California to determine the amount of water available for use from the lower river by Arizona, California and Nevada. No appreciable difference exists in the basic data used for the various studies, such as the principal one of virgin flow at Lee Ferry for various years. Some difference does exist, however, in respect to the net losses of water between Hoover Dam and Mexico, which is discussed subsequently.

All studies disclose without exception that any increase in the use on the lower river must now be made from water apportioned to the Upper Basin, but now unused by it. Actually, at present the aggregate demand on Lake Mead is close to 9 maf per year. It is apparent that even present uses on the lower river are dependent upon significant amounts of water released from Lake Powell in excess of those required by the Colorado River Compact.

As the Upper Basin develops there will arrive a time when its water will no longer be available for further uses on the lower river. The question is when will that time arrive. To forecast this, studies have been made using various assumed rates of depletion in the Upper Basin and various assumed rates of releases from Lake Powell. All of the studies indicate that substantial shortages, amounting to more than 1.0 maf per year before the end of the present century, will exist in the supplies required to meet total uses of 7.5 maf by Arizona, California and Nevada and to meet a delivery of 1.5 maf of water per year to Mexico. The period

would be extended somewhat if Lake Mead were depleted to absolute dead storage, during long periods of drawdown.

A period of low water supply in the Colorado River Basin, such as existed from 1930 to 1964, will occur again at some time, or one which might be more severe could occur. Under such conditions, minimum releases from Lake Powell would be necessary. Simple arithmetic indicates that there will not be enough water on the lower river to sustain a delivery of 7.5 maf for the states of Arizona, California and Nevada, and to take care of the Mexican burden, as shown by the following analysis:

**Lower River Requirements:**

1. Beneficial consumptive use by Arizona, California and Nevada	7.500 maf	
2. Mexican Treaty Deliveries	1.500	
3. Reservoir Evaporation	0.730	
4. Losses below Hoover Dam	0.810	
	<hr/>	
<b>Total Requirements</b>		10.540 maf

**Water Supply for the Lower River:**

1. Delivery at Lee Ferry	8.250 maf	
2. Net Inflow Lee Ferry to Lake Mead	0.675	
3. Net Inflow from Bill Williams River	0.055	
4. Release from Lake Mead (drawdown to rated power head)	0.365	
	<hr/>	
<b>Total Water Supply</b>		9.345
<b>Deficiency</b>		1.195 maf

Although an arbitrary initial delivery of 8.25 maf has been assumed in some of the studies, the amount delivered by the Upper Basin eventually will approximate 7.5 maf per year. When the delivery from the Upper Basin is 7.5 maf instead of 8.25 maf, then the deficiency will be 1.945 maf per year. If the provisions of Section (b) of Article IV of the Colorado River Compact are invoked, Lake Mead could be drawn down to absolute dead storage which would provide about 0.60 maf additional water per year which includes the decrease in evaporation from Lake Mead. In this case the above deficiencies would be reduced by about 0.60 maf.

The obvious conclusion is that a firm water supply is not available in the Colorado River to satisfy a basic beneficial consumptive-use requirement of 7.5 maf from the main stem by

Arizona, California and Nevada, plus delivery of 1.5 maf of water to Mexico. If these requirements as well as Upper Basin requirements are to be satisfied, projects must be authorized and constructed to import major amounts of water into the Colorado River Basin from sources of surplus. Such importation is important to both the Upper and Lower Basins.

## Studies Made

### Study Period

A fundamental item in any study of the Colorado River, taking into consideration the Colorado River Compact, the Mexican Water Treaty, and the Supreme Court decision in the case of Arizona versus California, is the recorded flow of the Colorado River at Lee Ferry and the virgin flow estimated therefrom. Measurements of the Colorado River at Lee Ferry were not begun until the spring of 1921. They have been continuous since that time. However, during the negotiations of the Colorado River Compact of 1922, and later during the studies of the hydrology of the Boulder (Hoover) Canyon Project in the late 1920's, estimates of the flow at Lee Ferry were made, based upon measurements of the river at Yuma and Topock and supplemented by estimates made on the basis of recorded flow of major tributaries above Lee Ferry when such records became available. These estimates extended back to the year 1896.

For the purpose of this report, river and reservoir operation studies were made both for the period 1914 through 1964 and for 1921 through 1964. The beginning year of 1914 was used because at the time the Upper Colorado River Compact was under consideration the Engineering Advisory Committee of the Upper Colorado River Compact Commission, in making an exhaustive study of the estimates of the flow of the river, concluded that estimates of flow prior to 1914 should not be used. The period 1921 through 1964 has been used because the actual records of measured flow at Lee Ferry first became available in 1921. For some studies the period 1930 through 1964 was used. Two studies were made based on the period 1906 through 1964.

For the period beginning in 1896 the estimated virgin flow at Lee Ferry was less than the long-time average until 1903. The period following 1903 includes a generally increasing estimated flow at Lee Ferry up to 1930. From 1930 through 1964 the flow of the river has gradually declined, the 35-year period from 1930 through 1964 being the lowest period of record.

No matter what periods between 1896 through 1964 are used for particular studies, the period of low water supply beginning in 1930 and ending in 1964 cannot be avoided. It would be optimistic to assume a firm water supply any greater than that which existed during the period 1930 through 1964 plus whatever water might have been available from holdover storage at its beginning. This period represents 35 years of reservoir draw-down, which is an exceedingly long time.

The accuracy with which future water supplies and demands can be predicted depends in large measure on how closely the future flow of the river will correspond to that assumed for the purpose of the studies. It must be recognized that the magnitude and sequence of flows which will occur during the next 44-year period will not duplicate, and may not even approximate, the magnitude and sequence of flows which occurred during the past 44 years. There is evidence to indicate that river flows along with other phenomena associated with and dependent upon climatic and meteorological conditions go through periods of high occurrences followed by periods of low occurrences. However, the occurrences do not follow any regular or cyclic pattern and there is no known method for establishing or predicting the extent or magnitude of the limits of the succession of high and low occurrences. Examination of tree-ring records in the southwestern part of the United States dated back as far as the year 1250 illustrate the ups and downs in precipitation caused by nature, without giving any evidence whatsoever of regular or predictable cycles.

### **Increased Depletions in the Upper Colorado River Basin**

A variable having an effect on the outcome of the studies is the estimated rate at which consumptive use in the Upper Colorado River Basin will increase. Figure 3 illustrates the estimates made by the State of Arizona, recent estimates made by the U.S. Department of Interior (U.S.I.D.), those by the Colorado River Board of California, (C.R.B.), and those by the States of the Upper Colorado River Division. It may be noted that there is a wide range in the estimates of Upper Basin consumptive uses which might take place in the future. Arizona's low estimate and the

higher estimated of the States of the Upper Colorado River Division bracket the others shown.

Arizona's appraisal of the possibility of increased uses in the Upper Basin may be contrasted with the statement made by the U.S. Department of Interior in 1959 in a publication entitled "The Colorado River Storage Project and Participating Projects" which is quoted below:

*"The Upper Colorado River Basin may have been late in exploration, slow in settlement, and limited in development, but the Upper Basin boldly faces a new future which will see its many resources utilized on an ever-widening scale.*

*The future of the Upper Colorado River Basin lies in its resources. The most important resource is water—water which is corralled and put to work rather than allowed to plunge wildly toward the sea, wasting its energy in the rapids of the colorful canyons.*

*The Upper Colorado River Basin has the water—it has land to be irrigated—it has canyons with dam sites where much water can be stored and where hydroelectric power can be produced—it has petroleum, coal, and natural gas—it has oil shales and rare hydro-carbons—it has mineral resources of uranium and other atomic ores, of many strategic metals, of phosphate and other needed nonmetallic ores.*

*But, these many resources are largely dormant—sleeping giants yet to be awakened. The future will see the use of Upper Basin resources on an ever-widening scale under a development program which will bring together the resources of water, power, land and minerals . . .*

*The future begins to unfold for the Upper Colorado River Basin."*

The Arizona estimates have not been used in any of the present studies because they are considered to be unrealistically low; they do not account for all projects under construction or now authorized for construction.

The prime factor which will affect the lower river water supplies to meet 7.5 maf of consumptive uses from the main stem in the states of Arizona, California and Nevada, will be the amount of the deliveries at Lee Ferry from the Upper Basin.

### Colorado River Operation Studies

In addition to the studies made to determine the limits of depletions by the Upper Basin based on the provisions of the Colorado River Compact and available water supply, several river and reservoir operation studies were made involving the entire main stem of the Colorado River. The details of these studies are shown in the tables appearing in the Appendices to this report.

From the present to 1975, the year in which the first diversions for the Central Arizona Project are assumed, all studies were operated on a common basis. The starting content of the main river facilities is that which is estimated by the Bureau of Reclamation to occur on September 30, 1965. With study sequences commencing with either 1914 or 1921, no difficulty was experienced in filling all the reservoirs and all were spilling in 1975. For all practical purposes, the total filling of both upper and lower systems was simultaneous. A similar condition was obviously impossible under study sequences beginning with the water year 1930.

In 1975 a draft on the Upper Basin storage was sustained corresponding to alternative constant annual releases of 8.25 maf and 8.75 maf. Releases at Lee Ferry corresponding to the U.S. Interior Department estimates and to those of the Colorado River Board of California were also used for some of the studies.

Since generation of power and maintenance of rated head is important in both basin systems, the levels of rated head were used as cut-off points in several of the studies. However, a question could be raised as to whether the storage in Lake Mead could be held at rated power head and the consumptive-use requirements at that time be shorted. This would make domestic and agricul-

tural uses subservient to power. Article IV, Section (b) of the Colorado River Compact provides:

*"Subject to the provisions of this compact, water of the Colorado River System may be impounded and used for the generation of electrical power, but such impounding and use shall be subservient to the use and consumption of such water for agricultural and domestic purposes and shall not interfere with or prevent use for such dominant purposes."*

The foregoing provision if strictly enforced would prohibit the holding of water in storage for the generation of power if it were needed for consumptive-use purposes.

Recognizing this contingency other studies called on storage down to a content of 8.0 maf in Lake Mead (equivalent to the level of the Nevada intake) whereas still other studies withdrew all water stored in active capacity.

Alternative schedules of depletions were used in the various studies. Included were the depletions estimated by the States of the upper division, those of the Colorado River Board of California, and the recent estimates of the Bureau of Reclamation.

### **Future Uses in the Lower Basin**

It is not within the purview of this report to apportion shortages among the states of Arizona, California and Nevada. However, for the purpose of the studies certain assumptions were made of present and future uses by those states. It was assumed that the presently constructed projects in Arizona diverting from the Colorado River, including projects to irrigate Indian lands, will ultimately beneficially consume 1.23 maf. Inflow-outflow records indicate that at the present time the consumption by Arizona projects using Colorado River water is close to one million af per year. However, additional drainage will be required to prevent the water table from rising to the point where lands would become waterlogged on the Gila Mesa, Yuma Valley, and the North Gila and South Gila projects. Applications of water on the

mesa are causing the water table to rise beneath the Yuma Valley. It is estimated that substantial amounts of water per year should be withdrawn from the ground water in this area to prevent any further rise in the water table. Additional amounts must be withdrawn from the water table under the South Gila and North Gila projects to prevent further rise in the water table in those areas. It is assumed for the purpose of the present report that, as additional drainage works are installed, additional diversions will be made from the river so that the net beneficial consumptive use will remain at about one million af per year until 1975, and with full development, aside from the Central Arizona Project, will attain 1.23 maf in the year 2000.

It is estimated that the beneficial consumptive use of water by projects using Colorado River water in Arizona, aside from the Central Arizona Project, in 1990 will be about 1.16 maf. Should the Central Arizona Project be authorized at an early date, it is assumed that it would go into operation by 1975. The last report on the Central Arizona Project indicated that its operation would result in a beneficial consumptive use of 1.2 maf per year. This, added to the 1.23 maf for the other projects on the river, results in a total of 2.43 maf, leaving for Arizona a balance of 370,000 af per year to equal the basic 2.8 maf beneficial consumptive use from the main stem apportioned to Arizona. The present studies assume that this remaining 370,000 af of water would either be used on the Central Arizona Project or some place else in Arizona by the year 2000.

It was assumed that uses in Nevada would increase gradually from present uses of 25,000 af per year to 300,000 af per year in the year 2000.

If and when uses in Arizona and Nevada increase to the extent that shortages might occur, it is assumed that California's present beneficial consumptive use would be curtailed to 4.4 maf per year. The time when this curtailment would occur is not known. For the purpose of this study it was assumed that the uses by California would be curtailed to 4.4 maf per year prior to the time storage in Lake Mead would be insufficient to support all downstream main-stem demands without dropping below rated power head.

### Depletion Factor

A depletion factor was used to modify the assumed basic depletions by the States of the upper division of the Colorado River Basin. The philosophy of the depletion factor is based on the fact that during periods of low water supply in the Upper Basin all projects in operation will not receive a full water supply. Most of them will not have reservoirs, and some that have reservoirs will not have water in some years to fill those reservoirs. No rational means have been derived for varying the estimated uses by the States of the upper division because of varying water supply. The means used by the U.S. Bureau of Reclamation in its past studies, which it is assumed it is still using, are based on the assumption that the uses would vary from the normal use in a particular year by one-half of the percent that the virgin flow at Lee Ferry in that particular year varies from a long-time average of virgin flow. For the present studies the depletion factor using the U.S.B.R. formula was based on the mean virgin flow for the years 1921 through 1964, except for studies starting in 1906.

### River Losses Below Hoover Dam

The Department of Interior in previous studies assumed gross losses below Hoover Dam to be 1.27 maf per year (U.S.I.D. Report on the Southwest Water Plan dated January 1964). The U.S. Bureau of Reclamation has estimated future reductions in waste, salvage of water by channel improvement, salvage of water from phreatophytes and increased drainage return from the Yuma area in the amount of 680,000 af made up of the following items:

Reduction in waste of water by operation of Senator Wash Reservoir	170,000 af
Salvage of water by channel improvements	190,000 af
Salvage of water from phreatophytes	100,000 af
Increased drainage return from the Yuma area	220,000 af
<b>Total</b>	<u>680,000 af</u>

The U.S. Bureau of Reclamation then assumed the net loss of water below Hoover Dam, after the foregoing savings and salvages are effectuated, will be 590,000 af, (1,270,000 af minus

680,000 af). There is no good reason to question the above-mentioned amounts of water estimated to be saved by salvage, drainage, and operation of Senator Wash Reservoir. However, it is believed that the 220,000 af of additional drainage return from the Yuma area cannot be considered as an item in reducing the losses below Hoover Dam, which will reduce the draft on Lake Mead. The 220,000 af does not represent "new water" made available to the Basin, such as the water salvaged because of channel improvements and nonbeneficial consumption by phreatophytes. The 220,000 af is an increment of the original water supply that has been stored in Lake Mead and subsequently diverted by canals out of Lake Mead releases to supply Arizona projects. This amount of water will represent a credit to Arizona and will not in the end reduce the draft on Lake Mead. Therefore the value that is being used in the present studies for net losses below Hoover Dam is 590,000 af plus 220,000 af, or 810,000 af.

The actual amount of water which might be recovered by additional drainage of the Yuma Valley and Yuma Mesa areas is not known at the present time. It is believed, however, that the potential can be as great as 220,000 af. The actual amount recovered may depend somewhat on the outcome of the review of the U.S.I.D. definitive plan for the additional drainage works by the U.S. Commissioner of the International Boundary and Water Commission between the United States and Mexico. Because this item of return flow is not considered in this report as one which brings to the river "new water" thereby decreasing the demand on Lake Mead, whatever the ultimate amount might be will not affect the conclusions reached in this report.

In respect to the Bill Williams River, the U.S. Bureau of Reclamation assumes it will be depleted down to 55,000 af. This amount of inflow below Hoover Dam has been assumed for the purpose of this report.

The above may be compared with the studies made by the Colorado River Board of California which estimates the net losses after accounting for Bill Williams River under present conditions to be 1.2 maf. It estimates a future salvage of 200,-

000 af, leaving a net loss of 1.0 maf. This spread in difference in estimates of future losses below Hoover Dam is given for information. No one can precisely estimate what such losses will be in the future. They depend on the amount of wastes that can be reduced, and the amount of salvage that can be effectuated by the program that is being carried out by the Department of Interior. For this report, as stated above, 810,000 af has been adopted to represent losses below Hoover Dam after the salvage program has been completed.

### **Storage in the Basin Reservoir**

For the present studies the initial usable content of the Upper Basin reservoirs was assumed to be 3.099 maf and of Lake Mead 16.453 maf, which is the anticipated usable content as of September 30, 1965, including bank storage. Maximum usable capacity of Upper Basin reservoirs was assumed to be 29.0 maf, and 29.25 maf for Lake Mead including bank storage. In addition, 1.2 maf was reserved in Lake Mead for flood control.

The net gain between Lee Ferry and Hoover Dam was phased to correspond to recent estimates by the U.S. Bureau of Reclamation.

For Study No. 3 the Upper Basin depletions, deliveries at Lee Ferry, net gain between Lee Ferry and Hoover and losses from Hoover to Mexico corresponded to those of the Colorado River Board of California.

Studies No. 5 and 23 thru 34 differed from the other studies in that the total maximum Upper Basin reservoir content was assumed to be 32.0 maf and the depletion factor was unity. This assumed all existing reservoirs in the Upper Basin and the reservoirs of the Upper Colorado River Storage Project would operate more or less as a unit to make available water to the Upper Basin consumptive-use projects, and to enable the States of the upper division to make the required deliveries at Lee Ferry.

## Results of the Studies

### *Upper Basin*

To determine the amount of maximum depletion (beneficial consumptive use) under the terms of the Colorado River Compact that can be made by the States of the upper division of the Colorado River Basin, river and reservoir operation studies were made for the period 1903 through 1964 and for the period 1921 through 1964 to determine the relationship between required storage capacity and depletion. In the studies various amounts of depletion were assumed ranging from 3.0 maf per year to 6.79 maf per year. The results of the studies for the two study periods were identical.

Two sets of studies were made, one assuming an annual delivery at Lee Ferry of 8.25 maf and the other assuming an annual delivery at Lee Ferry of 7.50 maf. The following table indicates the results of these studies. The results are depicted graphically on the two curves shown in Figures 1 and 2. The detailed operation studies are given in Appendix C.

Even with an annual delivery at Lee Ferry of only 7.50 maf, to attain the total beneficial consumptive use (7.5 maf) allocated to the Upper Basin by the Colorado River Compact would require over 72.0 maf of active storage. This storage potential does not exist. It should be noted also that if it did exist, about 1.4 maf of depletion would be because of evaporation from the storage reservoirs, leaving a net of 6.0 maf for beneficial consumptive use by projects within the basin.

### STORAGE CAPACITY AND UPPER BASIN DEPLETIONS

Regulated Firm Flow	Required Storage	Estimated Evaporation	Available Upper Basin Depletions for Annual Deliveries at Lee Ferry of			
			8250		7500	
			Total	Net	Total	Net
11,250	6,766	250	3,000	2,750	3,750	3,500
12,250	10,766	350	4,000	3,650	4,750	4,400
13,250	20,388	550	5,000	4,450	5,750	5,200
13,951(a)	35,370	820	5,701	4,881	6,451	5,631
14,250	45,536	980	6,000	5,020	6,750	5,770
15,040(b)	72,551	1,380	6,790	5,410	7,540	6,160

(a) Mean Virgin Flow 1921-1964

(b) Mean Virgin Flow 1903-1964

All values in 1,000 acre-feet

In 18 of the 34 studies, details of which are continued in Appendix B, assumed future depletions (beneficial consumptive uses) were those estimated by the four States of the upper division. These studies all show an impossible situation; before the end of the study period in each case, beneficial consumptive uses would begin to be encroached upon and in some cases all such uses would be essentially extinguished to satisfy the Colorado River Compact provision that depletions at Lee Ferry shall not exceed 75 maf in successive 10-year periods. The studies were made and their results presented, by design, to show the danger of overdevelopment with present water supplies, and to demonstrate dramatically the results of those studies which are shown on figures 1 and 2, Upper Basin Depletion vs. Required Reservoir Capacity.

If credit for deliveries above 7.5 maf per year at Lee Ferry were taken, in no case would more than one year be gained before encroachment on beneficial consumptive uses would commence.

#### *Lower Basin*

It has been pointed out that the most important factor affecting the water supplies of the main stem of the Colorado River in the Lower Basin is the amount of water passing Lee Ferry from the Upper Basin. A certain amount, in addition to the Compact obligation of 75 maf in successive 10-year periods, will be required to be delivered out of Lake Powell for a period of time to generate sufficient energy, the sale of which will be relied upon to aid in the financing of additional projects in the States of the upper division of the Colorado River Basin. One series of studies contemplated a delivery of 8.25 maf per annum at Lee Ferry. It is understood that the Secretary of Interior and some engineers of the U.S. Bureau of Reclamation consider the release of such an amount of water through the power plants at Glen Canyon Dam to be sufficient to provide funds for substantial additional development in the Upper Basin. Another series of studies was made assuming a release of 8.75 maf per annum from Lake Powell. It

is assumed such a release would be more than adequate to provide funds through the sale of electric energy to aid in the financing of additional projects in the Upper Colorado River Basin.

In one group of studies the depletion schedule of future Upper Basin development as assumed by the U.S. Department of Interior (U.S.I.D.) was used; in another set the depletion schedule as estimated by the States of the upper division of the Colorado River Basin was used. In each set of studies three conditions of drawdown of Lake Mead were assumed; the first was a drawdown which would result in 16.453 maf remaining in storage as representing the rated power head. The second assumed a drawdown which would leave in storage 8.0 maf which is the minimum content at which the present intake for the City of Las Vegas, Nevada, could be supplied. The third condition of drawdown assumed Lake Mead would be depleted to absolute dead storage.

Two study periods were assumed for the above series of studies; first, the study period 1914 through 1964, and second, the study period 1921 through 1964. For the study period 1914 through 1964, 32.0 maf of storage capacity was assumed in the Upper Basin and a depletion factor of unity was assumed.

Tables No. 1 and 2 attached hereto indicate the results of the two sets of studies described above.

## Conclusions

### Upper Basin

If it is assumed that the operating capacity of the Upper Colorado River Storage Project is 29.0 maf, and if the delivery at Lee Ferry amounted to 7.5 maf per year, the depletions (beneficial consumptive use) in the States of the upper division of the Colorado River Basin would be limited to 6.3 maf per annum. The net depletion, excluding evaporation from the reservoirs of the Upper Colorado River Storage Project, would be 5.6 maf. If deliveries at Lee Ferry were 8.25 maf per year, the limit of depletions in the States of the upper division would be 5.6 maf including reservoir evaporation, and a net of 4.7 maf excluding reservoir evaporation.

With a storage capacity of 32.0 maf, as assumed by some, the limitation on the net depletion (beneficial consumptive use) in the States of the upper division, excluding evaporation from the reservoirs of the Upper Colorado River Storage Project, with a delivery at Lee Ferry of 7.5 maf per year would be about 5.6 maf per year, and would be 4.8 maf per year if the delivery at Lee Ferry were 8.25 maf per year.

Without importation of water, and such modifications in the required delivery of water at Lee Ferry as would be necessary for the Upper Basin to benefit from the importation of water, it is assumed that the total net beneficial consumptive use in the States of the upper division cannot be more than 5.6 maf per year, and might not be more than 4.8 maf per year.

The addition of more reservoir capacity than will be provided by the existing and authorized units of the Upper Colorado River Storage Project would not materially increase these depletions. The obvious means for enabling the States of the upper division to make a beneficial consumptive use of 7.5 maf per year allocated to them by the Colorado River Compact (less 50,000 af allocated to Arizona by the Upper Colorado River Compact), or even greater amounts, is the importation of water from areas of surplus.

### Lower Basin

What the actual future depletion will be in the States of the upper division of the Colorado River Basin is not known. The present studies were based on two future depletion schedules, one as estimated by the U.S. Department of Interior (U.S.I.D.), and the other as estimated by the States of the upper division of the Colorado River Basin. The studies indicate plainly that the latter schedule of depletions cannot be attained with the available water supply. It is believed, therefore, that the true schedule of future depletions will lie somewhere between these two estimates. Releases from Lake Powell for the purpose of generating energy probably will be somewhere between 8.25 maf per year and 8.75 maf per year. These are in excess of that required by the Compact.

It is concluded from the results of the studies summarized in Tables No. 1 and 2 that shortages of water in the main stem of the Colorado River to supply 2.8 maf for beneficial consumptive use in Arizona, and up to 4.4 maf for beneficial consumptive use in California, and 0.3 maf of beneficial consumptive use in Nevada plus 1.5 maf to Mexico will amount to well over one million af by the year 2000. The shortage could materially exceed 1.5 maf by that year. It is concluded that shortages could commence by the year 1991 and in no case would they start later than 1995 under the conditions shown in Tables No. 1 and 2.

The same general conclusions as to the shortage by the year 2000 are indicated from the results of the studies covering the period 1906 through 1965 (estimated). See Studies Numbers 21 and 22 in Appendix B.

The only exception to the above would be if Lake Mead were completely drained to absolute dead storage. Under this condition substantial shortages for the Lower Basin beneficial uses would occur sometime after the year 2000, after which they would be as severe as those indicated in Tables No. 1 and 2, and Studies 21 and 22 of Appendix B.

The beneficial consumptive use of main stem Colorado River water as made at the present time by California is something over 5.0 maf. In the studies it was assumed that California would continue this level of use until it became fairly imminent that the contents of Lake Mead, because of releases for consumptive-use purposes, would approach rated power head. It was assumed that at this point the uses by California would be cut back to 4.4 maf. Some have taken the position that this cutback should be made at the time the Central Arizona Project would go into operation, which is estimated to be about the year 1975 if the project is authorized at an early date and is expeditiously constructed. It is not considered that this position is a sound one.

Under each of the studies from which these conclusions have been derived, deliveries at Lee Ferry of amounts greater than the 75 maf in successive 10-year periods as required by the Compact, have been made. The excess amount of water is more than sufficient under the assumptions made for the studies to supply the amount which California now is using in excess of 4.4 maf. Even if California were cut back to 4.4 maf in 1975, the studies indicate the shortage in the Lower Basin would be substantially greater than one million acre-feet in the year 2000, if the rated power head at Lake Mead is to be maintained.

While the Colorado River Compact by its terms makes the generation of power subservient to the consumptive use of Colorado River water for agricultural and domestic purposes, there arises the question as to whether it would be possible and practicable to deplete storage in Lake Mead to the point that no power could be generated. Power contracts with the Secretary of Interior exist, and many industries and municipalities now are dependent upon the power generated at Hoover Dam. This poses a question that probably cannot be answered at this time.

However, it would appear that it might be unwise at this

time to authorize a new project for use of substantial amounts of water from the main stem of the Colorado River in the Lower Basin when a study of stream-flow records discloses that the requirements for such a project might cause the depletion of Lake Mead below the level where it could generate power. Even then, there would be no assurance that water would be available to the project if storage in Lake Mead were entirely depleted to absolute dead storage. At that time the only water available would be the amount released at Lee Ferry plus accretions to the river between Lee Ferry and Hoover Dam. This would fall far short of enough water to sustain present uses and the new development. Otherwise the assumption would have to be made that after Lake Mead had been depleted to absolute dead storage it would rapidly fill by a succession of years of good runoff. It is considered that such an assumption is not warranted.

Finally, it would be fair to conclude that the authorization of projects in the Lower Colorado River Basin which would utilize substantial additional quantities of water would be unwise at this time unless at the same time a project, or projects, for the importation of substantial amounts of water from sources of surplus are authorized.

Table 1  
 SHORTAGES TO CALIFORNIA, ARIZONA AND NEVADA  
 BASED ON STUDY PERIOD 1914-1964, DEPLETION  
 FACTOR = 1.0 AND MAXIMUM UPPER BASIN  
 RESERVOIR CONTENT = 32.0 maf

Study Year	U.S.D.I. Depletion Schedule						States of the Upper Division Depletion Schedule					
	Minimum Lake Mead Content, maf:	Lee Ferry Delivery = 8:25 maf			Lee Ferry Delivery = 8.75 maf			Lee Ferry Delivery = 8:25 maf			Lee Ferry Delivery = 8.75 maf	
	16.453	8.0	0	16.453	8.0	0	16.453	8.0	0	16.453	8.0	0
1966												
1967												
1968												
1969												
1970												
1971												
1972												
1973												
1974												
1975												
1976												
1977												
1978												
1979												
1980												
1981												
1982												
1983												
1984												
1985												
1986												
1987												
1988												
1989	1057						1051					
1990	1412						1412					
1991	1429			413			1429			391		
1992	1446			946			2196			2196		
1993	1464			964			2214			2214		
1994	1481			981			1481	666		2231		
1995	1498	523		998			1498	1272		998		
1996	1515	1289		1015			1515	1289		1015		
1997	1532	1307		1032			1532	1307		2282	1960	
1998	1549	1324		1049			2299	2074		2299	2074	
1999	1566	1341		1066			2316	2091	81	2316	2091	
2000	1583	1358		1083	22		2333	2108	1729	2333	2108	
2001	603	378		1084	859		2334	2109	1731	2334	2109	1550
2002	1585	1360	9	1085	860		1585	1360	1047	2335	2110	1732
2003	1586	1361	1035	1086	861		2336	2111	1733	2336	2111	1733
2004	0	0	0	1087	862		2337	2112	1734	2337	2112	1734
2005	0	0	0	1088	863		2338	2113	1735	2338	2113	1735
2006	795	137	0	1089	864		2339	2114	1597	2339	2114	1315
2007	1590	1365	566	1090	865		2340	2115	1231	2340	2115	1231
2008	1591	1366	1040	2341	2116		2341	2116	1368	2341	2116	1368
2009	1592	1367	1041	2342	2117	1198	2342	2117	1738	2342	2117	1738
2010	1503	1368	1042	1093	868	583	2343	2118	1739	2343	2118	1739
2011	1594	1369	1043	1094	869	584	2344	2119	1740	2344	2119	1740
2012	1595	1370	1044	1095	870	585	2345	2120	1426	2345	2120	1426
2013	1596	1371	1045	2346	2121	1721	2346	2121	1174	2346	2121	1174
2014	1597	1372	1046	2347	2122	1722	2347	2122	1743	2347	2122	1743
2015	1598	1373	1047	2348	2123	1723	2348	2123	1355	2348	2123	1355
2016	2349	2124	1724	2349	2124	1724	2349	2124	1310	2349	2124	1310

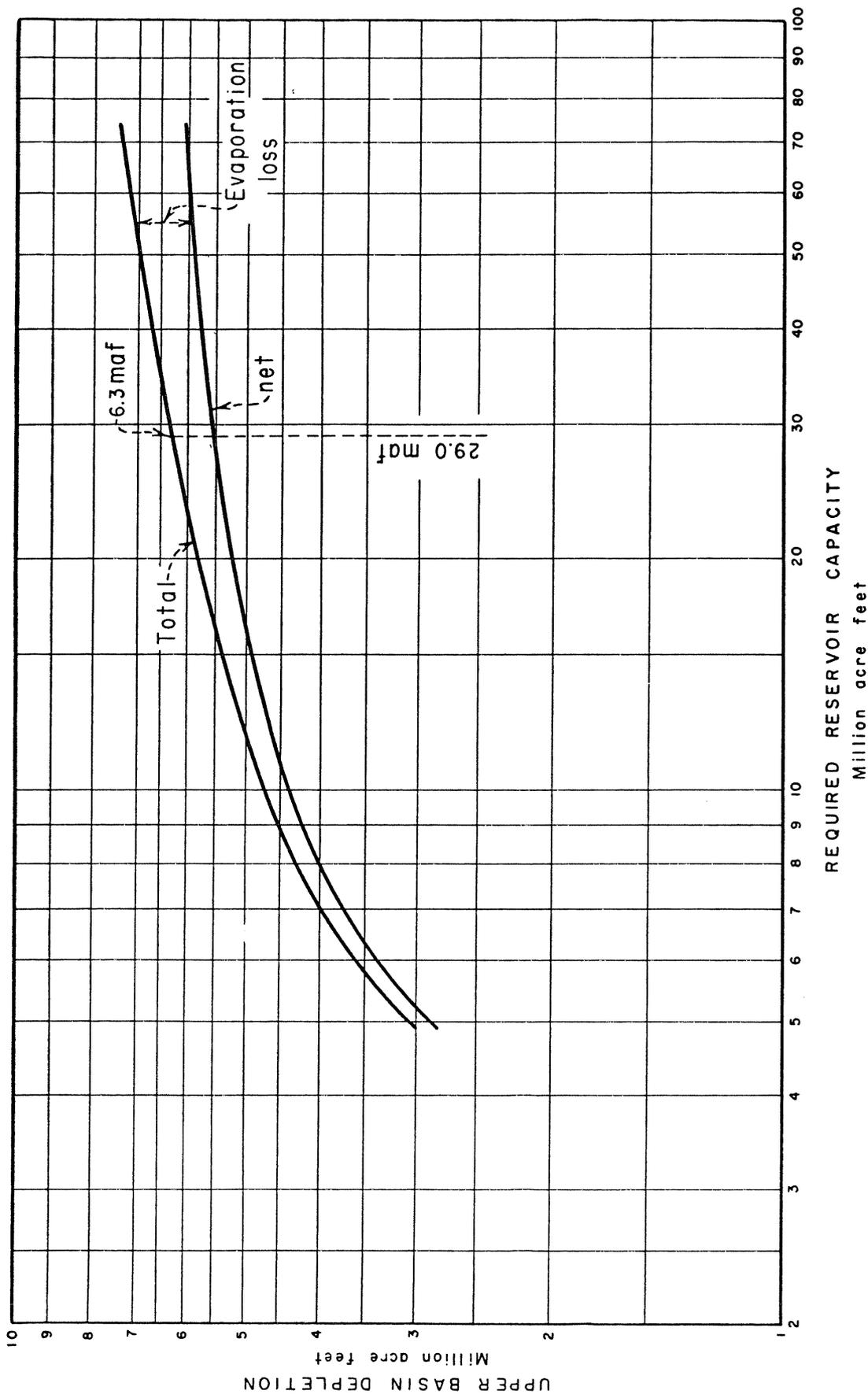
Shortages in 1,000 acre-feet.

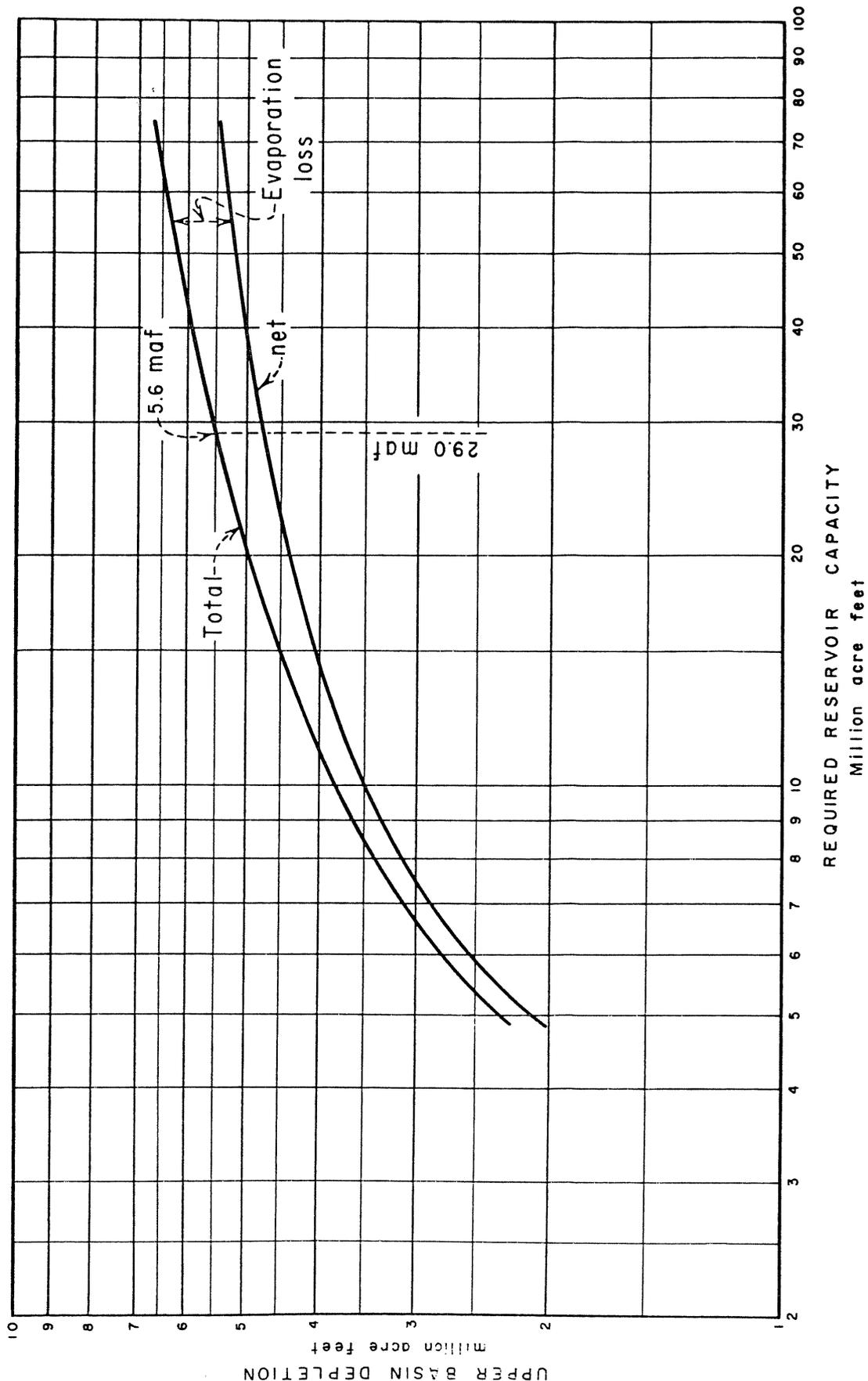
Table 2  
SHORTAGES TO CALIFORNIA, ARIZONA AND NEVADA  
BASED ON 1921-1964 PERIOD

Study Year	U.S.D.I. Depletion Schedule						States of the Upper Division Depletion Schedule						
	Minimum Lake Mead	Lee Ferry Delivery = 8.25 maf			Lee Ferry Delivery = 8.75 maf			Lee Ferry Delivery = 8.25 maf			Lee Ferry Delivery = 8.75 maf		
	Content, maf:	16.453	8.0	0	16.453	8.0	0	16.453	8.0	0	16.453	8.0	0
1966													
1967													
1968													
1969													
1970													
1971													
1972													
1973													
1974													
1975													
1976													
1977													
1978													
1979													
1980													
1981													
1982													
1983		452							58				
1984		1159							1159				
1985		1205							1205				
1986		1247			12				1247			12	
1987		0			788				1288			788	
1988		0			829				1329			829	
1989		0			871				1371			871	
1990		806			912				1412			912	
1991		1429			929			1429	1057		929		
1992		1446			946			1446	1221		946		
1993		143			964			1464	1238		964		
1994		0			981			1481	1255		981		
1995		564			998			1498	1272		2248	143	
1996		1515			1015			1515	1289		2265	2039	
1997		0			0			1532	1307		2282	2057	
1998		0			437			1549	1324	919	2299	2074	
1999		813	58		1066	571		1566	1341	1018	2316	2091	
2000		1583	1358		1083	858		2333	2108	1715	2333	2108	1595
2001		1584	1359		1084	859		2334	2109	1722	2334	2109	1414
2002		1585	1360		1085	860		2335	2110	1732	2335	2110	1732
2003		1586	1361		1086	861		2336	2111	1733	2336	2111	1733
2004		1587	1362		1087	862		2337	2112	1720	2337	2112	1720
2005		1588	1363		1088	863		2338	2113	1714	2338	2113	1582
2006		1589	1364	632	1089	864		2339	2114	1235	2339	2114	1235
2007		1590	1365	1043	1090	865		2340	2115	1736	2340	2115	1736
2008		1591	1366	1031	2341	2116	389	2341	2116	1433	2341	2116	1433
2009		1592	1367	1035	2342	2117	1707	2342	2117	1357	2342	2117	1357

Shortages in 1,000 acre-feet.

COLORADO RIVER 1921-1964  
UPPER BASIN DEPLETION  
VS. REQUIRED RESERVOIR CAPACITY  
7.500 maf DELIVERY AT LEE FERRY





COLORADO RIVER 1921-1964  
UPPER BASIN DEPLETION  
VS. REQUIRED RESERVOIR CAPACITY  
8.250 maf DELIVERY AT LEE FERRY

ESTIMATES OF  
UPPER BASIN DEPLETIONS

