REPORT

ON

DEPLETION OF SURFACE WATER SUPPLIES

OF

COLORADO WEST OF CONTINENTAL DIVIDE

BY

LEEDS, HILL AND JEWETT
CONSULTING ENGINEERS

PREPARED UNDER AUTHORITY OF H. B. 457
THIRTY-NINTH COLORADO GENERAL ASSEMBLY,
1ST REGULAR SESSION

BULLETIN NO. 1, SURFACE WATER SERIES

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DEPLETION OF WATER SUPPLIES
ALLOCATED TO
STATE OF COLORADO
BY
COLORADO RIVER COMPACTS

October 31, 1953

LEEDS, HILL and JEWETT
Consulting Engineers
Los Angeles, California

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LEEDS, HILL AND JEWETT
CONSULTING ENGINEERS
SUITE 1000 EDISON BUILDING
601 WEST FIFTH STREET
LOS ANGELES 17, CALIFORNIA

October 31, 1953.

Colorado Water Conservation Board,
212 State Office Building,
Denver 2, Colorado.

Gentlemen:

You directed us by contract dated May 18, 1953, pursuant to H.D. 457, 1st Session, 39th General Assembly of the State of Colorado, to make a study of the water resources available from surface supplies in that part of Colorado which lies west of the Continental Divide, and a study of the present and potential uses thereof to the full extent necessary to a unified and harmonious development of those waters for beneficial use in Colorado to the fullest extent possible under the law, including the law created by compacts affecting the use of said water. The studies so to be made were to include analyses of the extent to which water may be transferred from one watershed to another within the state without injury to the potential economic development of the natural watershed from which water might be diverted for the development of another watershed.

We wish to express our appreciation of the cooperation extended by the Director and his staff and by the Engineering Research Committee which has been advising the Colorado Conference Committee. We particularly wish to thank the Bureau of Reclamation for making data available in advance of completion of a number of its reports.

We had anticipated accepting the value of 3,855,375 acre feet per year as the amount by which Colorado could deplete the flow of Colorado River at Lee Ferry under the provisions of the law created by compacts, but we found it necessary to review previous studies with consideration to more recent records of stream flow.

We conclude, from analysis of all available data and from our own independent studies, that:

1. All of the 7,500,000 acre feet of water per annum apportioned to the Upper Basin by the Colorado River Compact may not actually be available for use because of the requirement that 75,000,000 acre feet be delivered at Lee Ferry during each consecutive ten-year period.

2. Compliance with this provision and limiting the carry-over in cyclic storage to the 22 years from 1930 to 1952 would have required that reservoirs of 21,000,000 acre feet capacity had been available in 1927 for cyclic regulation and that the aggregate depletion in the Upper Basin be no more than 6,200,000 acre feet per year.

3. The total of all depletions at sites of use in Colorado of the flow of Colorado River and its tributaries may thus be limited to 3,100,000 acre feet per year.

4. Depletions in Colorado under present conditions aggregate practically 1,450,000 acre feet per year.

5. Commitments for extension of existing projects and for other projects authorized would increase present depletions almost 200,000 acre feet per year.

6. The present uncommitted surplus which can be relied upon for use in Colorado is thus 1,450,000 acre feet per year.

7. Development of the oil shale reserves in western Colorado should be anticipated and the consumption of water for industrial, municipal, and other purposes resulting therefrom may reach 300,000 acre feet per year.

8. Consumptive uses by expansion of irrigation on the Western Slope will depend upon the degree to which new projects are subsidized. Should the subsidy be limited to $200 per acre, the resulting depletion would be no more than 100,000 acre feet per year. Should subsidies of $400 per acre be given, the stream depletion would be a little more than 400,000 acre feet per year. Should subsidies as great as $600 per acre be permitted, the resulting stream depletion at sites of use might reach 800,000 acre feet per year.

9. Depletions by new trans-mountain diversions will likewise depend upon the degree to which irrigation agriculture may be subsidized. Some diversions could be financed by municipalities without subsidies, but these would be limited to about 200,000 acre feet. Additional trans-mountain diversions for agricultural purposes

in any substantial amount would require subsidies in excess of $400 per acre. Even if subsidies as great as $600 per acre were permitted, the total of all new trans-mountain diversions for all purposes would not be more than 300,000 acre feet per year.

10. If subsidies to agriculture at any point in Colorado be limited to $600 per acre, future depletions caused by expanded irrigation on the Western Slope and by trans-mountain diversions would amount to 1,100,000 acre feet per year.

11. If any greater subsidies were to be allowed, the potential depletion caused by consumptive uses in agriculture and industry and by trans-mountain diversions would be in excess of the supply of water available to Colorado.

12. Increased diversions of water for use by agriculture and industry on the Western Slope and for trans-mountain diversions will depend upon the provision of sufficient storage capacity in reservoirs for conservation of flood flows and some cyclic regulation; in order that Colorado may make full use of the water allocated to it by the Compacts, cyclic regulation of Colorado River over periods longer than twenty years will also be necessary.

In submitting this report to you we hope that it will serve as a basis for reconciliation of conflicts among the citizens of Colorado.

Respectfully yours,

LEEDS, HILL and JEWETT

By

RAYMOND A. HILL

RAH/am

DEPLETION OF WATER SUPPLIES ALLOCATED TO STATE OF COLORADO BY COLORADO RIVER COMPACTS

Expansion of agriculture, development of industry, and growth of the cities of Colorado depend upon the most effective use of the available supplies of water. Substantially complete use has already been made of those portions of the total flow of Platte River, Arkansas River, and Rio Grande to which Colorado is entitled. The contrary is true, however, in the case of Colorado River and its tributaries. Hence, the basic question: Is the amount of water available to Colorado from this last source more than will be needed to satisfy all reasonable beneficial uses within the drainage basin of Colorado River?

It should be obvious to everyone familiar with physical conditions that all of the water to which Colorado is entitled under the provisions of the Colorado River Compact and the Upper Colorado River Basin Compact could be consumed in the irrigation of lands on the Western Slope if no limit were to be placed on costs of construction and operation of irrigation works. It is equally true, although less apparent, that all of the present surplus of Colorado River water

could be consumed in industrial processes if again there were no economic limitations.

It follows, therefore, that existing conflicts between interests in different parts of Colorado and potential conflicts between agricultural and industrial users of water on the Western Slope cannot be reconciled unless reasonable limits are placed upon the cost of providing water to satisfy each potential demand upon the available supply from Colorado River and its tributaries.

WATER SUPPLY

The surplus now available for agricultural, industrial and other purposes is materially less than might be presumed from observation of the flow of the rivers on the Western Slope during the period of snow melt each year. Under the provisions of the Colorado River Compact some of these flood waters must be passed down for use in the Lower Basin, and by the Compact of 1948 Colorado agreed to limit its use of water to a little more than one-half of the total allocated to the Upper Basin.

The annual discharge of Colorado River and each of its tributaries varies through wide limits and there has been a tendency for wet years to occur in groups, followed by extended periods in which the runoff is generally less than the long-time average. For example, the quantity of water passing Lee Ferry in northern Arizona, the point of delivery to the Lower Basin, averaged 15.9

million acre feet per year for the 17 years from October 1, 1913 to September 30, 1930, as compared to only 11.7 million acre feet per year for the next 23 years; also, the historical runoff at Lee Ferry ranged from a maximum of 18.0 million acre feet to a minimum of 4.4 million acre feet within this last period in which the average was 11.7 million acre feet per year.

It is therefore evident that large reservoirs must be provided for cyclic storage as well as seasonal regulation in order that full use may be made of those waters of Colorado River to which Colorado is entitled.

ORIGIN OF SUPPLY

While very long periods of carry-over will be necessary in some reservoirs for other purposes, it is unlikely that more than ten years of carry-over would be justified to satisfy future demands for water in Colorado. The ten-year period ending September 30, 1950 was reasonably typical and more records of runoff were available for these years than for any earlier period; hence, it has been used as a basis for comparison.

The quantity of water originating in the Colorado River Basin within Colorado and which passed out of Colorado during these ten years averaged 9,347,000 acre feet per year. The total drainage area includes 38,932 square miles in Colorado, so that the average runoff was 240 acre feet per year per square mile. A little more than

19 per cent of this total was contributed by Yampa River, White River, and certain smaller tributaries of Green River; the contribution from the main stem of Colorado River was 31.7 per cent; Gunnison River added 21.4 per cent and Dolores River only 7.5 per cent; and San Juan River contributed the balance of 20.1 per cent.

Yampa River and small streams directly tributary to Green River drain the northwesterly portion of Colorado. The combined drainage area includes 6,820 square miles in Colorado and 2,000 square miles in Wyoming. The average discharge of Yampa River during the ten-year period ending September 30, 1950 was about 1,500,000 acre feet, of which about 1,290,000 acre feet originated in Colorado. The latter quantity is equivalent to 189 acre feet per square mile.

White River drains an area in Colorado just south of Yampa River, containing 3,863 square miles, but its headwaters do not extend back to the Continental Divide. The average runoff at the westerly boundary of the State for the same ten-year period was about 510,000 acre feet per year, equivalent to 132 acre feet per square mile.

Next in order from north to south is the drainage basin of the main stem of Colorado River. The total drainage area, excluding the Gunnison River Basin, is 10,180 square miles, of which 8,055 square miles are above the point of diversion to lands in the vicinity of Grand Junction. The average runoff at the State Line for the ten-year period ending September 30, 1950 was about 2,960,000 acre feet per

year (exclusive of the contribution from Gunnison River), equivalent to 291 acre feet per square mile.

Gunnison River actually enters Colorado River at Grand Junction but may properly be treated separately because little use is now, or is expected to be, made in Colorado of water diverted below the confluence of these rivers. Gunnison River drains 8,020 square miles and has its origin along the Continental Divide opposite the headwaters of Arkansas River. The average runoff for the ten years ending September 30, 1950 was 2,007,000 acre feet, equivalent to 250 acre feet per square mile.

Dolores River drains that portion of Colorado lying west of the Gunnison River Basin, and north of the San Juan River Basin. The drainage area of Dolores River includes 4,160 square miles in Colorado. The runoff originating in Colorado during the ten-year period ending September 30, 1950 averaged about 700,000 acre feet per year, equivalent to 168 acre feet per square mile.

The extreme southerly portion of Colorado lying west of the Continental Divide is drained by San Juan River and its tributaries, most of which join San Juan River in New Mexico. The combined drainage area in Colorado amounts to 5,889 square miles. The average annual flow across the boundary of Colorado during the ten-year period ending September 30, 1950 was about 1,880,000 acre feet, equivalent to 319 acre feet per square mile.

Most of such variations in runoff per square mile of drainage

area are due to differences in the elevation of the watersheds. Precipitation on the high mountains is much greater than in areas of lower elevation and consumptive uses at high altitudes are less, due to prevailing low temperatures and shorter growing seasons. Hence, a large part of the total contribution of each stream originates near its headwaters. For example, the average runoff per square mile from drainage areas above 9,000 feet in elevation, for the same ten-year period, was found to be 1,000 acre feet per year on the Roaring Fork, 600 acre feet per year in the Colorado River Basin east of Gore Range, and 440 acre feet per year in the upper portion of Gunnison River Basin.

LIMITATIONS ON USE

Colorado has entered into two interstate compacts limiting its use of Colorado River water: the Colorado River Compact signed in 1922; the Upper Colorado River Basin Compact signed in 1948. The former allocated the waters of the stream system between the Upper Basin and the Lower Basin; the latter allocated the Upper Basin share among the States in that Basin.

Colorado River Compact

During the 30 years which have elapsed since the Colorado River Compact became effective, many disputes have arisen regarding the intent and applicability of various provisions. However, for purposes of this report we need be concerned only with two sections

of Article III in which the waters of the Colorado River system are allocated:

> "(a) There is hereby apportioned from the Colorado River system in perpetuity to the Upper Basin and to the Lower Basin, respectively, the exclusive beneficial consumptive use of 7,500,000 acre-feet of water per annum, which shall include all water necessary for the supply of any rights which may now exist."
>
> "(d) 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 ten consecutive years reckoned in continuing progressive series beginning with the first day of October next succeeding the ratification of this compact."

When this compact was negotiated it was thought that the flow of Colorado River under natural conditions would average considerably more than 15 million acre feet per year. It is now evident that such is not the case and that the provisions of Section (d) of Article III will probably limit depletions of the waters of the Upper Basin to some amount less than that allocated in Section (a) of the same article.

In order for the requirement of Section (d) of Article III to have been satisfied during the past 36 years, with depletions in the Upper Basin aggregating 7.5 million acre feet per year, it would have been necessary to have had 38 million acre feet of reservoir capacity available in 1917 for storage of all floods since then. Such a reservoir, or combination of reservoirs, would not have filled until 1930, as shown on Plate A, and would not have been more than half full at any time during the past 19 years. Furthermore, even if the next 13 years

should be as wet as those from 1917 to 1930, these storage reservoirs would not re-fill until 1965, a carry-over of 35 years. If such a series of wet years should not recur, the delivery of 75 million acre feet at Lee Ferry in each ten consecutive years could not be maintained with depletions of 7.5 million acre feet per year in the Upper Basin.

While it is true theoretically that there could have been annual depletions in the Upper Basin aggregating 7.5 million acre feet without breach of the provisions of Section (d) of Article III to the present time, it is believed that a more conservative value should be used in the planning of new projects until the supply actually available to the Upper Basin has been determined by many more years of record.

Should the years of carry-over of water in storage be limited to the period from 1930 to 1952, the aggregate depletion of the natural supply in the Upper Basin could not be more than 6.2 million acre feet per year. A total of about 21 million acre feet of reservoir capacity would be required for regulation under this condition with the delivery of 7.5 million acre feet annually at Lee Ferry to comply with the provisions of Section (d) of Article III of the Compact. The performance of such reservoirs is shown on Plate B. Initial filling would have had to commence in 1927, the reservoirs would have been full in 1930, substantially empty just prior to the flood in the spring of 1941, and would have re-filled only in 1952.

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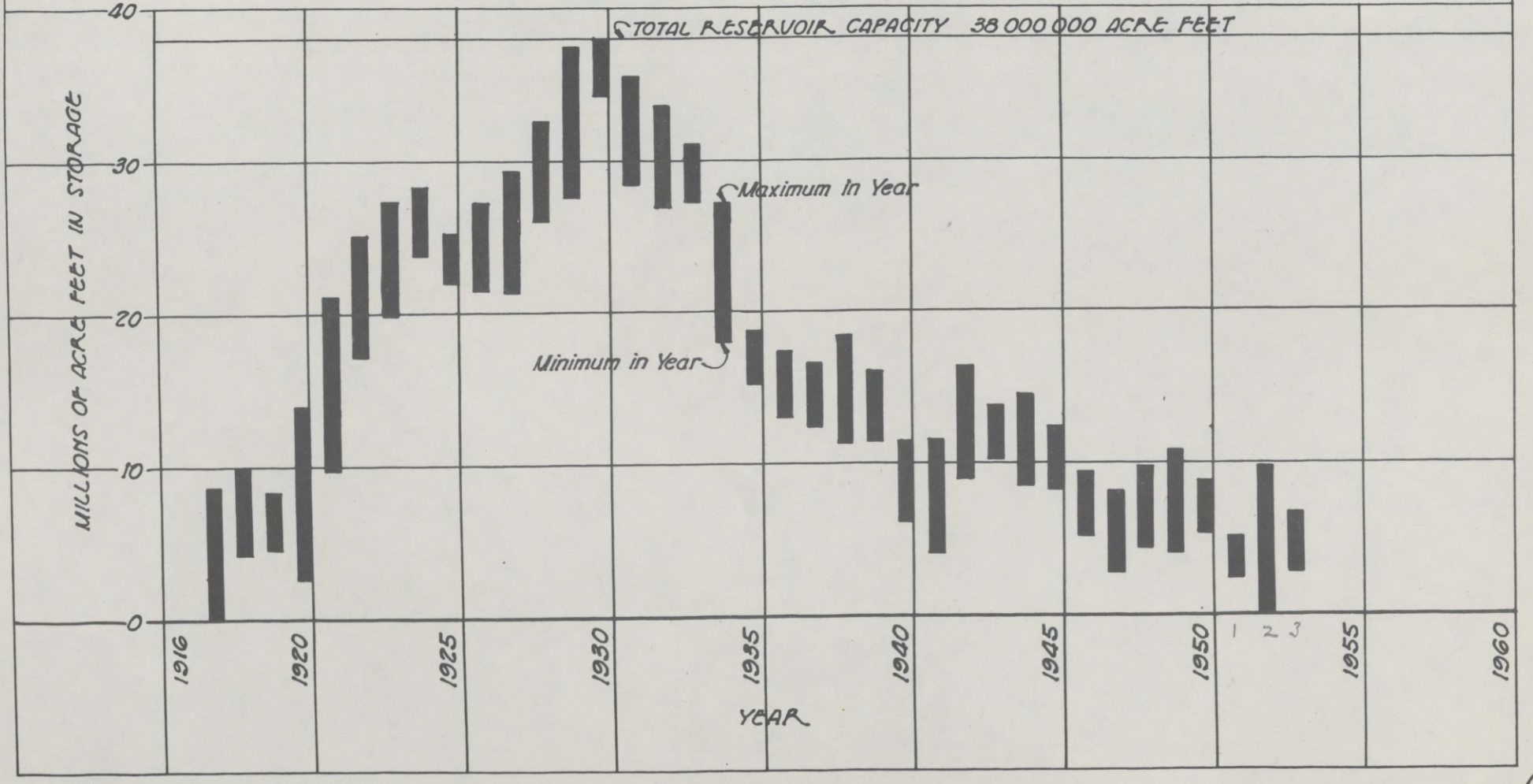
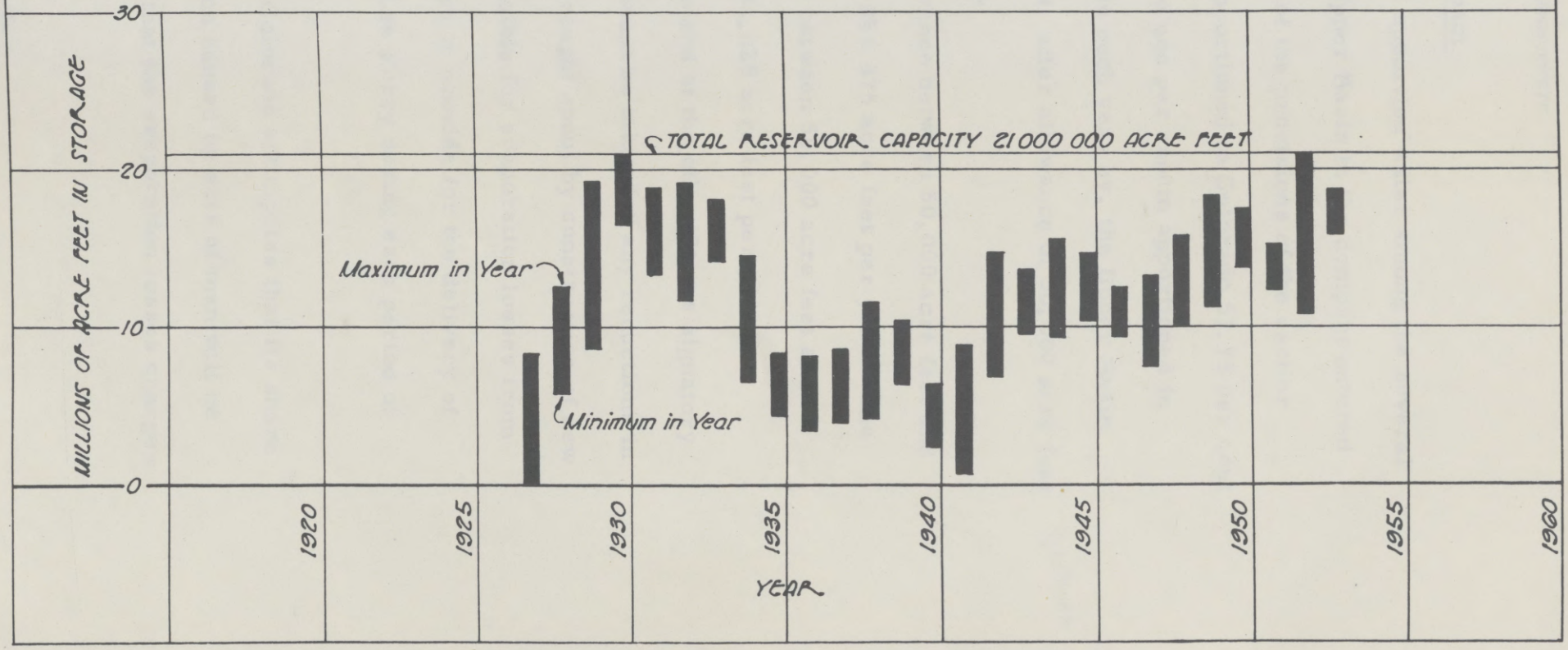
OPERATION OF RESERVOIRS ON COLORADO RIVER
FOR
DELIVERY OF 7.5 MILLION ACRE FEET ANNUALLY AT LEE FERRY
WITH
DEPLETION OF 7.5 MILLION ACRE FEET PER YEAR
IN
UPPER COLORADO RIVER BASIN



A

OPERATION OF RESERVOIRS ON COLORADO RIVER FOR DELIVERY OF 7.5 MILLION ACRE FEET ANNUALLY AT LEE FERRY WITH DEPLETION OF 6.2 MILLION ACRE FEET PER YEAR IN UPPER COLORADO RIVER BASIN



Upper Colorado River Basin Compact

The Compact of 1922 did not apportion water among the several States. This was done as to the Upper Basin in the compact entered into in 1948 without change of any of the provisions of the earlier compact. Basically, there was apportioned to Colorado 51.75 per cent of the total quantity of consumptive use per annum apportioned in perpetuity to, and available for use each year by, the Upper Basin under the Colorado River Compact, after allowance of 50,000 acre feet per annum apportioned to Arizona. 6,150000

This percentage of the difference between 50,000 acre feet and 7,500,000 acre feet amounts to 3,855,375 acre feet per year. The same percentage of the difference between 50,000 acre feet and 6,200,000 acre feet would be 3,182,625 acre feet per year.

It is the position of Colorado and of the other States signatory to the 1948 Compact that credit should be taken for any reductions in natural depletions which may be brought about by construction of new works but that they will be responsible for evaporation losses from reservoirs including those required to provide for the delivery of 75,000,000 acre feet of water at Lee Ferry during each period of ten consecutive years.

It is our understanding that Colorado anticipates that its share of the maximum allowable depletion caused by acts of man will be 4,043,000 acre feet per year and that the evaporation losses charge-

able to Colorado would be 316,000 acre feet per year. This would leave 3,727,000 acre feet as the limit (under Section (a) of Article III of the Colorado River Compact) of all depletions in Colorado arising from consumptive uses by agriculture, consumptive uses by industry, and diversions out of the drainage basin of Colorado River.

Should the total net depletion in the Upper Basin be limited to 6,200,000 acre feet per year by the provisions of Section (d) of Article III of the Colorado River Compact, then the aggregate of such depletions in Colorado could not exceed 3,100,000 acre feet per year in addition to reservoir evaporation losses.

Use of the waters of Yampa River in Colorado is limited somewhat by Article XIII of the Upper Colorado River Basin Compact in which it is stated in part:

> "The State of Colorado will not cause the flow of the Yampa River at the Maybell Gaging Station to be depleted below an aggregate of 5,000,000 acre-feet for any period of ten consecutive years. ....."

Inasmuch as the total flow of Yampa River at Maybell during the ten consecutive years of most deficient runoff of record amounted to 9.4 million acre feet, this provision will not prevent reasonable use in Colorado of the waters of this tributary of Colorado River.

Article XIV of this Compact, however, does impose definite limitations on future developments in the basin of San Juan River. The pertinent provision reads in part as follows:

> "The State of Colorado agrees to deliver to the State of New Mexico from the San Juan River and its tributaries which rise in the State of Colorado a quantity of water which shall be sufficient, together with water originating in the San Juan Basin in the State of New Mexico, to enable the State of New Mexico to make full use of the water apportioned to the State of New Mexico by Article III of this Compact, ..."

The quantity of water allocated to New Mexico by Article III is substantially 22 per cent of that allocated to Colorado. At least 90 per cent of the total flow of San Juan River originates in Colorado and less than 10 per cent in New Mexico. Hence, New Mexico is entitled to consume one-fifth as much as Colorado of all of the runoff from the Western Slope of Colorado. It so happens that the flow of San Juan River and its tributaries across the boundaries of Colorado into New Mexico also equals one-fifth of the total originating in Colorado. Therefore, because of this provision in the Compact and the physical situation, it is generally recognized by those who have studied the problem that there can be little additional depletion in Colorado of San Juan River and its tributaries above the confluence of Animas River, and that expansion of use in the San Juan Basin will be limited largely by the extent to which the waters of Animas River can be put to beneficial use.

In brief, Colorado would theoretically be entitled to deplete the flow of Colorado River to an aggregate of at least 3,700,000 acre feet under the limitations of the Compacts, after allowance for its share

of credits for salvage of natural depletions and charges for reservoir evaporation losses. The practical limit of all permissible depletions in Colorado may not exceed 3,100,000 acre feet per year in addition to its share of reservoir evaporation losses. Increases from the present level of depletions to either of these limits will be subject to certain legal and physical restrictions upon where the water is used.

PRESENT DEPLETIONS

During the period of negotiation of the Upper Colorado River Basin Compact an engineering advisory committee made very thorough studies of the depletions which had taken place. These are reported in detail in Volume III of the Official Record of Upper Colorado River Basin Compact Commission. In the case of Colorado, it was found that its contribution to the historic flow of Colorado River and its tributaries at the boundaries of the State had averaged 10,408,400 acre feet per year for the period from 1914 to 1945 and that its contribution to the virgin flow at the same points would have averaged 11,451,200 acre feet per year. The historical depletion within Colorado was thus found to have been 1,042,800 acre feet per year, which was the difference between computed depletions at sites of use aggregating 1,062,753 acre feet and about 20,000 acre feet of salvaged natural losses.

This total value was the summation of depletions in 30 sub-areas caused by irrigation of different types of crops, by the consumption of

water on seeped lands, and by trans-mountain diversions, reservoir losses and other uses. It has been deemed advisable for the purposes of this report to group such depletions in five geographic divisions; to wit:

1. All of the northwesterly portion of Colorado within the drainage basin of Green River, including Yampa River and White River, its principal tributaries. The reason for grouping these is that some of the potential irrigation projects involve diversions out of Yampa River for irrigation in part of lands in the White River Basin or diversions from White River for irrigation of lands in the Yampa River Basin. The other tributaries of Green River are too insignificant to warrant segregation.

2. All of the drainage basin of Colorado River from its headwaters to the westerly boundary of the State, exclusive of the portion drained by Gunnison River. Gunnison River is excluded because little use can be made in Colorado of water from this source by diversions below its confluence with Colorado River.

3. All of the Gunnison River Basin.

4. The areas drained by Dolores River and by tributaries of San Juan River which enter the latter below Shiprock. This portion of the San Juan Basin is grouped with the Dolores Basin because of transfers of water from Dolores River for the irrigation of lands in San Juan Basin, and because the westerly tributaries of San Juan

River are not physically available for use in New Mexico.

5. San Juan River Basin in Colorado above Shiprock, including La Plata River, Animas River, Florida River, and Los Pinos River.

The average depletion in each of these subdivisions of the drainage basin of Colorado River during the 32 years ending September 30, 1945 was found by the Engineering Advisory Committee to have been:

Green River Basin	99,123 acre-feet per year
Colorado River, main stem	385,939
Gunnison River Basin	351,613
Dolores River Basin and lower tributaries of San Juan River	120,367
San Juan River above Shiprock	105,711
Total Depletion at Sites of Use	1,062,753 acre feet per year

Since these data were assembled for use in the negotiation of the Upper Colorado River Basin Compact, there has been some expansion of irrigation on the Western Slope and new works for trans-mountain diversions have been constructed. The surplus available under existing conditions is therefore materially less than it was when the Compact of 1948 was executed.

Irrigation in Basin

The Engineering Advisory Committee to the Upper Colorado River Basin Compact Commission inventoried all the land under irrigation on the Western Slope and also estimated the extent of

other areas on which water was consumed. It found that the total irrigated area was 790,600 acres, and that there were 106,800 acres more on which water was consumed incidental to the practice of irrigation on adjacent areas.

Recently the Engineering Research Committee, which has been advising the Colorado Conference Committee appointed by the Colorado Water Conservation Board and which includes a number of those on the original Engineering Advisory Committee to the Compact Commission, has reviewed the prior estimates of irrigated lands and other lands consuming water. These revised estimates, which are believed to reflect present conditions, are as follows:

Geographic Unit	Irrigated Lands (Acres)	Incidental Areas (Acres)
Green River-Yampa River-White River	106,115	19,444
Colorado River, main stem, exclusive of Gunnison River	285,500	32,903
Gunnison River	254,737	32,915
Dolores River and lower tributaries of San Juan River	85,862	10,250
San Juan River above Shiprock	91,858	11,300
Total Irrigated Land	824,072 Acres	
Total Incidental Area		106,812 Acres

In the opinion of the Engineering Research Committee, the depletion at sites of use under present conditions amounts to

1,035,000 acre feet per year on account of irrigation agriculture on the Western Slope. This is an increase of only 35,000 acre feet above the average of depletions for this cause during the period from 1914 to 1945.

Other Depletions with Existing Facilities

Much more change in recent years has resulted from trans-mountain diversions. The Colorado-Big Thompson Project has practically been completed and the delivery of water across the Continental Divide through other facilities is now greater or could easily be greater than the average of such diversions during the period from 1914 to 1945. The total depletions arising out of trans-mountain diversions with existing facilities could be 388,200 acre feet, including evaporation losses from reservoirs provided to make such diversions possible.

Domestic uses and other municipal and industrial uses have increased somewhat in recent years and there is now more water lost by evaporation from reservoirs than when the detailed estimates were made at the time of negotiation of the Upper Colorado River Basin Compact. All such uses, however, amount to only about 10 per cent of the quantity now divertible across the mountains.

Summary of Present Depletions

The total of all depletions in Colorado of the waters originating in the drainage basin of Colorado River is now practically 1,450,000 acre feet per year, made up of the following:

DEPLETIONS WITH EXISTING FACILITIES
(Acre Feet per Year)

Geographic Division	Irrigation	Trans-Mountain Diversions	Other Depletions	Total at Sites of Use
Green River Basin	98,100	-	1,000	99,100
Colorado River, main stem	371,400	375,000	19,800	766,200
Gunnison River Basin	348,200	600	5,000	353,800
Dolores River Basin and lower San Juan River tributaries	116,600	-	3,900	120,500
San Juan River Basin above Shiprock	100,700	1,600	7,200	109,500
Totals at Sites of Use	1,035,000	377,200	36,900	1,449,100

If the provisions of Section (d) of Article III of the Colorado River Compact can be satisfied with aggregate depletions in the Upper Basin as great as 7,500,000 acre feet per year, then at least 2,250,000 acre feet of water now remain to satisfy potential developments in Colorado. On the other hand, if depletions in the Upper Basin must be held down to insure the delivery of 75,000,000 acre feet at Lee Ferry in each continuous ten-year period, then the actual surplus under existing conditions may not exceed 1,650,000 acre feet per year.

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Committed Supplies

Some of the present surplus of Colorado River water will be needed for expansion of existing projects and to supply Federal

projects which are now authorized. It is the view of many that this amount of water should be included among present depletions; others believe that these additional uses should be treated as potential depletions for which some water should be earmarked. In order that there may be no confusion, the estimates of the Engineering Research Committee as to these are set forth below.

No increase in depletion by existing projects is contemplated in the Green River Basin. An increase of only 400 acre feet is deemed probable in the San Juan Basin, this through existing facilities used for trans-mountain diversions. Other trans-mountain diversions, almost entirely from the headwaters of Colorado River, could be increased about 100,000 acre feet per year under present rights. Expansion of the irrigated area in the Grand Valley and Uncompahgre Federal Projects would consume 69,000 acre feet per year.

In addition, two projects have been authorized by the Congress of the United States for which appropriations have yet to be made. It is estimated by the Bureau of Reclamation that these would deplete the flow of Colorado River by 28,300 acre feet per year.

Such expansion of use by existing projects and new uses by authorized Federal projects would aggregate almost 200,000 acre feet per year. Hence, the quantity of water available to Colorado to satisfy other potential demands can be little more than about 2,050,000 acre feet per year, and because of the limitations of the Compacts may not exceed 1,450,000 acre feet per year.

POTENTIAL DEPLETIONS BY IRRIGATION

There is obviously enough land susceptible of irrigation on the Western Slope to consume all surplus water if there were no economic barriers to such unlimited expansion of agriculture. On the other hand, it is equally apparent that there can be no material enlargement of the presently irrigated area unless the costs of construction of irrigation projects be subsidized. The extent to which the existing surplus of water in Colorado River and its tributaries may be depleted by new agricultural uses will thus be dependent upon the extent to which the costs of such new projects may be borne by the citizens of the United States collectively.

UNIT CONSUMPTION OF WATER

In the report of the Engineering Advisory Committee to the Upper Colorado River Basin Compact Commission there are set forth the detailed methods followed in determining consumptive uses of water. It was found that the depletion caused by the irrigation of 790,600 acres of cropped land amounted to 821,400 acre feet per year and that there were consumptive uses of 178,700 acre feet on 106,800 acres additional as a result of irrigation of adjacent areas. The total consumptive use causing stream depletion was thus determined by the Engineering Advisory Committee to have been almost exactly one million acre feet per year. The Engineering Research Committee which is advising the Colorado Conference Committee now finds that

1,035,000 acre feet per year are being consumed on the Western Slope as a result of irrigation of 824,072 acres of land and incidental uses on 106,812 acres additional. Stream depletion at the sites of use thus averages 1.26 acre feet per acre of cropped land, or only about 1.11 acre feet per acre spread over both cropped areas and incidental areas consuming water.

Recent computations by the U.S. Bureau of Reclamation of stream depletions which probably would result from development of a large number of irrigation projects on the Western Slope indicate somewhat larger consumptive uses. The average depletion estimated by the Bureau for these new projects is only 1.16 acre feet per acre of all lands expected to receive water, but 30 per cent of the area in these potential projects is now being irrigated and only supplemental water would be furnished to such lands. If the consumptive use per acre of land given supplemental service should be one-half of the consumptive use on new lands, a depletion rate of 1.40 acre feet per acre of new land is indicated. It is not clear why there should be this increase from 1.26 to 1.40 acre feet per acre per year, because the potential projects are geographically scattered throughout the area in the same relative locations as existing irrigated lands and the nature of the crops grown should be similar to those which have been customary.

It is evident, in any event, that the resulting stream depletion for each additional 100,000 acres of land which may be brought under

irrigation will be not less than 125,000 acre feet per year nor more than 150,000 acre feet per year after allowance for all consumptive uses on non-cropped lands which may be seeped or otherwise receive water as a result of irrigation.

IRRIGABLE AREA ON WESTERN SLOPE

Before there can be any definite answer to the question as to how much land is irrigable on the Western Slope in Colorado, there must be a clear definition of what constitutes irrigable land. In China and India, where every available acre of ground must be cultivated to provide bare subsistence for the masses who would otherwise starve, any land would be deemed irrigable to which water could physically be delivered. In other more favored countries only those lands on which a farmer could make a profit would be deemed irrigable. Reasonable standards of desirability should be the measure of the extent to which irrigation agriculture may be expanded in Colorado.

Land Classifications

A very extensive survey was made about fifteen years ago by the United States Bureau of Reclamation to determine the areas of land suitable for irrigation in all of the Colorado River Basin. This is generally referred to as the Preston Survey from the name of the engineer who was in charge of the work for several years. The irrigated areas were mapped but these were not classified as to

soils or topography because the purpose of the Preston Survey was to determine how much additional land might be included in new projects. Only two classifications of arable and non-irrigated lands were used:

Class 1: Lands with ample depth of soil, good drainage, and topographically suitable for the production of any crops. In other words, lands as well adapted to agriculture as any of the better lands now under irrigation.

Class 2: Lands having shallower or less desirable soils, or somewhat deficient drainage, or slopes requiring special farming practices, or other limitations upon their usability. In other words, lands suitable to some crops, but not to all characteristic of the region, and from which the farmer could derive less return for his labor than from Class 1 land.

No attempt was then made to include lands which might be suitable for irrigated pasture or lands on steep slopes which might be used to a limited extent for orchards. These omissions have given rise to considerable adverse criticism of the Preston Survey, particularly because in recent years some parcels of land have been brought under irrigation which were not included in the irrigable areas mapped.

More detailed land classification surveys have since been made by the United States Bureau of Reclamation which do not cover all of

the Western Slope but do include the Colorado River Basin above the confluence of Gunnison River and a considerable part of the Gunnison River Basin. The land classifications used in these later surveys were similar to those used by Preston as to Class 1 and Class 2 but other lands suitable for irrigated pasture and orchards were included in the group designated as Class 4. Contrary to expectations, the findings of the recent surveys confirm the soundness of the work done by Preston within the areas mapped by him. For example:

(a) The more recent and detailed classification surveys of all lands along the main stem of Colorado River and its tributaries above Gunnison River show a total of about 121,000 acres of Class 1 and Class 2 land, but the potential projects known as the Cliffs-Divide Projects and the Silt and Collbran Projects only include 79,400 acres of such land. Preston did not map the areas which he deemed it would be impracticable to serve but his survey does show net irrigable land in Class 1 and Class 2 in the amount of 85,200 acres within the same area covered by the Cliffs-Divide Projects and the Silt and Collbran Projects.

(b) In the case of the surveys in the Gunnison River Basin the net irrigable area found by Preston was about 77,000 acres. Subsequent and more detailed surveys covering all potential projects in the Gunnison River Basin show only 61,000 acres of Class 1 and Class 2 land which could be served.

Hence, any areas omitted by Preston within these classifications are presumptively those lands which could not be included within the area of new projects even under very liberal standards. The great discrepancy which exists between the total of all irrigable areas found by Preston and those reported more recently arises from the inclusion in these subsequent surveys of Class 4 lands which were not mapped by Preston. In the case of the main stem of Colorado River, the recent inventory surveys show a total of 250,000 acres of Class 4 land, as compared to 121,000 acres of Class 1 and Class 2 land, the ratio being a little more than 2:1. Recent surveys do not cover all of the Gunnison River Basin but out of a total of 216,000 acres it was found that there were 147,000 acres of Class 4 land not now irrigated, slightly in excess of two-thirds of the total.

Reconnaissance of the areas mapped by Preston which are not covered by more recent land classification surveys leads us to believe that the areas of Class 1 land and Class 2 land reported by Preston may be accepted as reasonable. It was also apparent from general observation that it is reasonable to allow substantially two acres of Class 4 land for each acre of Class 1 and Class 2 land which Preston classified fifteen years ago. Actual surveys would probably disclose somewhat smaller areas, but the difference would not be material in any determination of the eventual depletion of water by irrigation agriculture on the Western Slope of Colorado.

Summary of Irrigable Areas

In the following tabulation there are given the irrigable areas not now irrigated, under different classifications, based on the most recent information available. For those tributary basins where the Preston Survey is the only one, an arbitrary allowance has been made for Class 4 land consistent with what was found elsewhere:

IRRIGABLE LAND NOT NOW IRRIGATED
(Quantities in Acres)

Geographic Division	Class 1	Class 2	Class 4 and Miscellaneous	Total
Green River Basin	21,300	205,400	450,000	676,700
Colorado River, main stem	3,600	117,800	251,000	372,400
Gunnison River Basin	1,400	67,200	160,000	228,600
Dolores River Basin and lower San Juan River tributaries	16,900	127,000	288,000	431,900
San Juan River Basin above Shiprock	6,400	71,700	156,000	234,100
Totals	49,600	589,100	1,305,000	1,943,700

LIMITATIONS ON DEVELOPMENT

Even if it were otherwise feasible to irrigate all of the irrigable land listed in the foregoing table, the surplus water to which Colorado is entitled would not be sufficient for the purpose. Actually, there are some physical and legal barriers to full development and a large part

of the area could not be brought under irrigation without going far beyond all reasonable standards of cost per acre of new land.

This is evidenced by the results of the investigations which the United States Bureau of Reclamation has conducted during the past ten years in a search for feasible projects. These include twenty projects in the drainage basin of the main stem of Colorado River, eighteen projects in the Gunnison River Basin, and four projects in the southwesterly portion of Colorado. The aggregate area of these forty-two projects is almost 600,000 acres, including about 250,000 acres of land now under irrigation to which supplemental water would be supplied. The area of new land is thus slightly less than 350,000 acres. The total cost allocable to irrigation is estimated to be 345 million dollars.

Subsidies for Main Stem Projects

In that part of the drainage basin of Colorado River above the confluence of Gunnison River there are twenty irrigation projects which have been or are soon to be reported on by the Bureau of Reclamation. These vary in size from about 2,000 acres to more than 60,000 acres in extent. The total project area is 263,000 acres, of which 166,500 acres is new land and the balance is land now under irrigation to which supplemental water would be furnished.

Construction costs chargeable to irrigation would be $177,000,000, an average of $674 per acre spread over all of the land in these projects.

Such costs on individual projects would range from a little less than $100 per acre in the case of one, designed to receive water from storage but not charged with any cost of storage, to some costing more than $1,000 per acre.

The required subsidies, disregarding the subsidy arising out of waiver of interest, would be more than $200 per acre with one exception, would exceed $300 per acre for one project if more than 65,000 acres were included, and would reach $500 per acre if as much as 160,000 acres of new land and lands given supplemental service were incorporated in new projects. Such subsidies would exceed 80 per cent of the construction cost with two minor exceptions and would exceed 90 per cent on twelve of the projects.

It must be recognized that waiver of interest constitutes a large subsidy even though this has been customary throughout the history of Federal Reclamation Projects. Actually, when the farmer is obligated to repay certain costs over a long period such as 50 years, he in effect amortizes only about half of the cost which he is called upon to repay without interest. Hence, the required subsidy to be paid out of revenues of the United States obtained by taxation of its citizens directly, or indirectly by diversion of other revenues requiring offsetting taxation, will be substantially greater than the amounts cited.

These subsidies are also based on the total area of land in new projects of which more than one-third is now irrigated. Such

supplemental lands will require less water and will cause less depletion, generally in the order of one-half of the depletion resulting from the service to new lands. If, therefore, one-half of the area of the lands given supplemental service be added to the area of new lands in each project, the subsidies required for new land or its equivalent can be computed. The effect of doing so and of including the subsidy due to waiver of interest is shown in the following tabulation:

RELATION OF SUBSIDIES TO DEPLETION
MAIN STEM OF COLORADO RIVER

Maximum Subsidy per Acre of New Land or Equivalent	Total Area of New Land or Equivalent (Acres)	Resulting Depletion of Stream Flow (Acre Feet per Year)
$ 200	7,000	10,000
400	62,000	87,000
600	113,000	158,000
800	130,000	182,000
1,000	140,000	196,000

Subsidies for Gunnison River Projects

A total area of 189,000 acres is included within the eighteen projects in the Gunnison River Basin investigated by the Bureau of Reclamation during the past ten years, of which about one-half is land now being irrigated but which would be benefited by the delivery of supplemental water or regulation of existing supplies. The total

construction cost chargeable to irrigation would be $90,000,000, an average of $476 per acre of all land included in these projects.

The required subsidy, disregarding the subsidy arising out of waiver of interest, would be less than $200 per acre in the case of only three projects having an aggregate area of about 20,000 acres. Subsidies exceeding $300 per acre would be required to expand the area to 60,000 acres, and if as much as 150,000 acres of new land and supplemental service land were included in the projects, some subsidies would have to be as great as $500 per acre. The Bureau of Reclamation estimates that in the case of seven of these projects the water users could not pay all costs of operation and maintenance.

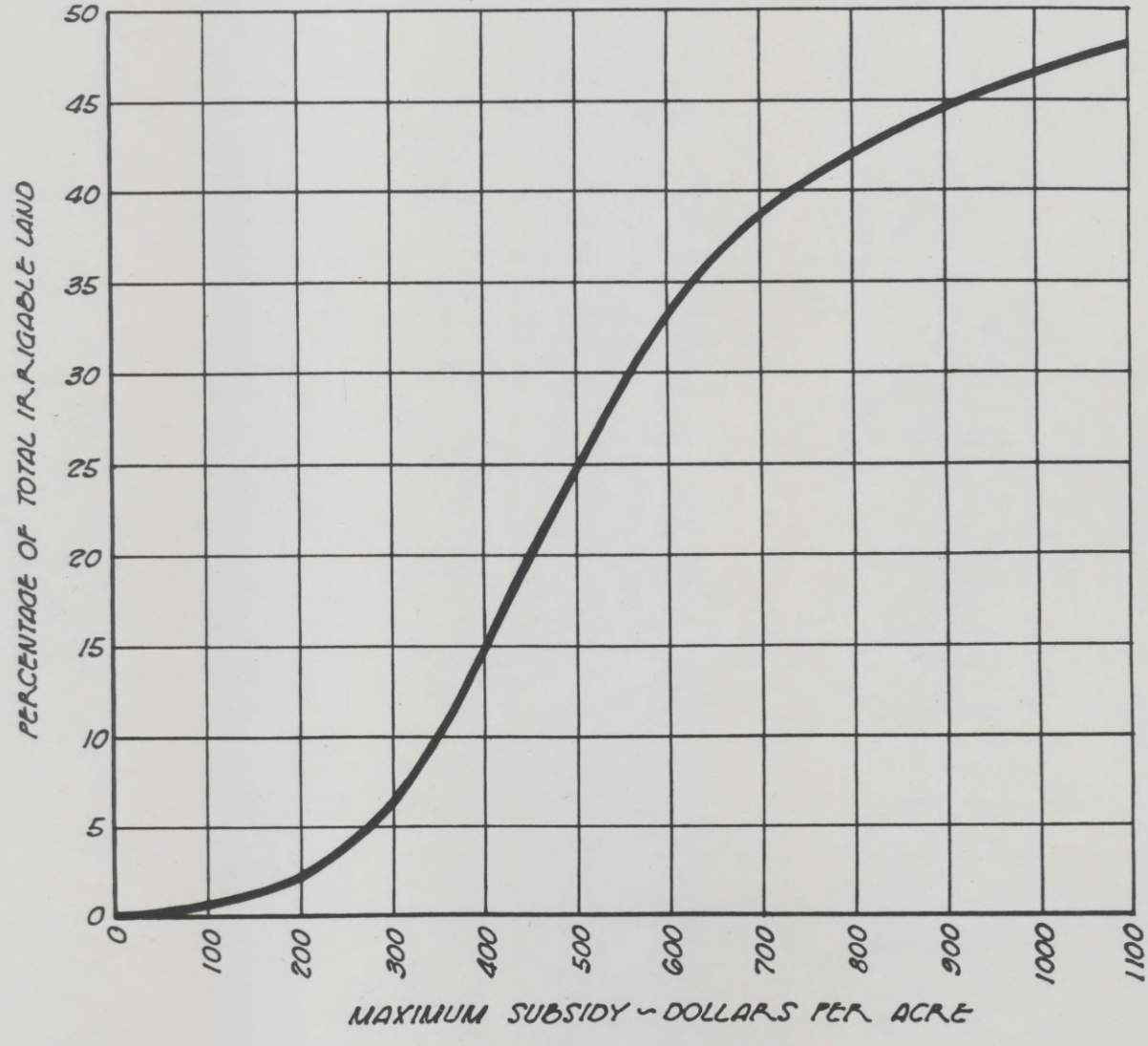
When the subsidy due to waiver of interest is added, the relation between the required subsidy per acre of new land or its equivalent and the resulting depletion of the contribution by Gunnison River to the total flow of Colorado River is as shown on the following table:

RELATION OF SUBSIDIES TO DEPLETION
GUNNISON RIVER BASIN

Maximum Subsidy per Acre of New Land or Equivalent	Total Area of New Land or Equivalent (Acres)	Resulting Depletion of Stream Flow (Acre Feet per Year)
$ 200	6,000	8,000
400	27,000	38,000
600	85,000	119,000
800	125,000	175,000
1,000	140,000	196,000

(C)

MAXIMUM SUBSIDY PER ACRE OF NEW LAND AND CORRESPONDING AREA OF NEW LAND IN IRRIGATION PROJECTS EXPRESSED AS PERCENTAGE OF TOTAL IRRIGABLE LAND IN COLORADO RIVER AND GUNNISON RIVER BASINS



Required Subsidies on Southwestern Projects

Sufficient studies by the Bureau of Reclamation have been completed on four projects in the southwestern portion of Colorado to determine the construction costs and the portion of such costs which could not be paid by the water users. The total cost of these projects would be almost $78,000,000, equivalent to an average of $536 per acre spread over 145,000 acres, of which 38 per cent is now irrigated.

The relation between the total subsidy, including that arising from waiver of interest, and the depletion of the flow of Dolores River and San Juan River resulting from development of these four projects, would be as follows:

Maximum Subsidy per acre of New Land or Equivalent	Total Area of New Land or Equivalent (Acres)	Resulting Depletion of Stream Flow (Acre Feet per Year)
$ 200	14,000	20,000
400	75,000	105,000
600	100,000	140,000
800	110,000	154,000
1,000	115,000	161,000

No other projects are possible in the Dolores River Basin and adjacent portions of the San Juan Basin because those considered would require the use of substantially all of the flow of Dolores River and the tributaries of San Juan River which enter it below Shiprock.

Due to the limitations of Article XIV of the Upper Colorado River Basin Compact, there is little room for increasing the irrigated area

elsewhere in San Juan Basin except for the potential Animas-La Plata Project. Studies now being carried on by the Bureau of Reclamation relative to the use of Animas River have not been completed but the essential data have been made available. The lands to be served in Colorado would be limited to about 62,000 acres and the estimated resulting depletion would be 87,000 acre feet per year. Other land in New Mexico could be included. The project would involve at least one storage reservoir and an expensive canal from Animas River into La Plata River Basin, so that the costs of construction would be large. It is almost certain that the project would be infeasible if lands in New Mexico be not included and its feasibility is deemed doubtful even in such event.

At least it may reasonably be assumed that depletions of the flow of San Juan River and Dolores River could not be 50 per cent greater than the depletions given in the foregoing table in relation to subsidies of different magnitudes.

Projects in Green River Basin

No recent investigations have been made by the Bureau of Reclamation to determine the amount of land which might be included in irrigation projects in Green River Basin in northwestern Colorado. This area was covered, however, in the investigations leading up to the report submitted in 1946 by the Commissioner of Reclamation to the Secretary of the Interior. The potential projects were also outlined

generally on the land classification maps of the Preston Survey and most of them were visited during the course of our investigation. We believe that there are sufficient data to determine within reasonable limits the extent to which the flow of Yampa River, White River, and other tributaries to Green River may thereby be depleted.

The total area of irrigable land in Colorado within the drainage basins of Yampa River, White River, and other tributaries of Green River is estimated to be less than 700,000 acres, of which two-thirds is Class 4 land suitable only for pasture. Three-fourths of the total is within the drainage basin of Yampa River; 48 per cent of this is in the basin of Little Snake River and about 25 per cent is on high benches south of Yampa River and in Axial Valley between Yampa River and White River. The remainder of the irrigable land in Yampa River Basin is scattered along tributary streams and near the headwaters. Almost 60 per cent of the land possible of irrigation in White River Basin lies in upland valleys north of White River and within forty miles of the State Line. Most of the remainder is adjacent to presently irrigated lands in the vicinity of Meeker.

These lands in northwestern Colorado are generally between 6,000 and 7,500 feet above sea level and the growing season would be relatively short. Large storage reservoirs would be needed for any material expansion of the presently irrigated area, particularly as to lands served from Little Snake River. Each of the major projects

that might be built would also require long and expensive canals to reach the lands and the costs of distribution facilities would be larger than for existing irrigation projects.

It is evident that conditions are no more favorable to expansion of irrigation agriculture in Green River Basin than elsewhere on the Western Slope. In the case of the main stem of Colorado River, the total area of new land included within the twenty projects studied amounted to less than 45 per cent of the total area in the basin found to be irrigable but not now under irrigation. In Gunnison River Basin, a little more than 40 per cent of all irrigable land not now irrigated was included in the eighteen projects considered as possibly feasible.

If the relationship between the maximum subsidy per acre of new land and the corresponding area of new land included in irrigation projects in the Colorado River and Gunnison River Basins be applied to Green River Basin, and if such subsidies were to be limited to $600 per acre, only one-third of the total irrigable land not now irrigated could be supplied with water; if such subsidies were limited to $400 per acre, the proportion would be only one-seventh of the total area of land found to be irrigable. The stream depletion for varying maximum subsidies would then be as follows:

RELATION OF SUBSIDIES TO DEPLETION
GREEN RIVER BASIN

Maximum Subsidy per Acre of New Land or Equivalent	Total Area of New Land or Equivalent (Acres)	Resulting Depletion of Stream Flow (Acre Feet per Year)
$ 200	15,000	21,000
400	97,000	136,000
600	223,000	312,000
800	282,000	395,000
1,000	314,000	440,000

In general, there is no likelihood that the required subsidies to irrigation would be less in the Green River Basin than for the projects including more land elsewhere on the Western Slope. On the contrary, it probably would be disclosed by detailed investigations that even greater subsidies would be required.

Probable Limit of Depletions

No definite limit can be placed upon the depletion of the flow of Colorado River at Lee Ferry which may result from expansion of irrigation agriculture on the Western Slope. The area of land which may be brought under irrigation will depend upon the degree to which new projects will be subsidized.

Should such subsidies be limited to $200 per acre of new land or its equivalent, then the resulting depletion of the stream flow would be no more than 100,000 acre feet per year. Should subsidies of $400 per acre of new land or its equivalent be given, the resulting stream

depletion would be a little more than 400,000 acre feet per year. Should subsidies as great as $600 per acre be permitted, the resulting stream depletion at sites of use might reach 800,000 acre feet per year. If there should be no limit upon subsidies to irrigation, then the entire surplus available to Colorado could be consumed by irrigation of new lands.

These limiting depletions include no allowance for conflicts between land uses for agriculture and industry. At least three of the potential irrigation projects along Colorado River in the vicinity of Rifle cannot be built if there is to be any commercial development of the oil shale reserves.

POTENTIAL INDUSTRIAL USE

Many years have elapsed since people began to talk about establishment of major industries on the Western Slope of Colorado and many more years may elapse before this becomes a reality, but the time could be relatively short. Such developments depend upon and must await utilization of the tremendous oil shale deposits along Colorado River. Whenever it becomes commercially feasible to mine and process these deposits for oil, great quantities of gas will become available as fuel for generation of power, and there will be many other by-products usable in chemical industries.

OIL SHALE DEVELOPMENT

The richest and most extensive oil shale deposits in the United States are in Colorado between White River and Colorado River

northwest of Rifle. They are in almost horizontal strata near the top of the high plateau and are exposed along the face of the Roan Cliffs.

It is estimated by the United States Bureau of Mines that these oil shale deposits cover an area of approximately 2,500 square miles and that an average yield of 15 gallons of shale oil per ton of shale could be obtained from beds aggregating 500 feet in thickness. About 1,000 square miles of the total area has already been explored by core drilling and other tests. The Bureau of Mines estimates that approximately 100 million barrels of shale oil could be produced from each square mile of the Mahogany Ledge, a section less than 100 feet thick, which assays about 30 gallons of shale oil per ton of shale. There can be no doubt that the reserves are more than sufficient to support mining operations at the maximum conceivable rate for several hundreds of years.

Processing of Oil Shale

Processing of such shale oils is not something which is untried; on the contrary, it is being done commercially in other countries. In Colorado the Bureau of Mines has been carrying on extensive tests and has built and operated pilot plants near Rifle to determine the process most suitable for the development of this resource.

About 500,000 tons of oil shale have been mined during the period of investigation, taking advantage of the fact that the rich beds are exposed along the face of the cliffs several thousand feet

above the level of Colorado River. In general, the mining process developed here consists of driving a series of headings, each 60 feet in width by about 40 feet in height, with cross connections so as to leave a succession of pillars 60 feet square with 60 feet clear space between them. Alternate rows of pillars are staggered to provide better support for the roof and freer access to all parts of the mine. The next step has been to remove about 35 feet more in depth by benching operations. The blasted material is loaded by power shovels into large trucks and hauled outside to the crushing plant. More efficient means may be developed for mining the oil shale, but it has been demonstrated that this can be done safely and economically and at any desired rate of production.

When the oil shale is brought out of the mine it is nothing but broken rock impregnated with organic matter. This rock must be crushed to suitable sizes before it can be started through the refining process. The crushing plants for large-scale operations would probably be located close to the openings of the mines.

The first step in the refining operation is known as "retorting" and consists essentially in driving off the volatile matter with heat under controlled conditions, the heat being supplied by burning the oil shale itself. Various types of retorts have been used in the test operations and the one now under test approaches the size which could be used commercially. Such retorts would naturally be located

near the mine headings and just far enough in elevation below the crushing plants to permit gravity feed.

Shale oil is somewhat similar to very viscous and impure crude oil and it could not be transported more than a few miles economically. Refining of the shale oil could be limited locally to reducing the viscosity enough for pipe line transportation, or complete refining could be undertaken to produce gasoline and all other products customarily obtained from natural petroleum. Neither is probable; it is the present belief of those best informed that gasoil would be produced locally and that this would be carried through pipelines to existing refineries on the Pacific Coast or elsewhere close to the consuming market.

Should the rate of production of shale oil reach one million barrels per day, the spent shale from the retorts would occupy a space of about 300,000 acre feet in each year. Fortunately, physical conditions are favorable to the disposal of such wastes. The richest deposits are about 3,000 feet above the elevation of Colorado River from which deep tributary canyons extend back into the plateau. Many millions of acre feet of storage capacity are thus locally available for the accumulation of wastes; eventually, however, it would be necessary to dispose of the spent shale by backfilling worked-out portions of the mines.

A large volume of gas would be produced at the oil shale retorts. This gas would have a heat value of only about 10 per cent

of that of natural gas and thus could not economically be transported any great distance. However, it could be used advantageously as fuel in refining operations and for the production of power at plants in the valley of Colorado River adjacent to the oil shale deposits. Other gas would be produced at the refineries and this could be used for domestic purposes as well.

Coke, sulphur and anhydrous liquid ammonia would be the principal by-products resulting from partial refining of shale oil. The National Petroleum Council, after very thorough study, estimated that almost 24,000 tons of coke, more than 800 tons of sulphur, and between 1,500 and 2,000 tons of anhydrous liquid ammonia would be produced in the processing of 1,000,000 barrels of shale oil.

Costs of Development

It is claimed by those most concerned with the development of the oil shale reserves that the cost of producing gasoline, diesel oil and other products from oil shale and delivering these at points of distribution in California would be very little more than present costs of producing the same products from crude petroleum. It is claimed further, and the contention seems to be borne out by available data, that the cost of gasoline made from crude oil obtained from new fields is actually more than the cost which would be incurred in the mining and refining of oil shale. The natural question is: If such be the case, why has shale oil not yet been produced

commercially? The answer lies in the tremendous capital investment required to construct plants of the capacity necessary for economical operation.

In the development of natural petroleum resources large capital investments are made per barrel of finished product, but such investments can be made progressively. The output from one well can be hauled to an existing refinery in tank trucks. As additional wells are drilled and the output becomes too great for this type of transportation, then a pipeline can be built. Finally, when the development becomes large enough to warrant construction of a new refinery, then this can be done.

In the case of oil shale, however, no greater total investment would be required but development in successive stages would not be practicable. The minimum economic unit of shale oil production is evidently about 50,000 barrels per day, and the cost of the required facilities would be about $300,000,000. It is apparent that no one oil company is going to commit itself to such an expenditure so long as it can obtain crude petroleum at a reasonable price, even if this involves imports from foreign sources. It may be that several oil companies would band together and make the required initial capital investment, and it is not unlikely that the Department of Defense might subsidize such a development in the interests of national security.

Whenever the first commercial plant be built and the economic value of it be demonstrated, the rate of production of shale oil then will be limited only by the market for the resulting products. The production of one million barrels of shale oil per day is well within the range of probability and twice that rate of production can be visualized without straining the imagination.

OTHER INDUSTRIES

It is inevitable that other industries will follow any commercial shale oil development without much delay. The principal motivating factors will be abundant cheap fuel for power and by-products usable economically by the chemical and related industries.

The largest single item of cost in the production of electric energy, except from hydroelectric plants, is that of fuel. Gas of relatively low but usable heat value will be produced in great volumes at oil shale retorts. These fuel gases would have to be wasted if they could not be used for the production of power in the immediate area. Additional gas of high heat value will be produced as a result of refining operations; this by-product could be piped elsewhere but could be used most economically in areas near the refineries.

Chemical industries making use of the by-products from the processing of oil shale could well be so extensive that the capital investments and payrolls would exceed those required for the oil shale industry itself. Such developments would in turn attract other

industries for the manufacture of products used in the basic industries. All in all, while we cannot subscribe to the concept of an industrial development rivaling any other in the United States, we can foresee a degree of industrialization that would dwarf the agricultural economy of the region.

PROCESSING OF COAL

There are many who visualize similar industrial developments resulting from the processing of the great coal deposits in western Colorado. Although this is within the realm of possibility, it is highly improbable because of economic obstacles.

Coal is widely distributed throughout the United States, much of it within a few hundred miles of the center of population of the entire country and equally close to established chemical industries. The deposits in western Colorado are remote from major centers of population. Furthermore, the cost of gasoline and related products made from coal would be so much more than the cost of obtaining the same products from shale oil that the use of coal for such purposes to supply the Pacific Coast market would be a last resort.

In brief, while processing of coal is probably inevitable on a large scale in the United States, there is little likelihood that more than a few small plants will be built in western Colorado. This will not preclude mining of coal for fuel or coke to supply industries in the area.

POPULATION INCREASE

There can be no substantial development of industry without a corresponding increase in population. Labor will be required to operate the mines from which oil shale is obtained, more labor will be engaged in refining operations, and each industry attracted to the area will likewise employ labor. The families of these men will swell the population. In the communities which will be needed to house those working in industry there will have to be many other people engaged in trade and in service occupations. The total population, based on ratios prevalent elsewhere, can be expected to be about six times as great as the number of persons actually on industrial payrolls.

Various estimates have been made of the personnel required to perform various steps in the processing of oil shales. These range from about 47,000 persons to 64,000 persons required for a one million barrel per day industry, but the two most recent estimates indicate 50,000 persons for one million barrels of daily capacity. If this value be multiplied by six, a total population of 300,000 persons would be directly supported in the area by the oil shale industry.

Equally definite estimates cannot be made of the personnel which might be employed in other industries. If allowance be made for another 50,000 persons on industrial payrolls, an additional 300,000 population would have to be considered in computations of water needs.

The round figure of one million additional persons on the Western Slope should be enough to provide ample margin for greater shale oil production and for all industrial developments which need be anticipated.

DIVERSION REQUIREMENTS AND STREAM DEPLETION

Failure to distinguish between rates of diversion of water and stream flow depletion resulting from industrial developments has been the source of much misunderstanding. All possible requirements of industry for the diversion of water could be provided for by the construction of suitable physical works. Stream flow depletion, on the other hand, involves the legal limitations imposed upon Colorado by interstate compacts. The diversion requirements of industry may be very large, but actual depletion of the flow of Colorado River at Lee Ferry will be relatively small.

Oil Shale Processing

Mining operations will naturally require very little water. This is fortunate because the cost of pumping water up to the mines would be high. Estimates range from less than 5,000 acre feet per year to almost 10,000 acre feet per year for shale oil developments aggregating one million barrels per day. The most recent and probably the most accurate estimates are about 5,000 acre feet per year for this output of shale oil.

Various estimates have been made by the U.S. Bureau of Mines, the National Petroleum Council, and others as to the quantity of water

that would be consumed in retorting oil shale. These range from an estimate of an actual gain to as much as 170,000 acre feet per year of stream flow depletion for an output of one million barrels daily of shale oil. This large value is based upon a retorting process requiring water. There are two basic reasons why this process would not be used on a large scale: first, the retorts would naturally be near the mines, approximately 3,000 feet above the level of Colorado River, so that the cost of delivering water to the retorts would be excessive; second, the process requiring water would result in the waste from retorts being saturated, which would make it impracticable to dispose of the spent shale in the tributary canyons to the depth necessary to accommodate mining operations for an extended period of years. The best estimates are that the actual consumption of water in the retorting process will be nominal and in any event will be less than 20,000 acre feet per year for an output of one million barrels daily of shale oil.

Refining operations may require the diversion of more than 150 cubic feet of water per second, but the actual consumption of water in the refineries will evidently not exceed 50,000 acre feet per year for the processing of shale oil at the rate of one million barrels daily.

Other Uses in Industrial Areas

Various estimates have been made as to the needs of other industries for water and of the quantity of water which would have

to be provided to serve the increased population. In one case, it was stated that these requirements would be equivalent to the average flow of Colorado River at Rifle, from which the erroneous conclusion was drawn that industrial development of the area would be throttled if any more water were diverted from the river for other purposes. The writer of this statement was actually referring to diversion requirements which could be satisfied from storage reservoirs and no allowance was made for the very large proportion of the water diverted which would return to the stream system for satisfaction of Colorado's obligations to deliver water at Lee Ferry in common with the other Upper Basin States.

Future depletions caused by industrial and domestic uses of water can best be determined from experience in major industrial centers in the West where the quantity of water produced for use is measured accurately and the quantity returned through sewage systems is likewise known.

In the twelve-month period ending June 30, 1950, the total quantity of water produced for use in Los Angeles and the contiguous cities of Glendale, Burbank, Beverly Hills and Santa Monica was 444,900 acre feet. The outflow through the sewage disposal plant which serves these five cities was 218,460 acre feet in the same year, leaving 226,440 acre feet unaccounted for by measured return flow. The population of these cities, according to the 1950 census,

445,000 ÷ 2,245,000 = .2019 F/million
Diversion

was 2,245,264. The water unaccounted for was thus one acre foot per year for each ten persons. The actual consumption of water was even less than that indicated because the San Fernando Valley portion of the City of Los Angeles, with a population of about 500,000, is largely unsewered, and the return from domestic uses in this area augments the groundwater supplies from which a considerable part of the total water production is obtained.

Recently, a sewerage system was completed to serve the Cities of Alameda, Albany, Berkeley, Emeryville, Oakland, and Piedmont in the San Francisco Bay area. During the months of June and July, 1953, a total of 156,400 acre feet of water was delivered by East Bay Municipal Utility District to consumers in these cities, and during the same months 111,700 acre feet were discharged through the sewer system. The quantity of water unaccounted for was thus 44,700 acre feet, which was 29 per cent of the total production. The gross annual requirements in the East Bay Area, including all industrial uses, are in the order of one acre foot of water for each five persons, so that the unit consumption must be about one acre foot of water per year for each fifteen persons. = .20 AF/person Denver

Comparable consumptive uses of water were found to be characteristic of the area served by Denver. Records furnished by that city for the five years from 1946 to 1950, inclusive, showed an average diversion for municipal purposes of 107,000 acre feet per

107,000 ÷ 460,000 = .23 AF/person Denver

year and returns through the sanitary sewers which averaged 68,000 acre feet per year. This leaves 39,000 acre feet per year as the apparent consumption of water. The average population during the five years was about 460,000 persons, so that the rate of depletion was only 0.085 acre feet per year per capita, equivalent to about 12 persons per acre foot of water per year.

The east shore of San Francisco Bay is highly industrialized and so is Los Angeles and the contiguous cities of Glendale and Burbank. The population of the East Bay cities is approximately that for which provision should be made on the Western Slope and the population of the Los Angeles area is very much greater. It is reasonable to assume, therefore, that while diversion requirements for industrial and municipal purposes on the Western Slope of Colorado may be quite large, the actual consumption of water resulting in depletion of stream flows should not exceed one acre foot per year for each ten persons. In other words, allowance for the consumption of 100,000 acre feet per year in addition to the actual consumption of water in the mining and processing of oil shale should be ample to cover all other industries and the uses of the population supported by all industries.

It is thus unlikely that stream depletions resulting from full industrialization will amount to more than 200,000 acre feet per year; allowance for depletions aggregating 300,000 acre feet per

year would certainly provide ample margin for any conceivable development stemming from processing of the shale oil reserves, and be enough to cover any probable use of the coal deposits.

NEED FOR STORAGE OF FLOOD WATERS

Under present conditions, very little water would be available during the irrigation season to satisfy the diversion requirements of industry. The natural flow of the rivers is already being used to its utmost to serve lands under irrigation, except during the winter months when the demand for water is insignificant and except during the period of snow melt when the rivers are in flood. Hence, conservation of flood flows by storage in reservoirs will be necessary to satisfy even a small industrial demand.

The only existing reservoir which might be used for this purpose is Green Mountain Reservoir on Blue River constructed by the United States as part of the Colorado-Big Thompson Project. The diversion requirements of the oil shale industry itself might be satisfied by releases from this reservoir but the far greater requirements of the other industries could not so be met. The additional storage reservoirs which will be needed do not have to be located upstream from Rifle; on the contrary, there would be considerable advantage in having a large reservoir in the immediate vicinity of the potential industrial area.

Opportunity exists for the creation of a suitable reservoir by construction of a dam in De Beque Canyon at the lower end of the

valley within which the industrial development would presumably be centered. Diversion requirements of such industries could be satisfied by the withdrawal of water from the reservoir without regard to the inflow at the time. Return waters, except the very small proportion which might be unduly contaminated by chemical processes, could be returned to the same reservoir without waste downstream. All irrigation requirements in the Grand Junction area could be satisfied, without conflict with any other use, by the release of water from the reservoir, and the average quality of the irrigation water would be somewhat improved over that now available in the summer months.

It is recognized that the cost of construction of such a storage project would be large, primarily because of the necessity of relocating the trunk highway and railroad which now follow Colorado River. This cost, however, would be insignificant in comparison to the tremendous capital investment which must be made to industrialize the region and which will not be made until there is assurance of ample water.

FUTURE TRANS-MOUNTAIN DIVERSIONS

The supply of water from Colorado River which was allocated to Colorado has already been depleted to the extent of 388,000 acre feet per year because of trans-mountain diversions; commitments for increased diversions through existing facilities would bring the total up to 503,000 acre feet per year. Although there are few opportunities for the diversion of still more water across the Continental Divide, a very large quantity of water could be taken if there were no legal nor economic barriers to these potential projects.

The proposal of Denver to divert the waters of Blue River into the South Platte Drainage Basin is now in litigation in both the State and Federal courts. No opinion can be expressed as to the legal rights of Denver or any other agency to make new or increased trans-mountain diversions.

New trans-mountain diversions will be limited generally to the headwaters of the main stem of Colorado River and to the Gunnison River Drainage Basin above the head of Black Canyon. Some water could be diverted from Yampa River into the headwaters of North Platte River but this is improbable because the use would be only for agricultural purposes. Neither White River nor Dolores River extends back to the Continental Divide. Allowance has already been made for existing and authorized diversions from San Juan River into the head of Rio Grande.

DIVERSIONS FROM COLORADO RIVER BASIN

Trans-mountain diversions through existing facilities above Hot Sulphur Springs could be 400,000 acre feet per year. This is about 350,000 acre feet in excess of the diversions which were made during the years 1939 to 1949, the period of less than average runoff which determines the safe yield of the stream. This safe yield, after reservoir evaporation losses, is only 420,000 acre feet per year, leaving about 20,000 acre feet per year for maintenance of a live stream. Hence, there is no opportunity for increasing trans-mountain diversions from the watershed of Colorado River above Hot Sulphur Springs except to the extent of the allowances already made for present and committed uses.

Two plans for trans-mountain diversions from Blue River and adjacent streams have been advanced. The United States Bureau of Reclamation contemplates the diversion of 430,000 acre feet per year, which would be obtained from Blue River and Williams River, augmented by diversions into Blue River from Eagle River and other streams on the west side of the Gore Range. The City and County of Denver proposes the diversion of 177,000 acre feet per year from Blue River and Williams River alone. It would be physically possible to carry out either of these plans, but not both.

Colorado Springs is already taking water out of the basin above the proposed points of diversion from Blue River. Hence, the

foregoing estimates of the Bureau of Reclamation and of Denver may have to be reduced about 17,000 acre feet per year.

A bill is now before the Congress to authorize construction of the Fryingpan-Arkansas Project which would involve the diversion of about 72,000 acre feet annually from Fryingpan Creek, a tributary of Roaring Fork, into the headwaters of Arkansas River. This would be physically feasible.

Economic Factors

Colorado Springs is paying for its trans-mountain diversion works. The City and County of Denver now states that it is the intention to finance the construction of the works in its plan in the manner customarily followed by municipalities making additions to water systems. Hence, subject to the legal rights of these communities and other municipalities, depletions approaching 200,000 acre feet per year may be made without subsidies by the Federal Government.

Trans-mountain diversions for other purposes, however, will require subsidies. For example, when the Colorado-Big Thompson Project was undertaken for the diversion of water across the Continental Divide, contracts were entered into by the water users which limited their obligation to the then estimated costs of works allocated to irrigation. The intent was thus to limit the subsidy to that arising out of the waiver of interest. However, costs of construction were so much greater than those originally estimated,

due to inflation and other causes, that the actual subsidy will be substantially more than $200 per acre of land furnished supplemental water.

In the case of the Fryingpan-Arkansas Project, the total estimated cost at present price levels is $172,898,000 of which $75,128,000 is allocated to irrigation. Total payments aggregating approximately $43,000,000 are expected to be made for water during a period of 69 years, which would amortize about $20,000,000 of the cost allocated to irrigation. The gross subsidy to irrigation will thus be $480 per acre spread over the 114,500 acres included in the area to be supplied with supplemental water. Under the proposed plan of financing (modified Collbran formula), about $32,000,000 of the total subsidy will be paid out of net power revenues and net revenues from water delivered to municipalities. About 60 per cent of the total subsidy to irrigation will thus be borne by the municipalities and power consumers in the trade area.

Should the Blue-South Platte Project of the Bureau of Reclamation be undertaken in lieu of the plan proposed by Denver, much greater subsidies to irrigation would be necessary. The costs allocated to irrigation are estimated to be $236,000,000 at 1947 price levels. The area of land to be supplied with water is given as 347,000 acres. The average cost at 1947 prices is thus $680 per acre; at present price levels, the unit cost would be close to $1,000 per acre. In its

preliminary financial analysis, the Bureau of Reclamation has assumed that payments for water directly and through taxes levied on the land would amount to about $97,000,000 in 61 years. Such payments would amortize about $45,000,000 so that the actual subsidy to irrigated land would be more than 80 per cent of the cost allocated to irrigation. At 1947 price levels this would be equivalent to $550 per acre; at current price levels the subsidy per acre of agricultural land would be about $800 per acre if the repayment capacity be taken as that determined five years ago.

DIVERSIONS FROM GUNNISON RIVER BASIN

No significant diversions have yet been made from Gunnison River Basin for the benefit of lands east of the Continental Divide, but various plans have been advanced for large trans-mountain diversions. The United States Bureau of Reclamation is now considering means for the diversion of most of the surplus water in Gunnison River above Black Canyon. One such plan would involve a reservoir with a capacity of 940,000 acre feet at the Curecanti site and a tunnel sixty miles long from this reservoir to a point on Arkansas River near Salida for the diversion of 500,000 acre feet per year.

The critical period that determines the safe yield of Gunnison River was from 1930 to 1949. A reservoir of about 2,000,000 acre feet capacity would be required to carry over a similar period of 19 years, and the yield for all purposes would be about 1,100,000

acre feet after allowances for reservoir evaporation losses. If the gross demand were reduced 10 per cent, only a little more than 1,000,000 acre feet of storage would be required at this site. This would seem to be the practical limit of the quantity of water which could be relied upon to satisfy irrigation uses and trans-mountain diversions. Such irrigation uses of this water in the Uncompahgre Valley already amount to about 400,000 acre feet per year. Another 100,000 acre feet may be needed to provide for increased consumption in the basin above Curecanti and for extension of Uncompahgre Project. Hence, 500,000 acre feet per year is about the physical limit on diversions from Gunnison River Basin into the Arkansas River.

Preliminary estimates indicate that the total cost of a project for the diversion of 500,000 acre feet annually would be close to $800,000,000, of which more than $500,000,000 would be chargeable to irrigation. It is assumed that 200,000 acres of land in the Arkansas Valley would be served which is not now irrigated, and that about 200,000 acres more would benefit by use of return waters. The gross cost would thus be about $2,500 per acre if charged against only the new land and $1,250 per acre if spread over all the land to be benefited.

In its preliminary estimates of revenues, the Bureau of Reclamation assumed that $278,000,000 would be received from the sale of water to irrigators during a period of 94 years; this would be at the rate of about $6.00 per acre foot. Such payments would amortize

less than $70,000,000 of the cost allocated to irrigation, leaving a subsidy of more than $2,000 per acre if charged against the 200,000 acres of new land, and still more than $1,000 per acre if spread over all the land which might be benefited.

RELATION OF SUBSIDIES TO DEPLETIONS

Further depletion of the flow of Colorado River by trans-mountain diversions will thus be dependent upon the extent to which new projects may be subsidized. It is evident that municipalities could not independently finance all costs of construction of works for the diversion of more than 200,000 acre feet per year. Subsidies to irrigation under the cheapest project contemplated, involving the diversion of 72,000 acre feet per year, would be about $480 per acre. Next in order is the Blue-South Platte Project for the diversion of 430,000 acre feet per year, but the required subsidies to irrigation would be at least $550 per acre and more likely would be as much as $800 per acre. The Gunnison-Arkansas Project, which might involve the diversion of 500,000 acre feet per year, would require subsidies to irrigation of more than $1,000 per acre of all land benefited.

STORAGE REQUIREMENTS

No large trans-mountain diversion can be made without the use of a storage reservoir or reservoirs to impound the flood waters which would otherwise be unused in Colorado.

Such reservoirs will be needed for regulation of floods at or near points of diversion to permit delivery of steady flows through the tunnels and other conduits. A second and no less important function of storage will be the maintenance of the natural flow of the streams to the extent necessary to satisfy rights of others.

Flood waters may be impounded and diverted out of the drainage basin of Colorado River under present conditions without danger of breach of the provisions of Section (d) of Article III of the Colorado River Compact. The margin is not large, however, because during the ten years ending September 30, 1940 the total flow of Colorado River at Lee Ferry was only 101,510,000 acre feet. Maintenance of deliveries of 75,000,000 acre feet at this point in each consecutive ten-year period will soon require storage to offset new depletions. It follows that, when new depletions are made by trans-mountain diversions, reservoir capacity for cyclic regulation of the remaining flow of Colorado River will be provided in the proportion necessary.

CONCLUSIONS

We conclude from review of all available data and from independent analyses that:

1. All of the 7,500,000 acre feet of water per annum apportioned to the Upper Basin by the Colorado River Compact may not actually be available for use because of the requirement that 75,000,000 acre feet be delivered at Lee Ferry during each consecutive ten-year period.

2. Compliance with this provision and limiting the carry-over in cyclic storage to the 22 years from 1930 to 1952 would have required that reservoirs of 21,000,000 acre feet capacity had been available in 1927 for cyclic regulation and that the aggregate depletion in the Upper Basin be no more than 6,200,000 acre feet per year.

3. The total of all depletions at sites of use in Colorado of the flow of Colorado River and its tributaries may thus be limited to 3,100,000 acre feet per year.

4. Depletions in Colorado under present conditions aggregate practically 1,450,000 acre feet per year.

5. Commitments for extension of existing projects and for other projects authorized would increase present depletions almost 200,000 acre feet per year.

6. The present uncommitted surplus which can be relied upon for use in Colorado is thus 1,450,000 acre feet per year.

7. Development of the oil shale reserves in western Colorado should be anticipated and the consumption of water for industrial, municipal, and other purposes resulting therefrom may reach 300,000 acre feet per year.

8. Consumptive uses by expansion of irrigation on the Western Slope will depend upon the degree to which new projects are subsidized. Should the subsidy be limited to $200 per acre, the resulting depletion would be no more than 100,000 acre feet per year. Should subsidies

of $400 per acre be given, the stream depletion would be a little more than 400,000 acre feet per year. Should subsidies as great as $600 per acre be permitted, the resulting stream depletion at sites of use might reach 800,000 acre feet per year.

9. Depletions by new trans-mountain diversions will likewise depend upon the degree to which irrigation agriculture may be subsidized. Some diversions could be financed by municipalities without subsidies, but these would be limited to about 200,000 acre feet. Additional trans-mountain diversions for agricultural purposes in any substantial amount would require subsidies in excess of $400 per acre. Even if subsidies as great as $600 per acre were permitted, the total of all new trans-mountain diversions for all purposes would not be more than 300,000 acre feet per year.

10. If subsidies to agriculture at any point in Colorado be limited to $600 per acre, future depletions caused by expanded irrigation on the Western Slope and by trans-mountain diversions would amount to 1,100,000 acre feet per year.

11. If any greater subsidies were to be allowed, the potential depletion caused by consumptive uses in agriculture and industry and by trans-mountain diversions would be in excess of the supply of water available to Colorado.

12. Increased diversions of water for use by agriculture and industry on the Western Slope and for trans-mountain diversions will

depend upon the provision of sufficient storage capacity in reservoirs for conservation of flood flows and some cyclic regulation; in order that Colorado may make full use of the water allocated to it by the Compacts, cyclic regulation of Colorado River over periods longer than twenty years will also be necessary.

Los Angeles, California.

October 31, 1953.