THE COLORADO RIVER PROBLEM

by

William Kelly

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AMERICAN SOCIETY

OF

CIVIL ENGINEERS

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WITH DISCUSSION BY

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By William Kelly,† M. Am. Soc. C. E.

With Discussion by Messrs. J. C. Allison, Frederick H. Fowler, E. C. La Rue, Arthur P. Davis, C. E. Grunsky, F. E. Weymouth, G. E. P. Smith, Louis C. Hill, C. S. Jarvis, E. W. Lane, Raymond A. Hill, E. B. Debler, and William Kelly.

Synopsis

So much has been written and spoken on the subject of the Colorado River in the past few years that perhaps the greatest need at present is an impartial digest of the facts and an estimate of the probabilities. This paper attempts to give both; it also presents some as yet unpublished studies of flood protection, water supply, irrigable areas, and power demand which are important factors in any study of the Colorado. Finally, it sets forth the salient features of a comprehensive scheme of development and points out the lines on which activities of the Federal Government should be directed.

Introduction

The Colorado has its sources in the melting snows of the mountains of the Continental Divide. Its drainage basin has an area of nearly 250 000 sq. miles and covers parts of seven States. Its delta is in Mexico through which it flows to the Gulf of California. Development, mostly irrigation, has gone forward to the present with little or no thought of a comprehensive use of the entire river. Fortunately, what has been done will not interfere materially with the full use of this great water resource, but in view of the large projects under consideration it is important that a general scheme of development be

* Presented at the Annual Convention of the Society, Pasadena, Calif., June 19, 1924.

† Col., Corps of Engrs., U. S. A.; Chf. Engr., Federal Power Comm., Washington, D. C.

adopted and that supervision be exercised to require future developments to conform thereto. Such supervision can be exercised under existing laws by co-operation between the Federal Government and the seven interested States. Although many additional data on stream flow, location, and character of irrigable lands, dam sites, etc., are needed before details of the ultimate development can be determined, sufficient information is available to determine the general scheme in so far as that is necessary for the consideration of projects now advocated.

Scheme of Development

The essential features of a comprehensive plan of development for the Colorado are determined by topographic conditions. The Upper Basin, which lies above the junction of the main river with the Green River in Utah, has possibilities of development for both irrigation and power; the total area that can be irrigated probably does not exceed 4 500 000 acres, of which about one-third is now irrigated. This area is from 4 000 to 8 000 ft. above sea level and use of water for irrigation will always be limited by climatic conditions. The depletion of water supply by irrigation in this area will probably never exceed 4 500 000 acre-ft. To this should be added diversions out of the Basin which may reach 500 000 acre-ft.

In the Upper Basin there are many possibilities for power development, the most promising of which are on the Green between Green River, Wyo., and the junction of the Green with the Colorado. Interference between these power developments and irrigation should be given careful consideration before the developments are undertaken. Such consideration is assured by the fact that practically all such projects involve the use of public lands and thereby come under the jurisdiction of the Federal Power Commission.

The Middle or Canyon Section extends from the junction of the Green to a short distance below Needles, Calif. Irrigation in this section will never be important, being limited to a few inter-canyon valleys of doubtful feasibility. The importance of this section is due to the 4 000 000 h.p. it can produce. If water is reserved for up-stream irrigation, and re-regulation is provided for irrigation below, there will be no interference with irrigation by power in this section.

Below Needles, including Mexico, there are more lands that can eventually be irrigated than there will be water to serve. Power possibilities in this section are small and will be incidental to irrigation development. The Gila River enters the Colorado just above Yuma, Ariz. The development of its water resources has no bearing on the plan for the Colorado, except in the matter of flood protection of the delta region.

Permanent settlement of the Colorado Basin will be largely dependent on irrigation. It is probable that in the immediate future power will have a greater value than irrigation, but as power can be obtained from other sources than the river, it should not be allowed to curtail the ultimate irrigation development.

Although it is impossible to predict the rate at which either irrigation or power will develop, it is certain that there are more than enough irrigable lands to use all the water available and that all the power that can be developed in the main section of the river will be needed. The plan of development, therefore, should provide that:

1.—Losses from evaporation should be kept to a minimum.

2.—All available head should be used for power.

3.—Storage for regulation of flow should be located above the Canyon Section so that the equated flow can be used through the greatest practicable head.

4.—Storage in and below the Canyon Section should be limited to that necessary for re-regulation of flow for irrigation in the Lower Basin plus such quantity as is essential for immediate flood relief of existing developments in the Lower Basin. Failure to conform to this provision will mean ultimate duplication of storage capacity and consequent curtailment of irrigation due to unnecessary evaporation losses.

There are reservoir sites in the Upper Basin of sufficient capacity to provide regulation of flow. The first cost of such reservoirs per acre-foot of storage will be more than that for sites in the lower Canyon Section, but they will be worth as much for irrigation, three times as much for power, and, on account of regulated flow, will make possible material savings in cost of power dams built below them. Moreover, they can be developed successively as needed so that if interest on investment is considered, their ultimate cost may not be much greater, even on an acre-foot basis.

Present developments in the Lower Basin are subject to damage by floods. The development of storage in interest of power will relieve the flood menace in part. Full protection, in so far as it can be obtained by storage, requires that the storage capacity be available at the beginning of each flood season. Storage for power on the other hand should be operated to keep reservoirs as full as practicable at all times. The United States Bureau of Reclamation estimates that ultimately 4 000 000 acre-ft. will suffice for flood protection. As will be shown hereafter, 4 000 000 acre-ft. is all that is justified at present. Flood storage to afford the greatest benefit should be as far down stream as practicable.

Flood Protection

The Lower Basin is menaced by floods from both the Gila and the Colorado Rivers. The Gila floods are produced by winter rains and generally occur between November 30 and March 1. They reach a maximum flow of about 200 000 sec-ft. (approximately the flow over Niagara Falls). They are extremely flashy and, therefore, produce higher flood stages and greater velocities than the more deliberate floods of the Colorado. As long as the Gila remains uncontrolled, it will determine the height to which levees must be maintained at and below Yuma.

There is general agreement that, although the Gila, until controlled, will require maintenance of levees at present heights, it will never seriously inundate the Imperial Valley, because it discharges no water for a large part of the year. There are several irrigation and power projects under consideration, which, if completed, will materially reduce the magnitude of Gila floods. No proposal is being seriously advanced that the Federal Government should undertake control of the floods of the Gila River.

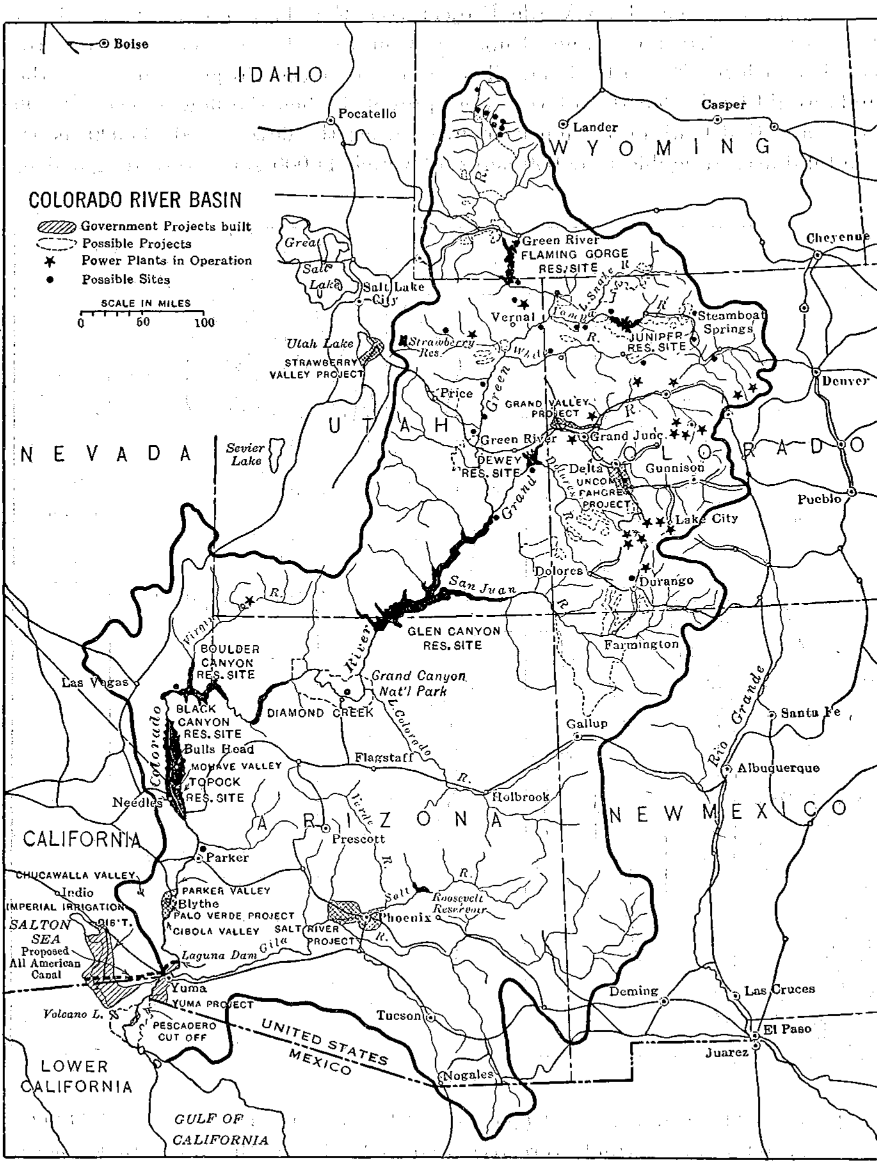

FIG. 1.

The main floods in the Colorado are due to melting snow in the upper regions of the river. About 86% of the total run-off at Yuma comes from north of Arizona. These floods begin as early as March and may last into July, and their maximum flow is about the same as that of the Gila, but they contain vastly more water. The floods in the Lower Colorado affect three existing projects, namely, Palo Verde, Yuma, and Imperial Valley, both in the United States and in Mexico.

Palo Verde.—The Palo Verde Project (see Fig. 1) is on the west side of the river in Riverside and Imperial Counties, California, and is protected by a levee 28½ miles long. The engineer of the Project states that the lands would be flooded if no levees were provided when the flow exceeds 50 000 sec-ft. and that bank protection is required when the flow exceeds 35 000 sec-ft. The total area irrigable is 78 000 acres, of which 44 000 acres were irrigated in 1922.

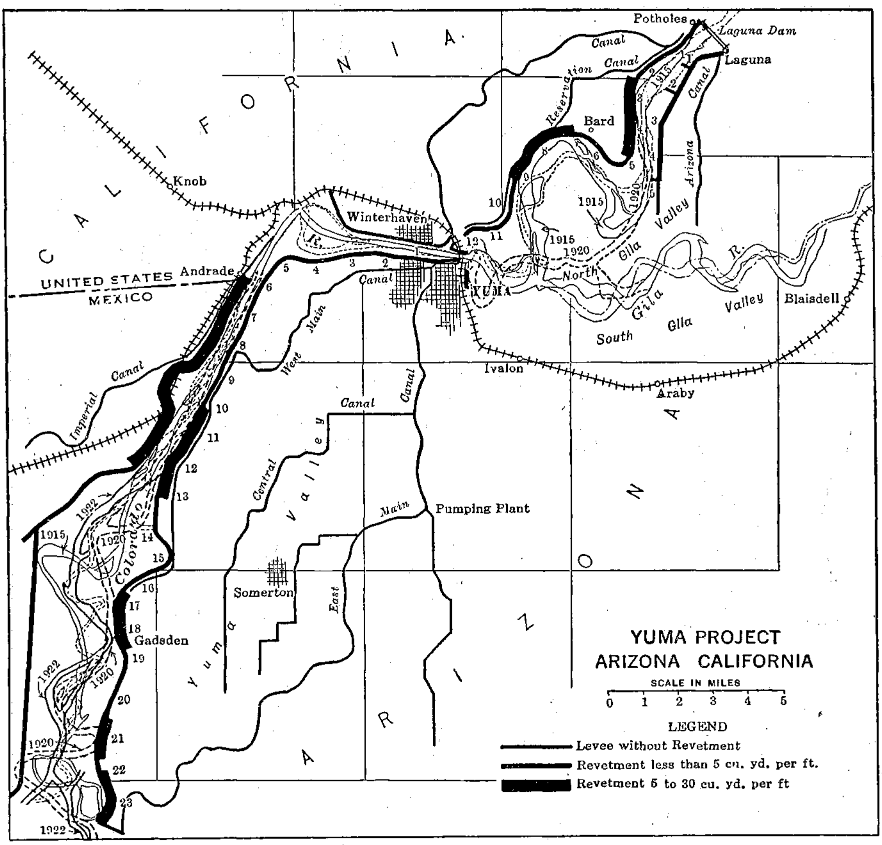

Fig. 2.

Yuma.—The Yuma Project (see Fig. 2) has a total irrigable area of 114 000 acres, 55 700 acres of which were irrigated in 1922. Of this land, 15 000 acres lie in the Yuma Indian Reservation on the California side between Laguna Dam and a point opposite Yuma. These lands were subject to overflow at extreme high water and have been protected by a levee about 12 miles long, extending from Laguna Heading to the Southern Pacific Railroad track near Yuma. The Potholes Branch of the Southern Pacific Railroad is located on this levee. The levee crosses several old meanders of the river and, consequently, is subject to attack by it at nearly every high water. Bank protection has been necessary to maintain the levee, and the bank is now revetted practically throughout its entire length. The levee has been breached by the Colorado River floods once (in 1913) and was overtopped at its lower end by the Gila flood of January, 1916.

Another 54 000 acres lie in Yuma Valley on the Arizona side between the Town of Yuma and the Mexican Boundary. These lands were subject to overflow at high water and have been protected by a levee 25 miles long, extending from Yuma to the Mexican Boundary. A Government railroad has been built on this levee in order to facilitate its maintenance. For 12 miles below Yuma, the river flows in a narrow and relatively straight channel with fairly stable banks and has never given much flood trouble. Below that point, it shows a determination to repeat its meandering into the land now occupied by the Project. Since 1909, the river has made direct attacks on this levee at 12, 16, and 24 miles below Yuma, necessitating heavy expenditure for bank protection. The levee has never been overtopped, but has twice failed from undercutting, once from the Gila flood of January, 1916, and once from the Colorado River flood of 1920. The construction and maintenance of the levees of the Yuma Project cost $3 234 470. The annual maintenance for the past six years has averaged $86 420. The remainder of the lands in the Project, about 45 000 acres, are on the mesa east of Yuma Valley, well above high water.

The Yuma levees are nearer the river than has been found to be economically practicable elsewhere. They encroach on a part of the valley that the river has used in the past and will try to use in the future. They can be maintained in their present location only by heavy bank protection, and maintenance expense will be high until the banks are sufficiently protected whether or not flood storage is provided. (See Fig. 2.)

Imperial Valley.—The Imperial Valley (see Fig. 3) comprises about 515 000 acres of irrigable land in California and 255 000 acres in Mexico. During 1923, about 400 000 acres of the area in California and about 170 000 acres in Mexico were irrigated. All this highly productive area lies below the low-water level of the river and much of it below sea level. Water is diverted for irrigation at Rockwood Heading about a mile up stream from the International Boundary line. The main canal follows generally an old flood channel called Alamo River. The Valley was first protected from flood waters by the head-works of the canal and by an embankment on the river side of the canal. This embankment now forms a secondary line of defense. It was supplemented by a stronger line of defense consisting of the levees of the California Development Company, Sais Levee, extending from the canal intake south along the river for about 10½ miles, thence bearing west for about 16 miles, and the Volcano Lake Levee north of Volcano Lake from high ground west of the Valley to the Inter-California Railway Company embankment and the Imperial Canal near Bataques Station.

In 1905, the Imperial Canal had silted, for about 4 miles below the Heading, to such an extent as to threaten a water famine during the low-water period. In order to get water into the canal, a cut was dredged to turn the river into it at a point about 7 miles below the Heading. An early flood season defeated attempts to close the dredged cut and the entire flood flow passed into the Valley. It was not until 1907 that efforts to turn the river back into its old channel were successful. The closing of this break cost about $2 000 000. In 1909, the river left its old channel at a point about 29 miles below Yuma and turned west through Bee River into Volcano Lake. This necessitated the extending of the Sais Levee to an intersection with the Volcano Lake Levee and of raising and reinforcing the Volcano Lake Levee. Almost the entire silt

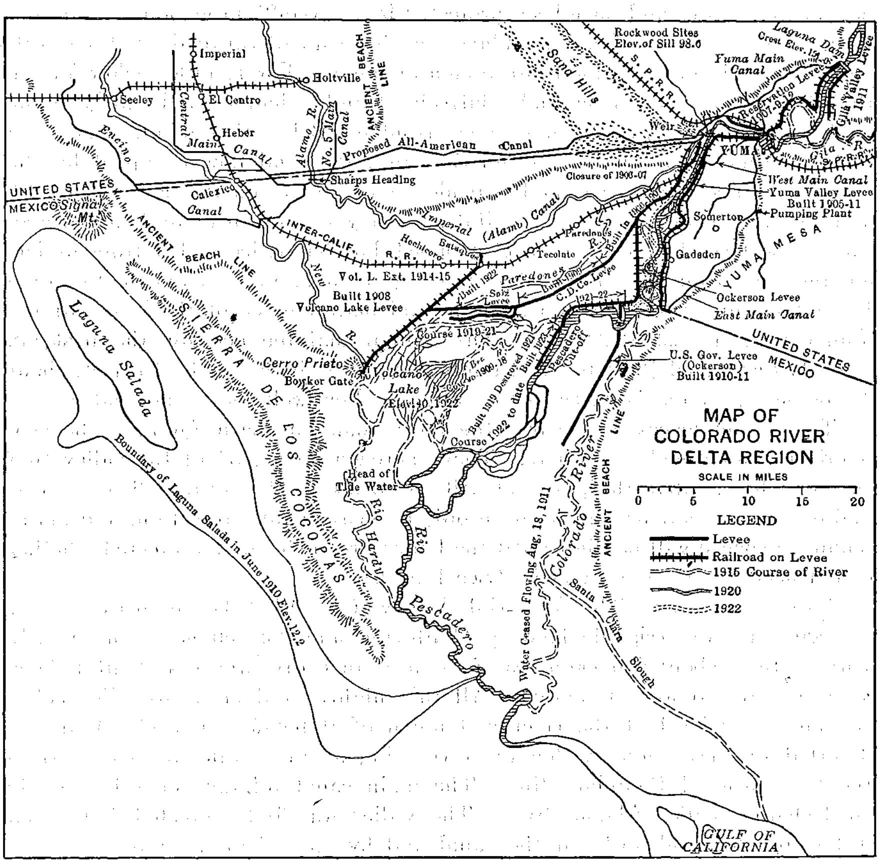

FIG. 3.

load of the river was deposited in Volcano Lake and its bed was raised at a rate that made it difficult to keep the Volcano Lake Levee above it. In 1911, the Federal Government provided $1 000 000 to relieve the situation. The funds were used to build the Ockerson Levee in an attempt to put the river back into its old channel. (See Fig. 3.) The attempt was unsuccessful. In 1922, the Pescadero Cut-off was built and the river successfully turned from Bee River and Volcano Lake into Pescadero River. As a part of the Cut-off project, the Ockerson Levee was repaired and extended about 8 miles along the north bank of Bee River, thence south across the river and down the west bank of the cut-off channel. This new levee now constitutes the main line of defense. No alarm is now felt for the levee of the California Development Company from the intake down to the Ockerson Levee, because, in its present condition, except during Gila floods, the river never gets over its banks along this stretch. Even if the levee were breached, as it was in 1914 and again in 1916, there would be no flow into the valley. If the new levee should fail, however, the river would return to Volcano Lake and again threaten the Valley with inundation over the Volcano Lake Levee. The new levee is a substantial structure with a railroad throughout its full length and rock revetment on the river side. During the long flood season, however, the ground under and on both sides of the levee becomes saturated and softened so that, if the river in its meanders should start a direct attack, the levee might fail by undercutting in spite of all efforts to save it. Between \$6 000 000 and \$7 000 000 has been spent on the flood protection of Imperial Valley, of which amount the Southern Pacific Railroad Company has paid about \$2 300 000 and the Federal Government, \$1 100 000. (See Table 1.) The annual maintenance is said to be from \$200 000 to \$600 000.

A study of the reports on flood protection of the Imperial Valley shows that the engineers engaged on the work have never been alarmed over the danger of serious inundation of the Valley since the river was shut out in 1907. In this connection attention is invited to the papers by H. T. Cory,* M. Am. Soc. C. E., who closed the gap in 1907, J. C. Allison,† M. Am. Soc. C. E., and by S. L. Rothery,‡ Assoc. M. Am. Soc. C. E.

Whatever its justification, the fear of permanent inundation has grown to such an extent as to affect the ability of the Imperial District to finance and has resulted in an appeal to the Federal Government which was answered by the Act of May 18, 1920, and the "Swing-Johnson" bill. The District has contributed about \$155 000 for the investigations made under the Act of 1920.

Table 1 shows the expenditures that have been made for river control below Laguna Dam.

During the past 6 years, the annual expenditures charged to maintenance§ have been as follows:

1918	\$ 65 789
1919	73 471
1920	86 609
1921	122 958
1922	74 854
1923	94 835
Total	\$518 516
Average	\$ 86 420

* "Irrigation and River Control in the Colorado River Delta", *Transactions*, Am. Soc. C. E., Vol. LXXVI (1913), p. 1204.

† "Control of the Colorado River as Related to the Protection of Imperial Valley", *Transactions*, Am. Soc. C. E., Vol. LXXXI (1917), p. 297.

‡ "A River Diversion on the Delta of the Colorado in Relation to Imperial Valley, California", *Transactions*, Am. Soc. C. E., Vol. LXXXVI (1923), p. 1412.

§ Applies only to maintenance of levees on the Yuma Project.

TABLE 1.—EXPENDITURES FOR RIVER CONTROL BELOW LAGUNA DAM.

Reclamation Service:		
Yuma Project levees (1905–12), 54 miles:		
Earth embankment.........3 040 000 cu. yd.		
Rock revetment.........1 650 000 " "		
Construction and maintenance, 1905–23.........		$3 234 500
California Development Company:		
C. D. Co. Levee (1906–09), 27 miles, 10 miles rocked.........	$1 100 000	
Volcano Lake Levee (1908), 8 miles; raised and revetted in 1912; 10-mile extension, built 1914–15.........	525 000	
		1 625 000
U. S. Treasury—General Fund:		
Ockerson Levee (1910–11), 24.5 miles:.........	$800 000	
Repairs and betterments to C. D. Co. and Volcano Lake Levees by Col. Ockerson (1910–11).........	200 000	
Repairs to C. D. Co. and Volcano Lake Levees by Gen. Marshall (1915).........	100 000	
		1 100 000
Imperial Irrigation District:		
Volcano Lake (1916–22):		
Raising and rip-rapping (approximate).........	$500 000	
Fund furnished Gen. Marshall for repairs, 1915 (raised by subscription)..	100 000	
Sais Levee (1919) (destroyed) (estimated).........	60 000	
" " (1922) (estimated).........	80 000	
Bee River Levee and Pescadero Cut-off (1921–22).........	413 000	
Raising and revetting upper end of Ockerson Levee and revetment and repairs to C. D. Co. Levee (estimated).........	300 000	
		1 453 000
Total cost of levees.........		$7 412 500
Southern Pacific Railroad:		
Closing first break, to December 1, 1906.........	$1 375 000	
Closing second break, December 7, 1906-July 21, 1907.........	1 084 000	
		$2 459 000
Total for river control.........		$9 871 500

Average annual cost of maintenance for past 6 years:
Yuma Project.......$ 86 500
Imperial Valley......200 000

EXPENDITURES ON LEVEES, YUMA PROJECT.

Yuma Valley Levee (built in 1905–11):		
1 125 969 cu. yd. of earthwork.........	$ 353 608	
26.5 miles of railroad.........	231 889	
Rock revetment and general maintenance.........	1 142 640	
		$1 728 137
Reservation Levee (built 1907–09 and 1912):		
1 166 404 cu. yd. of earthwork.........	$ 335 252	
Railroad.........	5 670	
Rock revetment and general maintenance.........	761 290	
		1 102 212
Gila Valley Levees:		
Arizona Levee (5½ miles built 1911):		
402 005 cu. yd. of earthwork.........	$ 84 996	
6.5 miles railroad.........	71 423	
Rock revetment and general maintenance.........	184 648	
		341 067
Gila Levees (7.8 miles built 1906; abandoned):		
339 804 cu. yd. of earthwork.........	$ 63 053	
		63 053
		$3 234 469
Totals:		
3 034 182 cu. yd. of earthwork.........		$ 836 909
Railroads.........		308 982
Rock revetment and maintenance.........		2 088 578
		$3 234 469

It is not possible from the data at hand to segregate the expenditures for rock revetment and maintenance prior to 1918 into amounts for current maintenance and for permanent improvements. Some of the rock has been used to slow down the erosion of natural banks at dangerous bends that were rapidly approaching the levee, and much that has been placed in concentrated quantities on the levee at temporary danger points should not be classed as permanent improvement. Of the rock, 1 650 000 cu. yd. have been placed at a cost of approximately $1 600 000, or about $1 per cu. yd. Of this amount, about three-fourths, or $1 200 000, should be considered, it is believed, as chargeable to permanent betterments. This leaves $888 578 as the current maintenance cost for the period, 1909-23, and an average of about $67 000 per year for the 13 years of active defense of the entire system.

Flood Relief Required

The difficulties in maintaining the levees in the Lower Colorado Basin have resulted in an effort to seek relief by providing storage to reduce the flood flow.

There is considerable difference of opinion as to what flow can be handled with safety in the Lower Colorado. This is not surprising because of the wide difference in flood height for any given flow. The Yuma gauge has recorded a stage of 25 ft., with flows ranging from 35 000 to 121 000 sec-ft. In a river with a stable channel, flood heights can be predicted for any given flow, but the Colorado is not such a river. It flows in a deep bed of silt and the channel enlarges as the flow increases, so that the effect of reducing the flow by storage is uncertain. The best information available on the Lower Colorado is contained in records and reports of the U. S. Bureau of Reclamation. The most accurate data regarding flow, velocity, silt content, and scour come from the Yuma gauging station and cannot be generally applied to the entire river. They do apply with fair accuracy, however, to the river from Laguna to the delta cone.

E. C. Bebb, Assoc. M. Am. Soc. C. E., has collected and compiled most of the information on which the following conclusions are based. The ability of the river to pass its flood flow without damage to the Lower Basin depends on three factors, namely, (*a*) the quantity of water that has to be passed and the rate at which it passes; (*b*) the quantity of silt carried through and deposited in the lower reaches; and (*c*) the amount of scour performed in the bed of silt through which the river flows.

The danger of breaching the levees is rarely from pressure of high water, but from undercutting due to meandering of the stream. The tendency to meander is present at all stages, but is particularly serious during a falling stage when the banks are saturated and sloughing is accelerated by reduction of hydrostatic pressure from the river. During this stage, also, meandering is accentuated because, with the checking of velocity, the heavier silt deposits rapidly in the slower water near the convex bank at bends, thus contracting the channel and deflecting the main current more and more toward the concave bank. If at this stage a small quick rise occurs that rapidly increases the velocity without giving time for the removal of the newly formed bar, the saturated bank will be cut away rapidly. The records indicate that undercutting is likely to proceed more rapidly and to a greater depth the greater the quantity of water flowing in the river and, therefore, may get beyond control when the flow is very large.

The silt brought down by the river affects the flood problem in three ways:

1.—It accentuates the meandering of the stream and the instability of the channel as just described.

2.—It deposits in the delta and gradually raises the bed of the river, thereby requiring higher levees. This process is slow unless the deposit is concentrated over a small area near a levee as happened with the Volcano Lake Levee from 1909 to 1922.

3.—It may fill the flood channel excessively. Winter floods from the lower tributaries, including the Gila, carry excessive quantities of sediment, much of which deposits in the flood channel. In years when late summer and winter floods are above normal, the flood channel is filled to a point that may cause trouble when the large summer flood starts. This is shown by comparing the gauge heights at a flow of 10 000 sec-ft. (Fig. 4) with the hydrograph (Plate I).

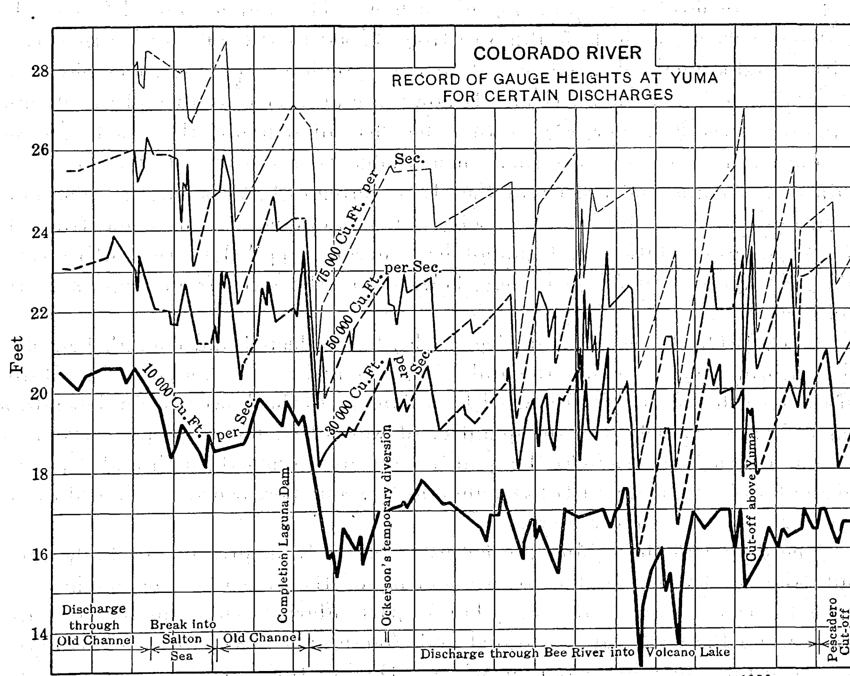

FIG. 4.

From Laguna Dam to Yuma, the river flows through a broad valley and has all the characteristics of a meandering alluvial stream. At Yuma, it is contracted by solid banks to a width of less than 600 ft. and continues in a channel

PLATE I.
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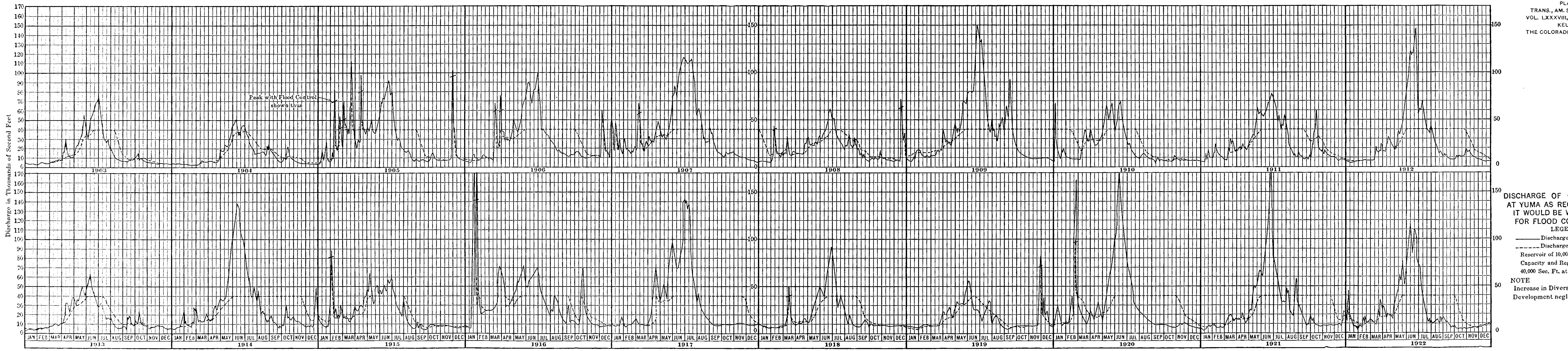


DISCHARGE OF COLORADO RIVER AT YUMA AS RECORDED AND AS IT WOULD BE WITH STORAGE FOR FLOOD CONTROL ONLY

LEGEND

———— Discharges at Yuma as recorded

- - - - - Discharges with Flood Control

Reservoir of 10,000,000 Acre Feet Capacity and Regulation to 40,000 Sec. Ft. at Yuma

NOTE

Increase in Diversions by Upstream Development neglected not more than 1 000 ft. wide for about 9 miles. This section of the river has never given serious flood trouble. The upper end of the old delta begins at this point, but in its present condition the river does not take the characteristics of a stream in its delta until it reaches the Pescadero Cut-off about 30 miles below. In the stretch from 9 to 40 miles below Yuma, the river now meanders with about the same characteristics as it does above Yuma. Just below the Pescadero Cut-off, the river spreads on its present delta cone. The area covered by the spread is relatively small and the accretions are correspondingly rapid. As the cone builds up, the delta condition probably will extend up stream so that the banks will eventually overflow at high water for some distance above the Pescadero Cut-off no matter how much the maximum flood is reduced. The normal slope of the Colorado is 1.1 ft. per mile. Under present conditions, when the Yuma gauge is below 25.4 ft., the river does not ordinarily get over its banks on the Yuma Project from Laguna to Mile 16 on the levee below Yuma, nor on the Imperial side above the junction of the Ockerson and C. D. Co. Levees. The river has passed more than 120 000 sec-ft. at this gauge height and the curves on Fig. 5 show that if the rate of increase in flow is properly retarded, the river will pass at least 80 000 sec-ft. at this stage. Below the 16-mile point, the banks are not so high above low water and the river shows a disposition to widen and not cut so deep at high water, so that the banks near the Pescadero Cut-off now overflow at a discharge of 35 000 to 50 000 sec-ft. (See Fig. 6.)

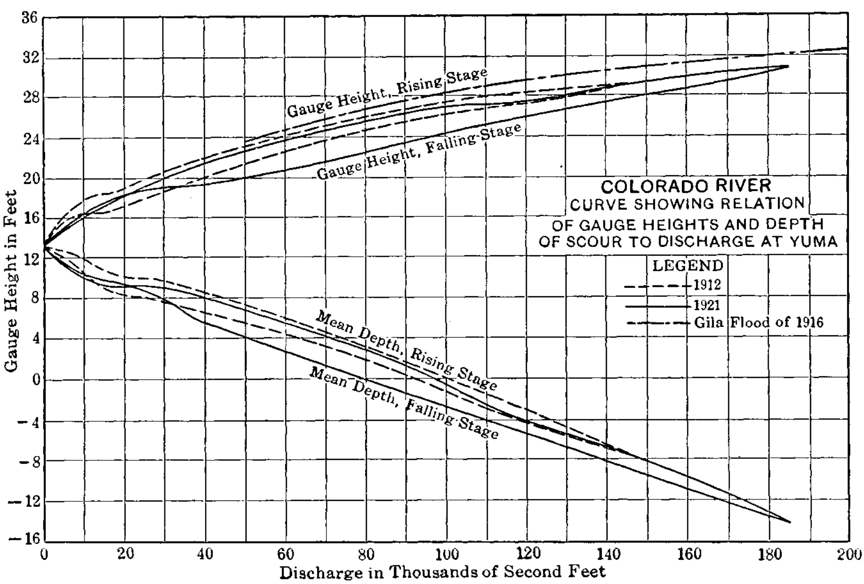
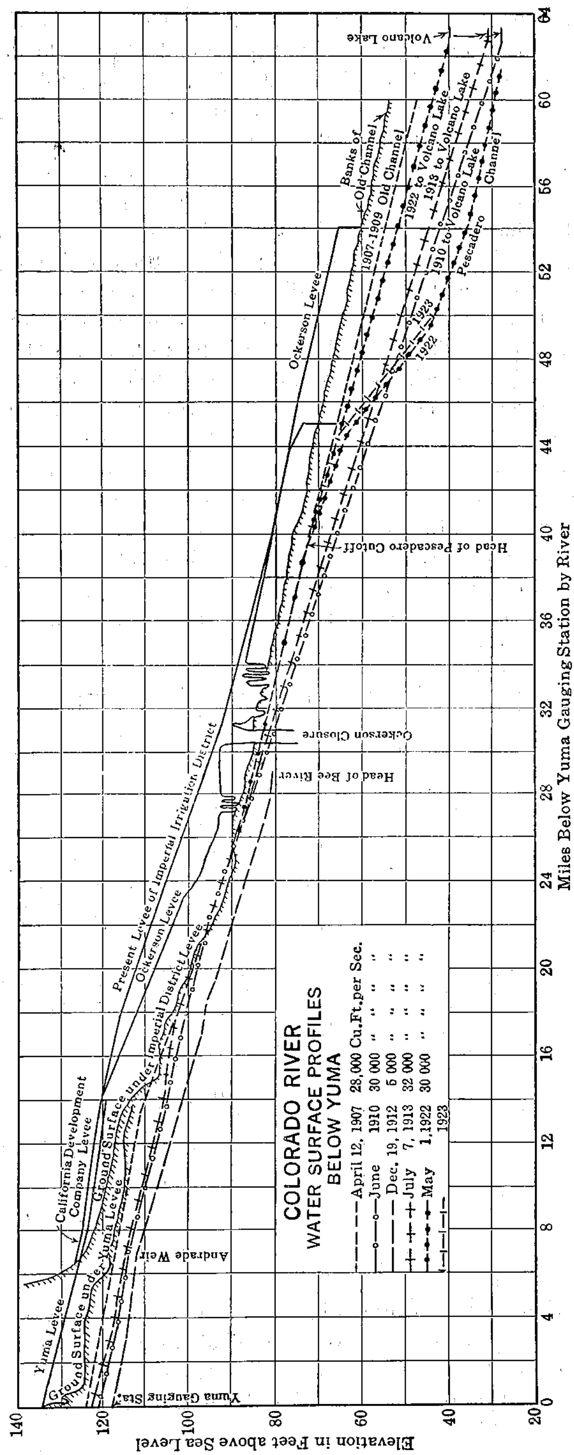


FIG. 5.

Scouring action varies theoretically as the square of the velocity. On the Colorado, active scour begins at a velocity of about 4.5 ft. per sec. and a discharge of 10 000 sec-ft. The velocity increases with discharge until a flow of about 26 000 sec-ft. is reached, at which discharge the average velocity is 6.2



COLORADO RIVER
WATER SURFACE PROFILES
BELOW YUMA
April 12, 1907 28,000 Cu.Ft.per Sec.
June 1910 30 000
Dec. 19, 1912 5 000
July 7, 1913 32 000
May 1,1922 30 000
1923
Elevation in Feet above Sea Level
Miles Below Yuma Gauging Station by River
Yuma Levee
Ground Surface
California Development Company Levee
Ground Surface under Yuma Levee
Ground Surface under Imperial District Levee
Present Levee of Imperial Irrigation District
Ockerson Levee
Andrade Weir
Yuma Gauging Sta.
Head of Bee River
Ockerson Closure
Head of Pescadero Cutoff
Banks of Old Channel
1907-1909 Old Channel
1922 to Volcano Lake
1913 to Volcano Lake
1910 to Volcano Lake
Pescadero Channel
Volcano Lake

FIG. 6.

ft. per sec. It then remains practically constant until the discharge reaches 75 000 sec-ft. after which it slowly rises. (See Fig. 7.) After a velocity of 6.2 ft. per sec. is reached, the increase in area of channel, due to scour and rise of water level, keeps pace with the increase in discharge. (See Figs. 5 and 8.) A rapid increase in discharge produces higher water levels than a slow

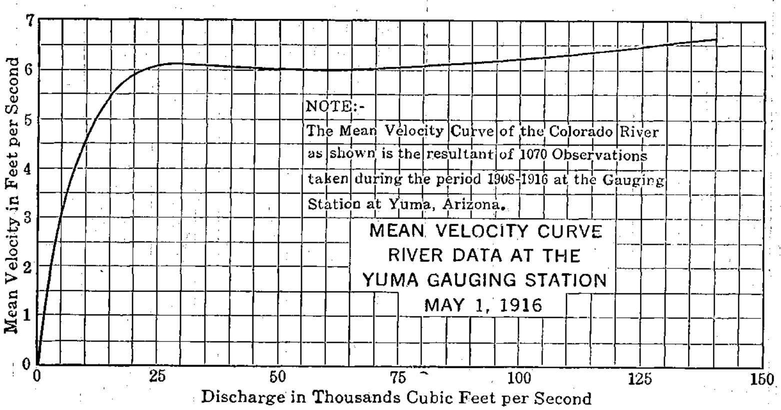


FIG. 7.

increase, because there is not time for the scour to take place. This may be seen by examination of the discharge and gauge-height curves. (See Fig. 9.) Between 20 000 and 40 000 sec-ft. appears to be a critical stage on a rising river. The silt carried within that range of discharge is excessive (see Fig. 10) and the channel on a rising river enlarges more by raising the water surface than by scour. Sudden changes in flow within that range will probably start more changes in channel than at discharges outside that range.

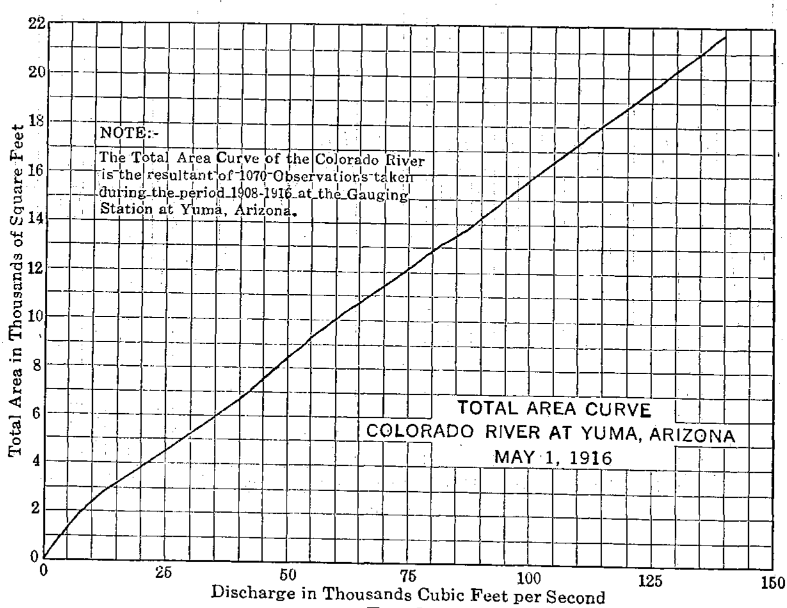


FIG. 8.

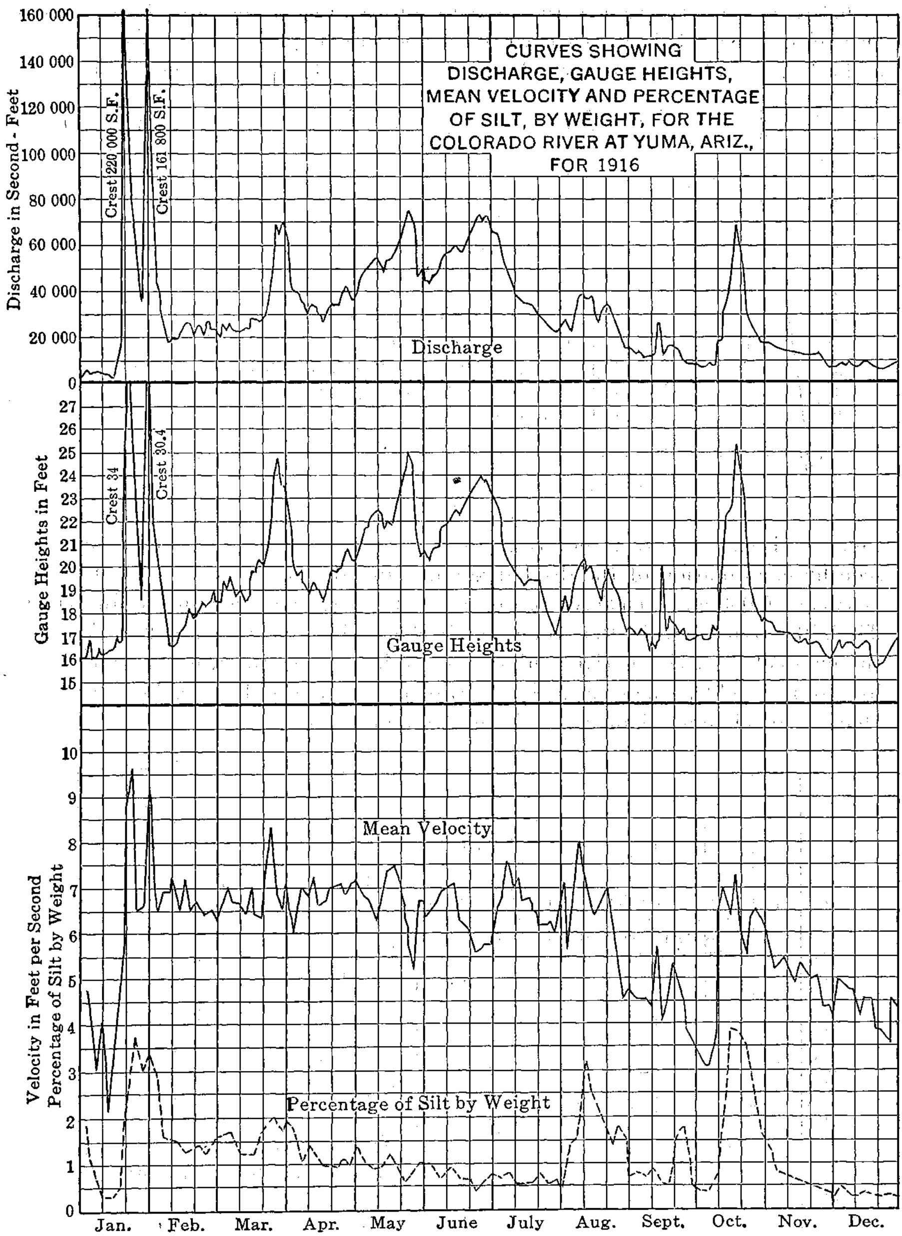

CURVES SHOWING DISCHARGE, GAUGE HEIGHTS, MEAN VELOCITY AND PERCENTAGE OF SILT, BY WEIGHT, FOR THE COLORADO RIVER AT YUMA, ARIZ., FOR 1916
Discharge in Second - Feet
160 000
140 000
120 000
100 000
80 000
60 000
40 000
20 000
0
Crest 220 000 S.F.
Crest 161 800 S.F.
Discharge
Gauge Heights in Feet
27
26
25
24
23
22
21
20
19
18
17
16
15
Crest 34
Crest 30.4
Gauge Heights
Velocity in Feet per Second
Percentage of Silt by Weight
10
9
8
7
6
5
4
3
2
1
0
Mean Velocity
Percentage of Silt by Weight
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.

FIG. 9.

If the increase in discharge from 20 000 to 40 000 sec-ft. could be made gradual and extend over a period of, say, 20 or 30 days, there probably would be less trouble due to instability of channel. After 40 000 sec-ft. is reached, the discharge can be increased more rapidly without much risk of starting new meanders. Small peaks in the flow are likely to cause trouble because they are accompanied by temporary rises in gauge heights which mean temporary rises in velocity. Examination of the operation and maintenance reports of the U. S. Bureau of Reclamation shows that such peaks are particularly objectionable on a falling river. Such peaks on a falling river have been present nearly every time the undercutting of levees has gotten beyond control. On a falling river, the discharge should be decreased slowly until the flow is about 20 000 sec-ft., in order to decrease the effect of sloughing banks and to avoid undue silting of the channel.

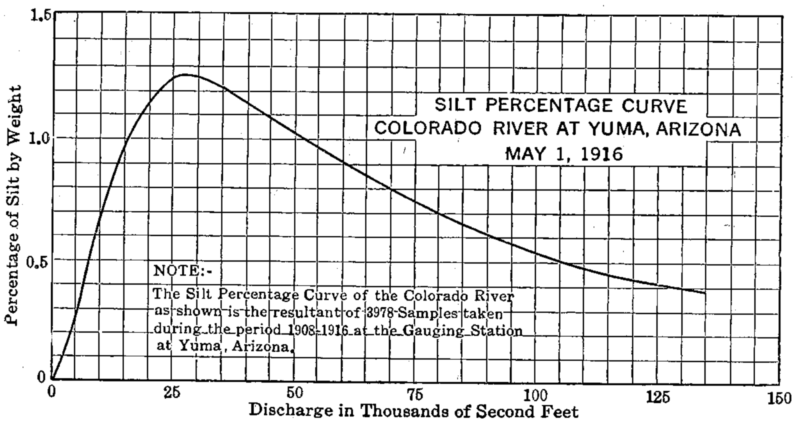


FIG. 10.

A study of the velocity curve, Fig. 7, the scour of channel curve, Fig. 5, and cross-sections on Fig. 11,* shows that the river will have the power to meander and cut its banks whenever the discharge is more than 10 000 sec-ft. It is impossible to reduce the flow to that quantity, so storage of flood water will not eliminate the necessity for bank protection and levee maintenance. The records of past flood troubles show that the river has never gone beyond control sufficiently to damage property behind the levees, except when the discharge was more than 100 000 sec-ft. If the flow is reduced to a maximum of 80 000 sec-ft. and abrupt variations in discharge are eliminated, the river will be within its banks so that danger of property damage due to flooding will be reasonably removed for the Yuma and Imperial District Projects. It is doubtful whether reducing the maximum discharge below this point will produce much saving in cost of upkeep of flood-protection works on the Yuma and Imperial District Projects and there is small chance that it will reduce the cost of property damage.

Gila floods have occurred at various times between December 1 and March 1, and they come without much warning. As any storage dam on the Colorado

* In Fig. 11, 100 ft. was added to the gauge readings to avoid the use of negative heights. In the other diagrams, straight gauge heights were used. Zero of the gauge is approximately 102 ft. above sea level.

will be 200 miles or more above Yuma, it will take at least three days for a change in discharge at the storage dam to be felt at Yuma and accurate regulation will not be possible. If the Colorado is regulated to a discharge of 40 000 sec-ft. as proposed by the U. S. Bureau of Reclamation, the flood waters will not be discharged before the middle of February in years like 1909. That means there will be a discharge of 40 000 sec-ft. in the Colorado through the period of Gila floods. It is impossible to predict what the effect of such a condition will be, but there is certainly a chance that damage from Gila floods may be increased, or that the irrigation supply may be interfered with, if an attempt is made to shut off the Colorado to conform to floods in the Gila, as proposed by the U. S. Bureau of Reclamation. It would seem wise to plan on reducing the discharge of the Colorado to the irrigation demand during the three months of probable Gila flood. In order to do this, it will be necessary for the outlet works at the dam to be capable of passing a maximum discharge in the Colorado of at least 75 000 sec-ft. so as to insure emptying the flood storage for the summer flood of the next year.

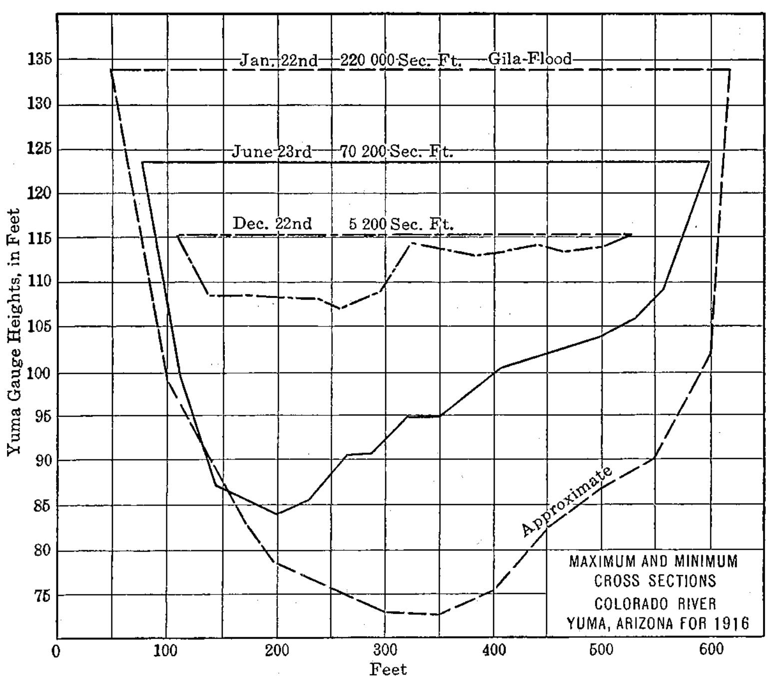


FIG. 11.

The most positive benefit that may be obtained by flood storage is that it will give insurance against permanent inundation of the Imperial Valley, provided it is great enough to permit releasing no more water than necessary to meet the irrigation demand over a period of low-water flow sufficient to enable any break into the Valley to be closed in the dry. Such a break can doubtless be closed in less than three weeks with the railroad and quarry equipment available. If storage is provided to hold the low-water flow for two months for the year of greatest run-off on record, there will be no reason for fear of disaster to the Imperial Valley. To make this practicable a maximum discharge of 80 000 sec-ft. in the Colorado is necessary in order to free flood storage for the succeeding flood season. If the maximum discharge is fixed at 75 000 sec-ft., the same result can be obtained by adding about 600 000 acre-ft. to the flood-storage capacity.

The engineers of the U. S. Bureau of Reclamation state that, considering diversions for irrigation since 1909, the flow of 1920 may be taken to represent the largest flow of record at Yuma. They give the storage required at Boulder Canyon for flood control as shown in Table 2.

TABLE 2.

Permissible discharge at Yuma, Ariz.	Required Storage, in Millions of Acre-Feet.		
	Excess flow at Yuma.	Stream storage.	Total.
40 000 sec-ft.	6.7	0.4	7.1
50 000 sec-ft.	5.5	0.4	5.9
60 000 sec-ft.	4.4	0.3	4.7
75 000 sec-ft.	3.2	0.2	3.4

The following conclusions seem to be justified:

1.—It is not feasible, with the quantity of water now passed by the Colorado, to relieve the Lower Basin from the expense of bank protection and levee maintenance by the construction of flood storage.

2.—Flood damage to property behind the levees will probably be avoided if the maximum discharge of the Colorado is reduced to 80 000 sec-ft., and there will be little, if any, reduction in cost of bank protection and maintenance by a greater reduction in discharge.

3.—It may be desirable, until the Gila is controlled, to reduce the flow in the Colorado during the months of December, January, and February, to that required for irrigation. This means that discharge facilities with a capacity of at least 75 000 sec-ft. should be provided.

4.—It is desirable to allay the fear of permanent inundation of the Imperial Valley by making it possible to stop completely the flow below Rockwood Heading for a period sufficiently long to permit remedial works to be carried out in the dry. This can be done by using the storage provided for flood control, if flood waters are discharged at a rate of 75 000 sec-ft. and an extra 600 000 acre-ft. of storage capacity is provided.

5.—Storage for flood control is justified to a quantity that will reduce the maximum discharge for any year of record to 75 000 sec-ft. Storage in excess of that quantity may be deferred until provided as an incident to other development on the river.

6.—The conditions mentioned will be met by 4 000 000 acre-ft. of flood storage. Additional storage to allow for silting of reservoirs may be advisable. The quantity of such storage necessary will depend on the shape, location, and method of operation of the storage reservoir and should be determined after the reservoir site is chosen.

7.—The reservoir should be designed so that when the summer flood starts, the discharge can be increased gradually without intermediate peaks. In so far as the river discharge permits, the maximum discharge of 75 000 sec-ft. should be reached by the time the June peak arrives. After the June peak has passed and the inflow to the reservoir has diminished to less than 75 000 sec-ft., the discharge should be gradually reduced, avoiding intermediate peaks until the discharge is less than 20 000 sec-ft., in order to avoid excessive sloughing and undercutting of banks and excessive silting of the channel.

8.—For flood protection of the Lower Basin, the reservoir should be as far down stream as practicable.

All-American Canal

The Swing-Johnson Bill provides that the United States Government finance and construct the so-called All-American Canal to serve the Imperial Valley and other lands in California, reimbursement to be sought from the lands benefited. The project is one that has been under consideration in one form or another for some time. It was reported on in July, 1919, by the "All-American Canal Board" and the report is printed in a public document entitled "The All-American Canal".

On October 23, 1918, an agreement was entered into between the Secretary of the Interior and the Imperial Irrigation District to provide for extension of Imperial Canal to Laguna Dam and committing the Imperial Irrigation District to the construction of an All-American Canal. This agreement was ratified by the voters of the Imperial Irrigation District on January 21, 1919, prior to the completion of the report by the All-American Canal Board, by a vote of 2 535 in favor and 922 against. Payments have been made by the Imperial District in accordance with the agreement so that the agreement is still in force but, on account of financial difficulties and the possibility that the United States might undertake the project, no construction work has been done.

Analysis of the All-American Canal project as proposed in the Swing-Johnson Bill shows that it may be considered as three separate propositions which have different degrees of urgency, as follows:

1.—Connection with Laguna Dam so that water for lands on the west side of the river may be diverted at that point instead of at the present Rockwood Heading.

2.—Serving lands in the Imperial Irrigation District through a canal entirely on the American side of the International Boundary in order to avoid complications that have arisen in the past over the operation and maintenance of a canal in Mexico.

3.—Serving lands on the East Side Mesa and in Coachella Valley which are too high to be served by the present canal system.

The proposition to connect with Laguna Dam has been under consideration for some time. It would overcome the difficulties and dangers incident to diversion at Rockwood Heading and would materially reduce the cost of maintaining the main Imperial Canal by keeping a considerable part of the silt out of it. It would also incidentally reduce the construction costs against the Yuma Project and furnish power for its pumping area. This part of the project will cost about $6.50 per acre for the Imperial District, and the cost will be practically the same whether the connection is made to the present Imperial Canal or to the proposed All-American Canal. The Imperial District is on record as ready to pay its share of the undertaking and there is no doubt that the project should be carried out. The only question at issue is whether the Federal Government shall finance the proposition and that is a matter of policy to be determined by Congress.

The All-American Canal proposition is the result of international complications incident to operating the main Imperial Canal through Mexico. Physically, the present canal is in excellent condition. It follows the natural line for a canal and if connected to Laguna Dam and relieved of Mexican troubles would be more satisfactory than the proposed All-American Canal which must cross drifting sand hills and difficult terrain for about 15 miles in cuts more than 100 ft. deep. The cost of the All-American Canal to the Imperial District, if undertaken alone, would be about $40 per acre. If undertaken in conjunction with all other lands possible of irrigation therefrom, the cost to the Imperial District will be about $30 per acre. These costs are additional to the $6.50 per acre for connecting to Laguna Dam. The question of whether the advantages of getting out of Mexico justify the cost is one for the Imperial District to decide. It did decide in 1919, but since that time the estimate of cost has been increased and the Mexican Government has been recognized, so that the prospect of relief by treaty is improved. If the Imperial District is ready to stand by its agreement to pay for this project, as it appears to be, the only question at issue is, shall the United States finance

TABLE 3.—COST OF CONNECTING THE IMPERIAL CANAL (OR ALL-AMERICAN CANAL) WITH THE LAGUNA DAM.

	Including power.	Power charged separately.
Case I.—All-American Canal as Projected. (Capacity 9 000 sec-ft. + 1 600 sec-ft.):		
Yuma Project (114 000 acres)	$13.00	$33.00 pump lands 0.00 non-pumplands
Imperial Irrigation District (515 000 acres)	8.00	6.50
New land under All-American Canal (300 000 acres)	8.00	6.50
Case II.—Mexican Lands now Under Imperial Canal Added to All-American Canal Area. (Capacity 11 500 sec-ft. + 1 600 sec-ft.):		
Yuma Project (114 000 acres)	13.00	33.00 pump lands 0.00 non-pump lands
Imperial Irrigation District (515 000 acres)	6.50	5.75
New lands under All-American Canal (300 000 acres)	6.50	5.75
Mexican lands under Imperial Canal (255 000 acres)	6.50	5.75
Case III.—Connection Made with Imperial Canal and Water Distributed Through That System (8 500 sec-ft + 1 600 sec-ft.):		
Yuma Project (114 000 acres)	13.00	33.00 pump lands 0.00 non-pump lands
Imperial Irrigation District (515 000 acres)	8.00	6.50
Mexican lands under Imperial Canal (255 000 acres)	8.00	6.50

TABLE 4.—COST OF ALL-AMERICAN CANAL.

(Including Cost of Connection with Laguna Dam. Yuma Project Charged for Its Interest in the Improvement.)

	Distribution system and power.	All-American Canal.	Total per acre.
Case I.—Cost if Built for New Lands Only (Excluding West Side Area) (Capacity 3 000 sec-ft.):			
(*A*). Cost of All-American Canal, not including cost of distribution systems and power installation: $18 321 000 for 265 600 acres at $69.00 per acre.			
(*B*). Cost of All-American Canal with distribution systems and power installation included:			
"A" Line Canal south of Iris (98 000 acres)........	$44.70	$69.00	$113.70
"A" Line Canal north of Iris (77 100 acres)........	84.00	69.00	153.00
South Side Gravity:			
(Mexico 22 000 acres; United States 8 800 acres)..	20.00	69.00	89.00
"E" Line (15 700 acres)...........................	23.50	69.00	92.50
"D" Line (Pump) (44 000 acres)...................	30.60	69.00	99.60
Case II.—Cost if Built for Imperial Irrigation District and New Lands Listed in Senate Document No. 142* (Capacity 9 000 sec-ft.):			
(*A*). Cost of All-American Canal, not including cost of distribution system and power installations: $29 793 000 for 813 600 acres at $36.60 per acre; $29 793 000 for 736 500 acres at $40.40 per acre. (North of Iris excluded.)			
(*B*). Cost of All-American Canal per acre with cost of distribution systems and power installations included:			
Imperial Irrigation District (515 000 acres).........	4.00	36.60	40.90
"A" Line Canal south of Iris (98 000 acres)........	44.70	36.60	81.30
"A" Line Canal north of Iris (77 100 acres)........	84.00	36.60	120.60
South Side Gravity:			
(Mexico 22 000 acres; United States 8 800 acres.)..	20.00	36.60	56.60
"E" Line (15 700 acres)...........................	23.50	36.60	60.10
"D" Line (Pump) (44 000 acres)...................	30.60	36.60	67.20
"B" Line (Gravity and Pump) (33 000 acres)......	56.00	36.60	92.60
Case III.—Cost if Built for Imperial Irrigation District Alone (Capacity, 6 000 sec-ft.):			
Cost of All-American Canal, without power installation or new distribution systems, but prepared for later enlargement to take care of new lands: $24 504 057†, or 515 000 acres at $47.60 per acre.			

* 67th Congress, 2d Sess.

† All-American Canal Rept., p. 96.

and build the project? Decision on this question is more or less dependent on the decision on the third proposition.

If the United States decides to undertake the irrigation of the lands too high to be reached by present canals, there will be advantages in combining with the Imperial District. The cost of an All-American Canal for the 270 000 acres that can be irrigated outside the Imperial District will be about $62.50 per acre, if undertaken alone, and $31 per acre, if undertaken in conjunction with the Imperial District. To these amounts should be added $6.50 per acre for connection with Laguna Dam and the cost of distribution systems. There is no information available to show the cost of a high canal through Mexico on a more favorable route, nor the cost of serving this land by pumping from the present canal system.

Tables 3 and 4 were prepared in order to analyze the costs of various parts of the project. They are based on unit costs of the All-American Canal Board and acreages given in the "Fall-Davis" report. It will be noted that if the

Imperial District and Mexican high lands participate in the All-American Canal, the cost of putting water on the East Mesa lands will be about $81 per acre and on Coachella Valley lands about $120 per acre. If the Imperial District and Mexican high lands do not participate in the All-American Canal, these costs will be raised to $113 and $153, respectively. On the East Side Mesa, 148 000 acres of the 160 000 irrigable are public lands. In the Coachella Valley and Dos Palmas combined, of a total of 77 000 acres irrigable, 4 500 acres are public lands and 11 400 acres are Indian lands. If the East Side Mesa and Coachella Valley lands are combined so as to average the costs, the figures become $90 per acre and $118 per acre, respectively, depending on whether or not the Imperial District participates in the All-American Canal. The data available are not sufficient to determine how much cost is justifiable to bring the 270 000 acres of lands outside Imperial District under irrigation.

Water Supply, Storage Required, and Irrigable Areas

The following is extracted from a report recently made to the Secretary of the Interior by Herman Stabler, M. Am. Soc. C. E., Chief of the Land Classification Branch of the U. S. Geological Survey:

"Water Supply of Colorado River

"The run-off of Colorado River available for future development above the diversion for the Yuma Project at Laguna Dam and for all development below this point can be expressed in terms of discharge at Laguna Dam, obtained by subtracting from the run-off of the Colorado at Yuma (*a*) the run-off of the Gila at Yuma and (*b*) depletion by reason of irrigation use and diversions from the basin above, and adding to the result thus obtained the diversions for the Yuma Project.

"In this study there have been used (*a*) records of discharge of the Colorado at Yuma since 1902; (*b*) rough estimates of discharge of the Gila at Yuma since 1903; (*c*) records of diversions for the Yuma Project since 1910; and (*d*) estimates of depletion since 1899, all furnished by the Bureau of Reclamation. In addition, gauge heights of Colorado River at Yuma from 1878 to 1922 have been used to extend the record of discharge back to 1878, and the estimates of depletion have also been extended on the assumption that irrigation in the basin began about 1850. Records of run-off of Salt River since 1889 and estimates of inflow to Great Salt Lake under the assumption of present-day development estimated from the record of Salt Lake levels have been studied as comparates, but have not been used in estimates of run-off.

"Two methods were used to develop a relation between discharge and stage at Yuma, effort being made in both to establish a method by which allowance for shifting channel conditions could be made from the record of gauge heights alone. Both methods give similar results in years of moderate flow. One method gives results rather high for years of low flow, while the other appears to give results slightly low for years of low flow. The average results by the two methods are presented as probably being more reliable than either, though apparently indicating discharges too great for years of low flow. For the period 1902-1922, in which comparison with discharge records is possible, the annual results obtained are less than the recorded discharge by as much as 10% in three years (1907, 1914, and 1920), the maximum being 20% for the year 1907. Considered as 5-year progressive means, the period 1906-1910 is found to be lower than the recorded discharge by 5%, while the period 1902-1907 is higher than the recorded discharge by 7.6%, these representing the maximum digressions. These results check the accuracy of the method so far as it can be tested directly and indicate that it is fairly reliable as an indicator of mean discharge for periods of 5 years or more.

"The discharge of the Colorado as estimated for the period 1878-1922 at the diversion for the Yuma Project is given in following table [Table 5], in millions of acre-feet.

"The following table [Table 6], shows the mean discharge for various periods for Colorado River, Great Salt Lake, and Salt River, based on mean discharge for the period 1902-1922, the period of discharge records on Colorado River, all on the assumption that conditions of development were the same as in 1922 throughout the periods considered.

"The comparison here afforded tends to increase materially the confidence with which the estimated discharge prior to 1902 may be used.

"Effect of Storage on Water Supply

"Studies of water supply indicate that under conditions of development as in 1922, the water supply likely to reach Laguna Dam varies from about 6 000 000 to about 27 000 000 acre-ft. a year, and it is not unlikely that these limits may be exceeded in both directions. The mean flow (1922 conditions and equivalent flow at Laguna) for a period of 45 years, 1878-1922, is between 13 000 000 and 14 000 000 acre-ft. For periods of as much as or more than 20 years, however, the flow may be less than 11 000 000 or more than 16 000 000 acre-ft.

"TABLE 5.—Estimated Discharge of Colorado River at Laguna with 1922 Conditions of Development.
(Millions of Acre-Feet.)

Year.	Discharge.	Year.	Discharge.	Year.	Discharge.
1878	13.0	1893	11.7	1908	11.7
1879	8.7	1894	8.8	1909	24.6
1880	13.6	1895	9.4	1910	18.3
1881	11.2	1896	7.7	1911	16.8
1882	8.6	1897	10.2	1912	17.5
1883	14.0	1898	7.7	1913	11.5
1884	27.2	1899	14.0	1914	20.1
1885	15.3	1900	10.1	1915	12.6
1886	11.5	1901	14.2	1916	18.7
1887	9.1	1902	6.0	1917	19.6
1888	8.3	1903	10.3	1918	13.0
1889	9.4	1904	9.0	1919	10.3
1890	14.5	1905	14.9	1920	21.1
1891	12.9	1906	16.6	1921	19.5
1892	14.4	1907	23.9	1922	16.9
Mean	....	....	....	....	13 6

"Irrigation and power requirements both would be best served if the annual flow were made substantially uniform. The following tables [Tables 7, 8, 9, and 10], indicate what may be accomplished in this regard with specified amounts of storage capacity under the assumption that the storage reservoir or reservoirs would be full or, if of sufficient capacity, would contain 10 000 000 acre-ft. at the beginning of the 45-year period considered. The tables show the amount of water in storage each year, evaporation throughout being assumed to be 3% of the amount of water in storage. An empty reservoir and shortage in available water supply is indicated by parentheses and minus sign.

"TABLE 6.—MEAN DISCHARGE IN PERCENTAGE OF MEAN DISCHARGE FOR PERIOD 1902-1922, WITH 1922 CONDITIONS OF DEVELOPMENT.

Period.	Colorado River at Laguna.	Great Salt Lake inflow.	Salt River at Roosevelt.
1902–1922	100	100	100
1899–1922	98	97	92
1889–1922	89	90	90
1878–1922	87	89	..
1851–1922	..	92	..
1889–1901	72	78	72
1878–1901	76	78	..
1886–1904	67	75	..
1889–1904	68	75	64

"TABLE 7.—SHOWING SURPLUS OR DEFICIENCY OF WATER SUPPLY WITH REGULATION IN A RESERVOIR OF 5 000 000 ACRE-FT. CAPACITY FOR SPECIFIED ANNUAL DEMAND.
(Millions of Acre-Feet.)

Years.	Estimated flow at Laguna.	Annual Demand: 10.	Annual Demand: 11.
1877	....	5.0	5.0
1878	13.0	5.0	5.0
1879	8.7	3.5	2.5
1880	13.6	5.0	5.0
1881	11.2	5.0	5.0
1882	8.6	3.5	2.5
1883	14.0	5.0	5.0
1884	27.2	5.0	5.0
1885	15.3	5.0	5.0
1886	11.5	5.0	5.0
1887	9.1	3.9	2.9
1888	8.3	2.1	0.1
1889	9.4	1.5	(—1.5)
1890	14.5	5.0	3.5
1891	12.9	5.0	5.0
1892	14.4	5.0	5.0
1893	11.7	5.0	5.0
1894	8.8	3.6	2.6
1895	9.4	2.9	0.9
1896	7.7	0.5	(—2.4)
1897	10.2	0.7	(—0.8)
1898	7.7	(—0.7)	(—3.3)
1899	14.0	4.0	3.0
1900	10.1	4.0	2.0
1901	14.2	5.0	5.0
1902	6.0	0.8	(—0.2)
1903	10.3	1.1	(—0.7)
1904	9.0	0.0	(—2.0)
1905	14.9	4.9	3.9
1906	16.6	5.0	5.0
1907	13.9	5.0	5.0
1908	11.7	5.0	5.0
1909	24.6	5.0	5.0
1910	13.3	5.0	5.0
1911	16.8	5.0	5.0
1912	17.5	5.0	5.0
1913	11.5	5.0	5.0
1914	20.1	5.0	5.0
1915	12.6	5.0	5.0
1916	18.7	5.0	5.0
1917	19.6	5.0	5.0
1918	13.0	5.0	5.0
1919	10.3	5.0	4.1
1920	21.1	5.0	5.0
1921	19.5	5.0	5.0
1922	16.9	5.0	5.0

"TABLE 8.—Showing Surplus or Deficiency of Water Supply with Regulation in a Reservoir of 10 000 000 Acre-Ft. Capacity for Specified Annual Demand.
(Millions of Acre-Feet.)

Years.	Estimated flow at Laguna.	Annual Demand:					
		10.	11.	11.5.	12.	12.5.	13.
1877	....	10.0	10.0	10.0	10.0	10.0	10.0
1878	13.0	10.0	10.0	10.0	10.0	10.0	9.7
1879	8.7	8.7	7.7	6.9	6.4	5.9	5.1
1880	13.6	10.0	10.0	8.8	7.8	6.8	5.5
1881	11.2	10.0	9.9	8.2	6.8	5.3	3.5
1882	8.6	8.6	7.2	5.1	3.2	1.2	(—1.0)
1883	14.0	10.0	10.0	7.4	5.1	2.7	1.0
1884	27.2	10.0	10.0	10.0	10.0	10.0	10.0
1885	15.3	10.0	10.0	10.0	10.0	10.0	10.0
1886	11.5	10.0	10.0	9.7	9.2	8.7	8.2
1887	9.1	9.1	7.8	7.0	6.0	5.0	4.1
1888	8.3	7.1	4.8	3.6	2.1	0.6	(—0.7)
1889	9.4	6.3	3.0	1.4	(—0.6)	(—2.1)	(—3.6)
1890	14.5	10.0	6.4	4.4	2.5	2.0	1.5
1891	12.9	10.0	8.1	5.7	3.3	2.3	1.4
1892	14.4	10.0	10.0	8.4	5.6	4.1	2.8
1893	11.7	10.0	10.0	8.4	5.1	3.2	1.4
1894	8.8	8.8	7.5	5.4	1.7	(—0.6)	(—2.8)
1895	9.4	7.9	5.7	3.1	(—1.0)	(—3.1)	(—3.6)
1896	7.7	5.4	2.2	(—0.8)	(—4.3)	(—4.8)	(—5.3)
1897	10.2	5.4	1.3	(—1.3)	(—1.8)	(—2.3)	(—2.8)
1898	7.7	3.0	(—2.0)	(—3.8)	(—4.3)	(—4.8)	(—5.3)
1899	14.0	6.9	3.0	2.5	2.0	1.5	1.0
1900	10.1	6.8	2.0	1.5	0.0	(—0.9)	(—1.9)
1901	14.2	10.0	5.1	4.2	2.2	1.7	1.2
1902	6.0	6.0	0.0	(—0.6)	(—3.9)	(—4.8)	(—5.8)
1903	10.3	6.1	(—0.7)	(—1.2)	(—1.7)	(—2.2)	(—2 7)
1904	9.0	4.9	(—2.0)	(—2.5)	(—3.0)	(—3.5)	(—4.0)
1905	14.9	9.7	3.9	3.4	2.9	2.4	1.9
1906	16.6	10.0	9.4	8.4	7.4	6.4	5.4
1907	13.9	10.0	10.0	10.0	9.1	7.6	6.1
1908	11.7	10.0	10.0	9.9	8.5	6.6	4.6
1909	24.6	10.0	10.0	10.0	10.0	10.0	10.0
1910	13.3	10.0	10.0	10.0	10.0	10.0	10.0
1911	16.8	10.0	10.0	10.0	10.0	10.0	10.0
1912	17.5	10.0	10.0	10.0	10.0	10.0	10.0
1913	11.5	10.0	10.0	9.7	9.2	8.7	8.2
1914	20.1	10.0	10.0	10.0	10.0	10.0	10.0
1915	12.6	10.0	10.0	10.0	10.0	10.8	9.3
1916	18.7	10.0	10.0	10.0	10.0	10.0	10.0
1917	19.6	10.0	10.0	10.0	10.0	10.0	10.0
1918	13.0	10.0	10.0	10.0	10.0	10.0	9.7
1919	10.3	10.0	9.0	8.5	8.0	7.5	6.7
1920	21.1	10.0	10.0	10.0	10.0	10.0	10.0
1921	19.5	10.0	10.0	10.0	10.0	10.0	10.0
1922	16.9	10.0	10.0	10.0	10.0	10.0	10.0

"TABLE 9.—SHOWING SURPLUS OR DEFICIENCY IN WATER SUPPLY WITH REGULATION IN A RESERVOIR OF 20 000 000 ACRE-FT. CAPACITY FOR SPECIFIED ANNUAL DEMAND.
(Millions of Acre-Feet.)

Years.	Estimated flow at Laguna.	Annual Demand:			
		11.	12.	13.	14.
1877	....	10.0	10.0	10.0	10.0
1878	13.0	11.7	10.7	9.7	8.7
1879	8.7	9.1	7.1	5.1	3.1
1880	13.6	11.4	7.8	5.5	2.6
1881	11.2	11.3	6.8	3.5	(—0.3)
1882	8.6	8.6	3.2	(—1.0)	(—5.4)
1883	14.0	11.3	5.1	1.0	(—0.0)
1884	27.2	20.0	20.0	15.2	13.2
1885	15.3	20.0	20.0	17.1	14.1
1886	11.5	19.9	18.9	15.1	11.2
1887	9.1	17.4	15.4	10.8	6.0
1888	8.3	14.2	11.2	5.8	0.1
1889	9.4	12.2	8.3	2.0	(—4.5)
1890	14.5	15.3	10.6	3.4	0.5
1891	12.9	16.7	10.7	3.2	(—0.6)
1892	14.4	19.6	12.8	4.5	0.4
1893	11.7	19.7	12.1	3.1	(—1.9)
1894	8.8	16.9	8.5	(—1.2)	(—5.2)
1895	9.4	14.8	5.6	(—3.6)	(—4.6)
1896	7.7	11.1	1.1	(—5.3)	(—6.3)
1897	10.2	10.0	(—0.7)	(—2.8)	(—3.8)
1898	7.7	6.4	(—4.3)	(—5.3)	(—6.3)
1899	14.0	9.2	2.0	1.0	0.0
1900	10.1	8.0	0.0	(—1.9)	(—3.9)
1901	14.2	11.0	2.2	1.2	0.2
1902	6.0	5.7	(—3.9)	(—5.8)	(—7.8)
1903	10.3	4.8	(—1.7)	(—2.7)	(—3.7)
1904	9.0	2.6	(—3.0)	(—4.0)	(—5.0)
1905	14.9	6.4	2.9	1.9	0.9
1906	16.6	11.8	7.4	5.4	3.5
1907	13.9	14.3	9.1	6.1	3.3
1908	11.7	14.5	8.5	4.6	0.9
1909	24.6	20.0	20.0	16.1	11.5
1910	13.3	20.0	20.0	15.9	10.5
1911	16.8	20.0	20.0	19.2	13.0
1912	17.5	20.0	20.0	20.0	16.1
1913	11.5	19.9	18.9	17.9	13.1
1914	20.1	20.0	20.0	20.0	18.7
1915	12.6	20.0	20.0	19.0	16.7
1916	18.7	20.0	20.0	20.0	20.0
1917	19.6	20.0	20.0	20.0	20.0
1918	13.0	20.0	20.0	19.4	18.4
1919	10.3	18.7	17.7	16.3	14.1
1920	21.1	20.0	20.0	20.0	20.0
1921	19.5	20.0	20.0	20.0	20.0
1922	16.9	20.0	20.0	20.0	20.0

"TABLE 10.—SHOWING SURPLUS OR DEFICIENCY IN WATER SUPPLY WITH REGULATION IN A RESERVOIR OF 30 000 000 ACRE-FT. CAPACITY FOR SPECIFIED ANNUAL DEMAND.

(Millions of Acre-Feet.)

Years.	Estimated flow at Laguna.	Annual Demand.		
		12.	13.	14.
1877	....	10.0	10.0	10.0
1878	13.0	10.7	9.7	8.7
1879	8.7	7.1	5.1	3.1
1880	13.6	7.8	5.5	2.6
1881	11.2	6.8	3.5	(—0.3)
1882	8.6	3.2	(—1.0)	(—5.4)
1883	14.0	5.1	1.0	(—0.0)
1884	27.2	20.1	15.2	13.2
1885	15.3	22.8	17.1	14.1
1886	11.5	21.6	15.1	11.2
1887	9.1	18.1	10.8	6.0
1888	8.3	13.9	5.8	0.1
1889	9.4	10.9	2.0	(—4.5)
1890	12.9	13.6	3.2	(—0.6)
1891	14.5	13.1	3.4	0.5
1892	14.4	15.6	4.5	0.4
1893	11.7	14.8	3.1	(—1.9)
1894	8.8	11.2	(—1.2)	(—5.2)
1895	9.4	8.3	(—3.6)	(—4 6)
1896	7.7	3.8	(—5.3)	(—6.3)
1897	10.2	1.9	(—2.8)	(—3.8)
1898	7.7	(—2.5)	(—5.3)	(—6.3)
1899	14.0	2.0	1.0	0.0
1900	10.1	0.0	(—1.9)	(—3.9)
1901	14.2	2.2	1.2	0.2
1902	6.0	(—3.9)	(—5.8)	(—7.8)
1903	10.3	(—1.7)	(—2.7)	(—3.7)
1904	9.0	(—3.0)	(—4.0)	(—5.0)
1905	14.9	2.9	1.9	0.9
1906	16.6	7.4	5.4	3.5
1907	13.9	9.1	6.1	3.3
1908	11.7	8.5	4.6	0.9
1909	24.6	20.8	16.1	11.5
1910	13.3	21.5	15.9	10.5
1911	16.8	25.7	19.2	13.0
1912	17.5	30.0	23.1	16.1
1913	11.5	28.6	20.9	13.1
1914	20.1	30.0	27.4	18.7
1915	12.6	29.7	26.2	16.7
1916	18.7	30.0	30.0	20.9
1917	19.6	30.0	30.0	25.9
1918	13.0	30.0	29.1	24.1
1919	10.3	27.4	25.5	19.7
1920	21.1	30.0	30.0	26.2
1921	19.5	30.0	30.0	30.0
1922	16.9	30.0	30.0	30.0

"In the foregoing summary the percentage of maximum shortage is based on the stated amount of annual demand. As irrigation development proceeds, the annual flow at the storage reservoirs would be decreased by more than 1 000 000 acre-ft. when the area of lands estimated to be irrigable in the immediate future receives water, by over 2 000 000 acre-ft. when the area estimated to be irrigable in the near future receives water, and by about 5 000 000 acre-ft. when the area estimated to be irrigable in the distant future receives water. Furthermore, it cannot reasonably be assumed that the shortage will be prorated fully over the lands below Boulder Canyon that now receive a full water supply and require 3 000 000 to 4 000 000 acre-ft. for irrigation. The water shortages for new lands below Boulder Canyon will therefore be greatly increased over the percentages indicated in Table [11]. If irrigation development below Boulder Canyon is based on the theory that a flow of 14 000 000 acre-ft., or even of 13 000 000 acre-ft., can be maintained annually, years are indicated for the distant future when not only would there be no water for new lands, but lands now irrigated would receive a scant supply regardless of whether the storage capacity available be 10 000 000, 20 000 000, or 30 000 000 acre-ft. The data indicate that it is unsafe at this time to plan development on the basis of an annual flow of more than between 11 000 000 and 12 000 000 acre-ft.

"The data in Tables 7, 8, 9, and 10 are summarized, as follows:

	Storage Capacity, in Millions of Acre-Feet.			
	5.	10.	20.	30.
Annual Demand of 10 000 000 Acre-Feet:				
Shortage, percentage of time	2	0	....	....
Maximum shortage, percentage	7	0	....	....
Overflow, percentage of time	64	62	....	....
Annual Demand of 11 000 000 Acre-Feet:				
Shortage, percentage of time	16	7	0	....
Maximum shortage, percentage	30	Under 20	0	....
Overflow, percentage of time	60	49	31	....
Annual Demand of 11 500 000 Acre-Feet:				
Shortage, percentage of time	....	13	....	....
Maximum shortage, percentage	....	33	....	....
Overflow, percentage of time	....	33	....	....
Annual Demand of 12 000 000 Acre-Feet:				
Shortage, percentage of time	....	18	11	9
Maximum shortage, percentage	....	36	36	32
Overflow, percentage of time	....	28	31	16
Annual Demand of 12 500 000 Acre-Feet:				
Shortage, percentage of time	....	22	....	....
Maximum shortage, percentage	....	38	....	....
Overflow, percentage of time	....	26	....	....
Annual Demand of 13 000 000 Acre-Feet:				
Shortage, percentage of time	....	27	22	22
Maximum shortage, percentage	....	45	41	41
Overflow, percentage of time	....	22	16	11
Annual Demand of 14 000 000 Acre-Feet:				
Shortage, percentage of time	....	....	31	31
Maximum shortage, percentage	....	....	55	55
Overflow, percentage of time	....	....	11	4

"The storage capacity adequate to maintain reasonably uniform annual flow is difficult to determine. It is evidently greater than 5 000 000 and pretty certainly as great as 10 000 000 acre-ft. and less than 20 000 000 acre-ft. Capacity of 10 000 000 acre-ft. will provide annual flow of 11 500 000 acre-ft. with somewhat less onerous conditions of shortage than if capacity of 20 000 000 acre-ft. were utilized to provide annual flow of 12 000 000 acre-ft.

"INCREASE OF STORAGE CAPACITY FROM 10 000 000 ACRE-FT. TO THE AVAILABLE ANNUAL WATER SUPPLY.

"According to estimates of Bureau of Reclamation engineers the cheapest known storage capacity of 10 000 000 acre-ft. would be the top 65 ft. (approximately) of the large Boulder Canyon reservoir and would cost about $10 000 000. At $1 per acre-foot of storage capacity the increase in storage capacity from 10 000 000 to 20 000 000 acre-ft. would cost more than $20 per acre-foot of increase in mean annual flow. This would be a doubtful investment if the increase in possible power and irrigation development at and below Boulder Canyon be alone considered, but may be justifiable if the additional storage capacity be provided up stream so that the additional flow could be utilized for power purposes through the much greater head available, in the canyon section of Colorado River.

"It is concluded that storage capacity in excess of 10 000 000 acre-ft. should not be provided, if at all, until the conditions of water supply under future development are much better known than at present.

"EFFECT OF ESTIMATES OF WATER SUPPLY AND PRACTICABLE STORAGE CONTROL ON POSSIBILITIES OF IRRIGATION DEVELOPMENT

"The estimates of water supply and practicable storage for the period 1878-1922 indicate that through long periods not to exceed 12 000 000 acre-ft. of water a year may be relied on for future irrigation development above Laguna Dam and for present and future development below that point.

"Compilation of irrigable areas in the basin of Colorado River and the adjacent basin of Salton Sea, classified by degree of feasibility, has been made by engineers of the Bureau of Reclamation. These areas and estimated net consumption of water by them and by probable diversions from the basin are set forth in the following table [Table 11]:

"TABLE 11.—IRRIGABLE AREAS AND WATER REQUIREMENTS.

(Areas in Thousands of Acres and Shown to Nearest 10 000. Water Consumption in Thousands of Acre-Feet and Shown to Nearest 100 000.)

	PRESENT:		IMMEDIATE FUTURE:		NEAR FUTURE:		DISTANT FUTURE:		TOTAL:	
	Area.	Water.	Area.	Water.	Area.	Water.	Area.	Water.	Area.	Water.
Above Boulder.....	....	....	770	1 300	1 060	2 000	970	1 900	2 900	5 200
Between Boulder and Laguna......	....	....	170	500	50	200	870*	3 900	1 090	4 600
Below Laguna in United States....	470	2 100	430	1 900	....	....	....	....	900	4 000
Total in United States...........	470	2 100	1 370	3 700	1 110	2 100	1 840	5 800	4 990	13 600
In Mexico..........	190	900	300	1 300	310	1 400	200†	900	1 000	4 500
Grand total....	660	3 000	1 700	5 000	1 410	3 500	2 040	6 600	5 810	18 100

"* Includes a little over 800 000 acres listed in available areas by Bureau of Reclamation engineers, but excluded from their estimates of water consumption with the following statement: The Parker-Gila Valley Project is not considered fully as feasible as other Class C projects in either basin and as available water supply is insufficient for the inclusion of its entire area at the assumed diversion duty, the area of this project is reduced to fit the water supply.

"† This area not dependent on flow of Colorado River at Laguna as it may be served by return flow, waste, etc., near head of Gulf.

"The foregoing table [Table 11] does not include 1 500 000 acres of land now irrigated above Laguna Dam, requirements of which have been provided for and excluded from the estimates of water supply.

"The conclusion is obvious that the water supply is inadequate to provide for a very large area in the projects that have been classified as becoming feasible only in the distant future. However, before such projects are seriously considered for development, far more and better information as to water supply will be available and a reasonably accurate estimate of the adequacy or inadequacy of the water supply available for them can be made. An attempt to solve all the problems of Colorado River at a single stroke on the basis of the meager information now available is likely to result in ill-advised expenditure if nothing worse."

Storage Required at Present for Irrigation of Lower Basin

The entire low-water flow of the Colorado in the Lower Basin is now appropriated, and storage will be necessary for any expansion of acreage and a small amount of storage should be provided to take care of present acreage in years of less than average water supply. The Fall-Davis report (page 40) shows that, in the year of smallest run-off, 2 340 000 acre-ft. of storage would be sufficient to provide for the feasible acreage in both the Upper and the Lower Basins. Since the Fall-Davis report was issued, the U. S. Bureau of Reclamation has made extensive studies of possible irrigation in the Colorado Basin, the net results of which indicate that all lands likely to be irrigated by 1940 in both the Upper and the Lower Basins can be provided for by 2 300 000 acre-ft. of storage in the worst year of record. Aside from 1902, which was the worst year, 1 500 000 acre-ft. of storage would have been sufficient.

About 840 000 acre-ft. of storage will take care of all development contemplated in the Swing-Johnson Bill, including that in Mexico supplied by the Imperial Canal, for years like 1902, and 500 000 acre-ft. would be sufficient for all other years of record. If 4 000 000 acre-ft. of storage is provided for flood control, it can be operated in such manner as to take care of irrigation needs in the Lower Basin as far as it is profitable to do so at this time.

Power

The power demand in Southern California has increased in the past 14 years at a rate of about 13% compounded annually. There is a present mining load in Arizona carried by steam power that justifies the belief that 75 000 to 80 000 kw. could be absorbed from the Colorado as soon as it is available, and the development of power on the Colorado at Diamond Creek would now be under way but for lack of Federal authority to use the public lands necessary. There are mining possibilities in Nevada and Southern Utah that may create a large demand. They are too speculative at present to justify expenditure for power development, but may greatly accelerate such development once it is started. The mining load in the vicinity of Salt Lake City has grown so that development of the Flaming Gorge site on the Green River, just below the Wyoming line, is now under serious consideration by the Utah Power and Light Company.

The use of power in the United States has grown with surprising rapidity. When it is considered that the use of electrical power commenced about 30 years ago, it is not extravagant to conclude that all the power in the Canyon Section of the Colorado may be absorbed in the next 25 or 30 years. Although immediate expenditure should be limited to immediate needs, the possibility of such a demand for power is certainly great enough to justify taking it into account in planning the development of the Colorado, to the extent of insuring the ultimate development of the greatest possible power from the Canyon Section commensurate with the higher uses of the water. This means that projects should be planned to use all available head, that storage for equalization of flow should be provided above the Canyon Section, and that storage for re-regulation of flow for irrigation in the Lower Basin should be provided at the bottom of the Canyon Section. Storage located at the bottom of the Canyon Section for flood protection of the Lower Basin does not conform to the requirement that storage for equalization of flow should be above the Canyon Section. It should be built, therefore, only to the minimum capacity that will give relief, especially as storage above the canyon may be relied on to give additional relief in the near future, and it should be located, if practicable, so that later it will provide for re-regulation of flow for irrigation in the Lower Basin.

Aside from the Flaming Gorge and Diamond Creek developments on the Colorado, any developments of power in the immediate future must depend on Southern California for a market, and the size of the development should be limited to what that market can absorb with certainty, in order to keep the carrying charges at a minimum during the periods of construction and loading.

Table 12 has been compiled from information in the files of the Federal Power Commission to show the possible hydro-electric development in Southern California.

The projected developments of the San Joaquin Light and Power Company are on the North Fork of Kings River. Expenditures on these works have been commenced on a scale that will probably make necessary their completion in spite of the fact that their estimated cost is more than $200 per h.p. installed.

The projected developments of the Southern California Edison Company will probably go forward up to 1935. The installed capacity for that year includes what are known as the West Side Developments of the San Joaquin River. They will be expensive, costing probably more than $200 per h.p. installed, and may be deferred if Colorado River power becomes available.

The proposed developments of the City of Los Angeles are in two regions, namely, Owens Valley and South Fork of Kings River. The developments in the latter region, at least, may be deferred if Colorado power becomes available.

Table 13 shows the power generated in Southern California by the four principal producers. Their combined load has grown at an average rate of about 13% compounded annually. Nearly 80% of the power has been hydropower and has operated at an annual capacity factor of from 45 to 55 per cent.

Table 14 shows predictions of growth of load in Southern California. The prediction* made by Frederick H. Fowler, M. Am. Soc. C. E., is stated by him to be the probable maximum. The prediction† made by A. H. Mark-

* *Transactions*, Am. Soc. C. E., Vol. LXXXVI (1923), p. 836.

† *General Electric Review*, 1922.

TABLE 12.—CALIFORNIA HYDRO-POWER PROJECTS.

Companies.	Streams.	September 1921, installed capacities, in kilovolt-amperes.	Program of Development, in Kilovolt-Amperes: 1922	1923	1924	1925	1926	1927	1928	1929	1930	1935	1940	1945	Ultimate capacity of new projects.
San Joaquin..........	Kings River No. 175...	82 450	....	....	....	....	15 000	15 000	....	15 000	15 000	30 000	60 000	147 000	297 000
So. Calif. Edison......	Big Creek No. 67......	201 350	30 000	16 000	....	25 000	....	....	....	....	....	....	....	....	71 000
"	San Joaquin..........	....	....	75 000	....	16 000	....	99 000	99 000	....	195 000	212 000	....	....	696 000
Nev.-Calif. Power...	Leevining, Rush,	40 100	....	2 800	....	....	....	....	....	....	....	....	....	....	2 800
	Owens, and Snow	....	....	....	....	3 000	7 500	....	....	....	12 500	....	....	....	23 000
So. Sierras..........	Creeks..............	....	....	....	....	2 000	1 500	....	....	....	....	....	....	....	3 500
City of Los Angeles....	....	72 460	....	....	....	....	....	....	17 500	37 500	33 450	46 080	126 220	394 000	654 750
San Gorgonio..........	San Gorgonio.........	....	....	....	2 700	....	....	....	....	....	....	....	....	....	2 700
Sespe Light and Power	Piru Creek...........	....	....	....	....	....	6 000	....	....	....	7 000	....	....	....	13 000
Merced Irrig...........	Merced River No. 88...	....	....	....	....	30 000	....	....	....	....	....	....	....	....	30 000
Fletcher, Edison......	Boulder Creek........	....	....	....	....	....	....	....	....	....	980	....	....	....	980
Total....................	....	396 360	30 000	93 800	2 700	76 000	30 000	114 000	116 500	52 500	263 930	288 080	186 220	541 000	1 794 730
Accumulative total....	....	....	....	123 800	126 500	202 500	232 500	346 500	463 000	515 500	779 430	1 067 510	1 253 730	1 794 730	....
		....	426 360	520 160	522 860	598 860	628 860	742 860	859 360	911 860	1 175 790	1 463 870	1 650 090	2 191 090	....

wart, M. Am. Soc. C. E., was for the entire State of California and is probably low for Southern California. Column (3) of Table 14 which was compiled from Mr. Fowler's prediction on the assumption that hydro-developments will continue to furnish 80% of the power and will operate at an annual capacity factor of 55%, would be high as a basis for immediate investment if it were not for the fact, as mentioned previously, that some of the California installation may be deferred in favor of Colorado development. Column (5) of Table 14 contains the totals from Table 12. A comparison with Column (3) shows that California developments will probably take care of the growth of load in Southern California up to 1935. At that time the growth of load will call for increased installation of about 100 000 kw. per year.

TABLE 13.—POWER GENERATED IN SOUTHERN CALIFORNIA.*
(Systems Included: Southern California Edison Company; Southern Sierras Power Company; San Joaquin Light and Power Corporation; and City of Los Angeles.)

Year.	Hydro:		Steam:		Total:		Percentage hydro.
	Kilowatt-hours.	Percentage increase	Kilowatt-hours.	Percentage increase.	Kilowatt-hours.	Percentage increase.	
1910	324 331 916	....	124 181 024	....	448 512 940	....	72.3
1911	376 988 076	16.2	162 675 931	30.6	539 664 007	20.33	69.8
1912	383 136 890	1.6	273 354 263	68.0	656 491 153	21.64	58.35
1913	431 510 017	12.6	307 293 993	12.45	738 804 010	12.53	58.40
1914	740 991 812	71.7	104 288 601	—66.26	845 780 413	14.47	87.61
1915	788 344 373	6.4	93 557 059	—10.29	881 901 432	4.10	89.39
1916	876 636 452	11.11	63 578 530	—32.05	940 214 982	65.70	93.23
1917	924 781 935	5.4	165 909 200	160.80	1 090 691 135	16.00	84.78
1918	1 005 383 515	8.7	250 108 913	50.75	1 255 492 428	15.10	80.07
1919	986 852 219	—1.8	414 084 672	65.56	1 400 936 891	11.58	70.44
1920	1 161 522 861	1.76	432 753 084	4.50	1 594 275 945	13.80	72.85
1921	1 514 873 779	30.5	314 532 165	—27.32	1 829 405 944	14.74	82.08
1922	1 848 494 288	22.0	123 615 130	—60.7	1 972 109 418	7.80	93.73
1923	1 992 877 000	7.8	406 469 000	22.88	2 399 346 000	21.66	83.05
Total..	12 356 725 133	15.0†	3 236 401 698	9.5†	15 593 126 698	13.8†	79.8

* Compiled from *Water Supply Paper No. 493*, U. S. Geological Survey, and records of U. S. Geological Survey.

† Compound rate of increase for entire period.

A Colorado River power development probably cannot be completed before 1930, but should be completed by 1932. In view of the statements made, the estimates of power company engineers that a Colorado River development planned now should not exceed an installed capacity of 300 000 kw. appears to be sound. A larger development will ultimately be absorbed, but the risk of excessive carrying charges is not justifiable if the smaller development is feasible. It has become the custom to talk in such large figures concerning the Colorado that it may be pertinent to point out that the only hydro-electric developments in this country as large as 300 000 kw. are at Niagara Falls and Muscle Shoals, and that the total installed capacity in Southern California at present is about 500 000 kw.

TABLE 14.—PROBABLE POWER DEMAND OF SOUTHERN CALIFORNIA.

Year.	Per Fowler: Increase at: 13% to 1925 12% to 1930 10% to 1935 8% to 1940 in millions of kilowatt-hours. (1)	Per Markwart: Increase at: 11.1% to 1930 7.2% to 1940 4.1% to 1950 in millions of kilowatt-hours. (2)	Fowler's Estimate: Assume hydro produces 80% of kilowatt-hours and operates at 55% capacity factor. Required installed capacity, in kilowatts. (3)	Markwart's Estimate: Hydro produces 90% of kilowatt-hours and operates at 72% capacity factor. Required installed capacity, in kilowatts. (4)	Possible installed capacity of Southern California hydro per Table 12. (5)
1924	2 710	2 662	451 660	384 400	522 860
1925	3 062	2 954	510 330	435 700	598 860
1926	3 429	3 280	571 490	483 900	628 860
1927	3 840	3 640	640 000	537 000	742 860
1928	4 301	4 040	716 820	596 000	859 360
1929	4 817	4 484	802 820	661 600	911 860
1930	5 395	4 975	899 150	733 900	1 175 790
1931	5 935	5 109	991 510	753 700	....
1932	6 528	5 477	1 088 000	808 000	....
1933	7 181	5 879	1 196 810	867 700	....
1934	7 899	6 302	1 316 470	930 000	....
1935	8 689	6 755	1 448 140	996 700	1 463 870
1936	9 384	7 241	1 563 970	1 068 000	....
1937	10 134	7 762	1 689 000	1 145 000	....
1938	10 944	8 369	1 823 970	1 234 000	....
1939	11 819	8 971	1 969 800	1 323 000	....
1940	12 764	9 617	2 127 300	1 419 000	1 650 090
Extended at 7%: 1941	13 657	10 011	2 276 130	1 477 000	....
1942	14 613	10 421	2 435 460	1 537 000	....
1943	15 635	10 848	2 605 800	1 600 000	....
1944	16 729	11 292	2 788 120	1 666 000	....
1945	17 890	11 754	2 981 610	1 734 000	2 191 090

POSSIBLE STORAGE RESERVOIRS

Table 15, prepared by the U. S. Bureau of Reclamation, gives information on reservoir sites on the upper tributaries. Of these sites, it may be stated that:

1.—The Ouray site will be expensive to develop, because of depth to bed-rock and width between abutments.

2.—The Kremmling site is probably unavailable on account of interference with the Denver and Salt Lake Railroad.

3.—The Bedrock site commands a relatively small run-off.

TABLE 15.

Stream.	Reservoir site.	Raise in water surface, in feet.	Reservoir capacity, in acre-feet.	Average annual run-off at site, in acre-feet.	FOUNDATION CONDITIONS: Tests by	FOUNDATION CONDITIONS: Depth to bed-rock, in feet.
Green	Flaming Gorge..	240	4 000 000	2 300 000	Drilling	73
"	Ouray	210	16 000 000	5 200 000	"	121
Yampa......	Juniper..........	200	1 550 000	1 200 000	"	24
Colorado....	Kremmling......	230	2 200 000	1 200 000	"	104
"	Dewey..........	215	2 270 000	6 800 000	"	44
Dolores......	Bedrock.........	210	800 000	400 000	None	....
San Juan...	Bluff	206	1 350 000	2 300 000	"	....

The U. S. Bureau of Reclamation estimates the cost of developing four of these sites as shown in Table 16.

On the basis of cost as shown in Table 16 the average cost will be about $4.75 per acre-ft.

TABLE 16.

Reservoir.	Capacity, in acre-feet.	Cost.
Flaming Gorge	3 120 000	$16 000 000
Juniper	1 550 000	4 000 000
Dewey	2 270 000	11 200 000
Bluff	1 400 000	8 800 000
Totals	8 340 000	$40 000 000

The Flaming Gorge site is now under permit to the Utah Power and Light Company and will probably be developed in the near future.

The Juniper and Dewey sites can be developed for about 4 000 000 acre-ft. at a cost of about $4 per acre-ft.

In addition to these sites, there are possible reservoir sites at Glenn Canyon, Boulder Canyon, and Mohave, the capacities and areas of which are shown on Fig. 12.

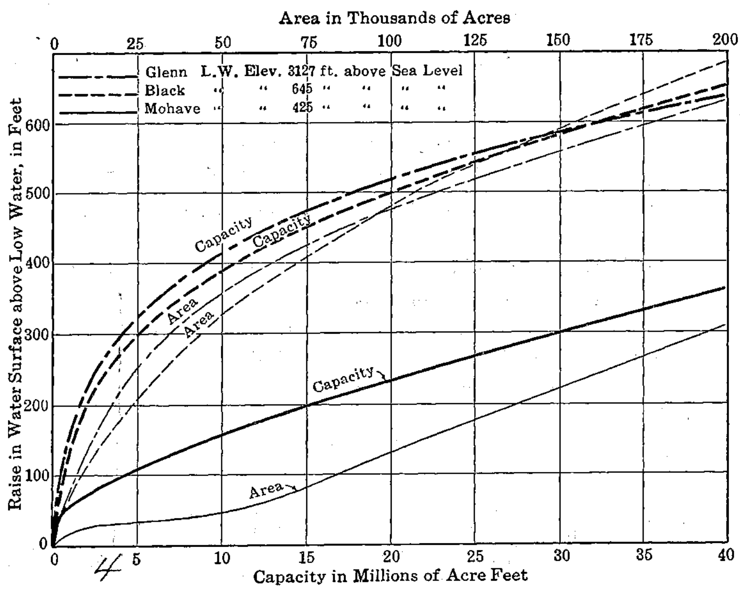


FIG. 12.—AREA AND CAPACITY CURVES FOR RESERVOIRS.

Glen Canyon.—This reservoir is near the head of the Canyon Section of the main river. The Southern California Edison Company explored the Glen Canyon site and found bed-rock at a maximum depth of 80 ft. The walls and bed of the canyon at the dam site are massive red sandstone, and the canyon walls rise almost vertical to heights of 1 000 to 1 500 ft. The engineers of the U. S. Bureau of Reclamation state that the sandstone is so poorly cemented that its safe bearing power will not be much more than 20 tons per sq. ft. Three samples of core in compression tests failed at 2 220, 12 900, and 10 480 lb. per sq. in., respectively. The strength in compression of the weakest sample tested is, therefore, greater than that of mass concrete and, contrary to the views of the engineers of the U. S. Bureau of Reclamation, it seems to be safe to assume that the maximum stresses will be determined by the concrete and not by the bearing power of the stone in the foundations and abutments. The greatest objection to the site is its great distance (about 135 miles) from a railroad.

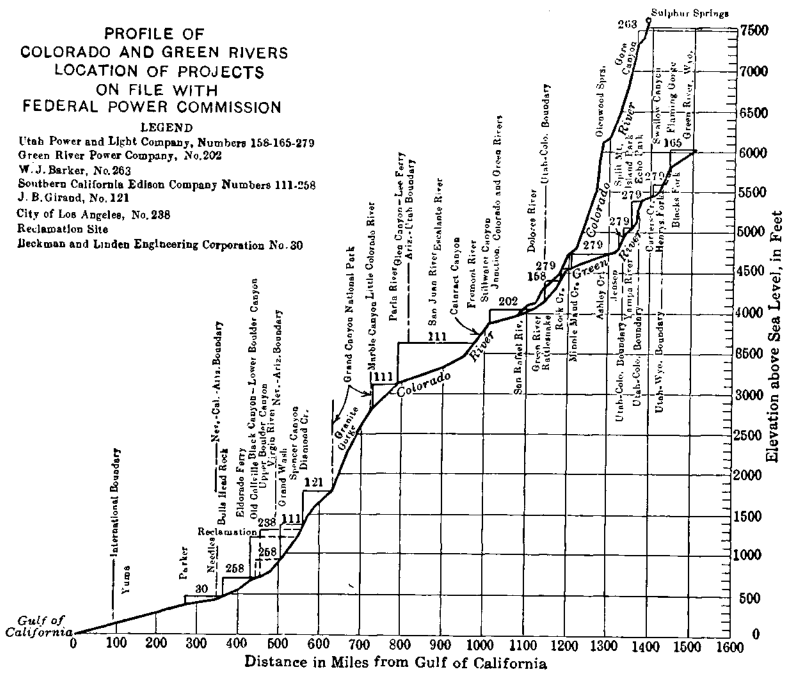


FIG. 13.

Boulder Canyon.—This reservoir site is near the foot of the Canyon Section. It has been extensively explored by the U. S. Bureau of Reclamation and is the site selected by it for a flood protection and irrigation reservoir for the Lower Basin. The project recommended contemplates a dam at a point in Black Canyon where the water surface is 645 ft. above sea level and the depth to bed-rock is 124 ft. The dam will raise the water surface to 1 250 ft. above sea level and provide 34 000 000 acre-ft. of storage, the top 8 000 000 acre-ft. of which are to be reserved for flood protection and irrigation of the Lower Basin. The dam will develop 660 000 h. p. continuously with an average head of 550 ft. This project will be further discussed under the head of "Development Between Needles, Calif., and Diamond Creek".

Mohave Valley.—The Mohave Valley site is about 100 miles nearer the Lower Basin than Boulder Canyon and presents many other advantages as a site for flood protection and re-regulation for irrigation in the Lower Basin. It is easily accessible, develops great capacity with a relatively low dam, and leaves the entire Canyon Section of the main river free to be developed for power. If satisfactory foundations are found, the only objection to the site is that its flowage damages may be high, as it will require moving the Town of Needles, a division point on the Santa Fé Railroad, and re-locating 15 to 20 miles of main-line railroad.

The U. S. Bureau of Reclamation has estimated the cost of providing 10 000 000 acre-ft. of storage at the previously mentioned sites, as follows:

Glen Canyon	$77 500 000
Boulder Canyon	27 000 000
Mohave Valley	26 000 000*

It also estimates that for a reservoir of 34 000 000 acre-ft. at Boulder Canyon, the 8 000 000 acre-ft. reserved for flood protection would cost $12 000 000, if the total cost were pro-rated on the basis of capacity used.

The data on which the estimates for Glen Canyon, Mohave Valley, and the upper reservoirs are based, are so incomplete that they constitute a doubtful basis for determining relative costs.

Possible Dam Sites on the Colorado

In 1923, a party from the U. S. Geological Survey went down the Colorado by boat from Lees Ferry, or Glen Canyon, Ariz., to Needles, Calif. This party made topographic surveys of sites that appeared favorable for dams, and it is understood that the data collected will be published. The list, shown in Table 17, includes some sites examined by this party. The depth to bed-rock at most of these sites has not yet been determined.

TABLE 17.—Possible Dam Sites, Colorado River.

Site.	Elevation of low water above sea level, in feet.	Probable limit of height of dam, in feet.	Distance, in miles, from Gulf of California.
Diamond	1 335	1 800	567
Bridge Canyon	1 207	2 000	557
Spencer Canyon	1 105	1 700	547
Devils Slide	1 034	1 330	537
Pierce Ferry	905	1 100	516
Boulder Canyon	705	1 250	459
Black Canyon	645	1 250	438
Bulls Head	496	650	372
Mohave	425	605	318
Laguna	151	......	135

Development Between Needles, Calif., and Diamond Creek

Tables 18 and 19 have been prepared to show the extent to which the Boulder Canyon Project of the U. S. Bureau of Reclamation fails to conform to a full development of the Colorado River below Diamond Creek.

In Table 19, Plan 1 is the Boulder Canyon Project. It is contemplated that when further irrigation is developed in the Lower Basin, a re-regulating dam will have to be constructed at Bulls Head.

Plan 2 includes the Bulls Head Dam. The head between the Boulder Project and Diamond Creek (about 80 ft.) is too small to permit of economic

* Includes $13 000 000 for flowage damage.

TABLE 18.—Data on Boulder Canyon and Mohave Reservoirs.

Maximum elevation of pool above sea level, in feet.	Minimum elevation of pool above sea level, in feet.	Height of dam above low water, in feet.	Mean head available for power, in feet.	Storage available for flood protection, in acre-feet.	Mean area of reservoir exposed to evaporation, in acres.	Evaporation loss per year at 5 ft., in acre-feet.	Present evaporation loss, in acre-feet.	Increase of evaporation loss, in acre-feet.	Acres that could be irrigated with water lost.	Horse-power available, (mean head x 1 210).
Boulder Canyon Reservoir.										
905	905	260	260	0	35 000	175 000	35 000	140 000	31 000	315 000
905	905	345	345	0	37 000	185 000	40 000	145 000	32 000	418 000
1 030	1 030	385	385	0	68 000	340 000	40 000	300 000	67 000	466 000
1 250	1 250	605	605	0	160 000	800 000	50 000	750 000	167 000	732 000
1 250	1 155	605	550	8 000 000	130 000	650 000	50 000	600 000	133 000	667 000
1 250	1 225	605	580	4 000 000	145 000	725 000	50 000	675 000	150 000	702 000
1 250	1 235	605	590	2 350 000	155 000	775 000	50 000	725 000	161 000	714 000
Mohave Reservoir.										
425	......	....	....	....	....	....	....	....	....	....
525	425	100	....	4 340 000	68 000	340 000	310 000	30 000	7 000	0
525	470	100	....	4 000 000	71 000	355 000	310 000	45 000	10 000	0
545	425	120	....	6 125 000	68 750	343 750	310 000	33 750	7 500	0
545	490	120	80	4 600 000	72 800	364 000	310 000	54 000	12 000	97 000
582	425	157	....	10 000 000	88 000	440 000	350 000	90 000	20 000	0
605	425	180	....	12 800 000	97 000	485 000	350 000	135 000	30 000	0
605	530	180	125	8 000 000	98 000	490 000	350 000	140 000	31 000	151 000
605	545	180	155	4 000 000	113 000	565 000	350 000	215 000	48 000	187 000

Note.—Average evaporation loss, Topock to Yuma, for 1922–23, 1 770 000 acre-ft.; overflowed area, 306 000 acres. Overflow area: Mohave Valley, 62 500 acres; Cottonwood Valley, 9 500 acres; total, 72 000 acres. Present evaporation loss may be taken as: Mohave Valley, 310 000 acre-ft.; Cottonwood Valley, 40 000 acre-ft.; total, 350 000 acre-ft.

TABLE 19.—COMPARATIVE PLANS OF DEVELOPMENT OF COLORADO RIVER BELOW DIAMOND CREEK

(Assuming Up-River Storage Developed. Evaporation Loss at 5 Ft. per Year; Irrigation Duty, 4 to 5 Ft. per Year.)

Plan.	Dam.	Elevation of pool above sea level, in feet.	Head available for power, in feet.	Storage available for flood and irrigation, in acre-feet.	Evaporation loss, in acre-feet.	Horse-power available.	Acres lost on account of evaporation.	Cost.
			U. S. Bureau of Reclamation Plan.					
1	Boulder	1 250	550	8 000 000	600 000	667 000	133 000	$50 000 000
2	Bulls Head	645	0	1 650 000	25 000	0	....	14 000 000
	Boulder	1 250	590	2 350 000	725 000	714 000	....	50 000 000
	Totals	......	590	4 000 000	750 000	714 000	169 000	64 000 000
3	Mohave	605	125	8 000 000	140 000	132 000	....	27 000 000
	Boulder	1 030	385	....	300 000	465 000	....	27 000 000
	Devils Slide	1 330	300	....	10 000	363 000	....	22 000 000
	Totals	......	810	8 000 000	450 000	960 000	100 000	76 000 000
4	Mohave	605	180	4 000 000	215 000	187 000	....	27 000 000
	Boulder	1 030	385	....	300 000	465 000	....	27 000 000
	Devils Slide	1 330	300	....	10 000	363 000	....	22 000 000
	Totals	......	865	4 000 000	525 000	1 015 000	117 000	76 000 000
5	Mohave	545	0	6 000 000	33 750	0	....	24 000 000
	Black Canyon (Lower End)	905	345	....	145 000	418 000	....	26 000 000
	Pierce Ferry	1 112	207	....	5 000	248 000	....	17 000 000
	Spencer Canyon	1 330	218	....	5 000	262 000	....	18 000 000
	Totals	......	770	6 000 000	183 750	928 000	38 000	$85 000 000

development, so that Plan 2 represents full development under the Reclamation plan.

Plans 3 and 4 contain similar structures, namely, a dam 180 ft. high at Mohave, a dam 387 ft. high at the Reclamation site in Boulder, and a dam 298 ft. high at Devils Slide. Plan 3 is comparable to Plan 1 and Plan 4 to Plan 2. The comparison shows that the Reclamation plan will cost $12 000 000 less, but will ultimately prevent the development of about 300 000 h. p. and 50 000 acres of land. The magnitude of this loss of power may be made clearer by pointing that the hydro-power generated in Southern California in 1923 was just about 300 000 h. p. If applied for under the Federal Water Power Act, the Reclamation project would be refused a license until it was modified to conform to a full plan of development. It should not be built by the Federal Government on the lines proposed.

Plan 5 is presented in order to illustrate the limit in curtailment of evaporation losses.

It should be stated in connection with the figures used in the comparative plans just mentioned, that power and evaporation losses of the Boulder Project are believed to be low and complete data probably will modify estimates of cost so as to wipe out more or less the difference of $12 000 000 and, as a flood protection and irrigation project, Mohave has so many advantages that it should be fully investigated before any other project is adopted. If it is found feasible, a site should be sought at the lower end of Black Canyon for a power dam sufficiently high to back water up to either Pierce Ferry or Devils Slide, and the relative feasibility of the two latter sites should determine the height to which the dam should be built.

Silt

The Colorado carries large quantities of silt. If a flood-control and irrigation dam at the lower end of the Canyon Section were the only one in prospect, large capacity would have to be provided for silt. With the Diamond Creek Dam ready to be built for power and other power dams sure to follow before Diamond Creek can become filled, there is no justification for a large increase in present expenditure to provide silt capacity. If the Mohave Reservoir is built to a capacity of 6 000 000 acre-ft., it will give liberal capacity for silt deposit.

Increase of Low-Water Flow Undesirable at Present

There is serious objection on the part of the upper States to a material increase of the low-water flow of the river until the Colorado Compact is ratified by Arizona, the only State which has not yet done so. This compact was negotiated for the purpose of determining by mutual agreement, rather than by litigation, the allocation of waters between the several States in the Basin. There is good basis for objection to the Boulder Project of the U. S. Bureau of Reclamation, because it would put to beneficial use for power practically all the water in the river and thereby acquire prior rights that might have to be purchased before any further irrigation up stream could be accomplished.

There would be little ground for objection if the project were reduced to provide only for present needs of flood protection and irrigation.

The Boulder Project would provide water in the Lower Basin at all seasons far in excess of present irrigation requirements. This water will pass into Mexico and there be used for irrigation. Once used, its withdrawal for use in the United States will be difficult, if not impossible. As heretofore shown, storage for flood protection will not obviate the need for maintaining levees and bank protection in Mexico, and a treaty to facilitate this work and to limit the quantity of water to be supplied Mexico should be negotiated before the quantity for irrigation in Mexico is increased.

Work Which Should Be Undertaken by the United States

There are now before the Federal Power Commission applications covering practically the entire Canyon Section of the river. (See Fig. 13.) All the development justified at present, including flood control and irrigation, will be undertaken by private capital under adequate Federal and State regulation if the Federal Water Power Act is left free to function.

If, notwithstanding this situation, Congress deems the special conditions on this stream such as to demand Federal construction of a flood protection reservoir, investigation of the Mohave site should be made at once and, if reasonable foundations can be found, the dam should be built there. In view of the objections to increasing the low-water flow at present, it would be best to construct this dam for purposes of flood control and regulation of flow for irrigation only and not for the development of power. It could then be operated so as to prevent the appropriation and use of water beyond present needs. If power is installed, there will be great pressure to operate for the power demand. There seems to be small justification for charging the entire cost of such a dam to the power consumers but, if Congress decides to do so, a dam 180 ft. high at Mohave will produce more than 130 000 h. p., which would justify an installation of about 240 000 h. p. Projects in Southern California have averaged about $130 per h. p. installed, but there are few developments left that can be built for less than $200 per h. p. installed. The estimated cost of the Mohave Dam is $27 000 000, which charged to 240 000 h. p., gives less than $115 per h. p. To this, add $35 per h. p. for cost of power equipment, and the total is $150 per h. p. installed. This price compares so favorably with prospective California developments that there is little doubt that the power can be made to carry the cost of the dam without raising present prices to consumers. If the Mohave Dam proves to be feasible, it can be built in 4 years as against the 8 years estimated for Boulder Canyon Dam.

Conclusion

The proposed high dam in Boulder Canyon should not be built because it will curtail ultimate power development by 300 000 h. p. and ultimate irrigation by about 50 000 acres.

All the development needed on the Colorado will be built by private capital under adequate Federal and State regulation if the river is given over to development under the Federal Water Power Act.

If the Federal Government decides to provide flood storage for the Lower Basin, it should be provided in Mohave Valley where it will conform to the maximum use of the river for all purposes. Such a dam should be designed and operated for the present in a manner that will not increase the low-water flow beyond present irrigation needs. Steps should be instituted as early as practicable to negotiate a suitable treaty with Mexico covering the maintenance of levees, canals, etc., in Mexico and an agreement as to the water that will be provided for Mexican lands.

DISCUSSION

J. C. ALLISON,* M. AM. SOC. C. E.—It has been well stated that an attempt to solve all the problems of the Colorado River at a single stroke on the meager data now available is likely to result in ill-advised expenditures if nothing else. Irrigation in the Lower Basin of the river is only twenty-two years old; in the Upper Basin it is not a great deal older and is less extensive. The idea of storage dams in the river canyons for the triple purposes of flood control, complete storage of water supply for irrigation and power, although not old in theory, is new in the respect that only recently has an attempt been made to investigate, by field survey, the actual elements involved in these three problems. On the strength of the relatively meager data at hand, the public expects a wholly untamed river to be harnessed completely with one dam, doing away with the necessity for the great systems of levees protecting the lower valleys; it expects every flat place shown on the map within the water-shed of the river (and a great deal of land outside the water-shed) to be irrigated immediately. Each State involved is naturally fighting for a right to the use of water on every acre possible, discounting the fact that perhaps only a small proportion of the acreage it is planned to irrigate will be found feasible for reclamation. International complications with Mexico are conjured up, with the result that great expenditures of money are planned solely for the purpose of holding the entire control of the flow of the stream in American territory. Suddenly, the power possibilities in the river are realized, and the fight for power rights is on. The only element in all the foregoing that requires immediate action, that is, the control of the floods sufficiently to save the lower valleys from annihilation, is almost smothered in the haste to solve all the problems of the river at one stroke.

Fortunately for all concerned, the Committee on Irrigation and Reclamation of the U. S. House of Representatives, which is investigating the Swing-Johnson Bill providing for the financing by the Government of works contemplated to solve all the Colorado River problems, has been wise enough to understand the importance of the problem and is studying all angles of the situation before reporting the Bill. As these involve purely an engineering analysis of the project, it is certainly the duty of every engineer to contribute all the information and study available to the data already assembled. In this connection, Colonel Kelly's paper is certainly most important.

Although all cannot agree with the author's conclusions in their entirety, most engineers can certainly agree that the immediate necessity for flood control is paramount, and that the Government should provide without delay the means for constructing a dam of sufficient proportions to minimize the flood dangers, leaving the multitude of remaining problems involved in complete river regulation for irrigation and power to be solved later. It is the purpose of this discussion to rectify a number of the conclusions drawn from insufficient data.

* Cons. Engr., Calexico, Calif.

Flood Control.—The lower irrigation projects of the Colorado River, including the Imperial Valley, the Yuma Valley, and the Palo Verde Valley, must continue their levee maintenance work until regulation of the river is complete. With the tremendous variation in the annual discharge from a low point of 9 110 000 acre-ft. in 1902, to as high as 25 400 000 acre-ft. in 1909, it must be evident that one dam can never perfectly perform the triple functions of providing maximum flood control, maximum conservation of water for irrigation, and maximum power development. The provision necessary for silting space alone should bar this unattainable feat from further consideration.

A dam in or below the Canyon Section having a storage capacity of 4 000 000 acre-ft. and discharge facilities of 75 000 sec-ft., should be sufficient to care for the immediate problem, this dam to be utilized later for re-regulation of the flow for irrigation when other dams for storage and power purposes are built above it. Such a dam meets all the requirements for immediate flood control noted by Colonel Kelly, with the possible exception of regulation to provide entirely for the Gila River floods. Unless the dam itself is located within a reasonable distance from Laguna Dam, above Yuma, Ariz., it is impractical to attempt any substantial regulation of the Colorado River supply to offset the flash discharges entering the river from the Gila at Yuma. Inasmuch as it is necessary to continue the maintenance of the levee system of the lower valleys, the floods of the Gila are automatically cared for until such time as its complete regulation is justifiable. The very fact that the duration of the Gila floods is so extremely limited, justifies the assumption that only local damage can be done to the lands in Yuma and Imperial Valleys in case of levee failure. The reasons for continuing the maintenance of the levee system in the lower valleys, as enumerated by the author, are conclusive.

Irrigation.—In the speaker's opinion the conclusion drawn by Colonel Kelly and by the engineers of the U. S. Reclamation Service, as well as by many of the State engineers interested in the project, that there are more lands to irrigate eventually than can be served by the water available, is erroneous. Only experience will determine this issue. If the speaker's judgment is correct, as the facts herewith indicate, a great many of the most serious problems involved in the regulation of the Colorado River disappear completely.

Table 20 illustrates the progress of irrigation and the net usage of water on the lands of Imperial Valley.

For a period of 5 years the average duty was 2.8 acre-ft. per annum, which can be safely applied to the other valleys below the Canyon Section. It has taken 22 years to reclaim and irrigate 731 893 acres below the Canyon Section, distributed as indicated in Table 21.

This relatively small total area represents the lands most easily irrigated during a period in which agriculture has had a great stimulant through the necessities of war.

TABLE 20.—IRRIGATION DATA FOR IMPERIAL VALLEY.

Year.	Acreage irrigated, Imperial Valley, United States, and Mexico.	Volume of water, in acre-feet, actually used on lands.	Actual water duty, in acre-feet.
1919	553 560	1 697 336	3.07
1920	607 000	1 792 484	2.95
1921	536 000	1 316 205	2.46
1922	565 000	1 474 999	2.61
1923	530 000	1 534 422	2.89

Familiarity with the lands in the Lower Basin, gained over a period of twenty-two years, indicates the following ultimate acreage below the Canyon Section (Table 22) as available for reclamation. By comparison with these lands, others are probably impracticable for any extensive irrigation, either because of altitude, lack of fertility, alkaline tendencies, or prohibitive costs of reclamation.

TABLE 21.—AREAS IRRIGATED.

Imperial Valley, United States (measured by the actual lands covered by water stock)	448 893 acres
Imperial Valley, Mexico	190 000 "
Yuma Valley	54 000 "
Palo Verde Valley	35 000 "
Parker Project	4 000 "
Total	731 893 acres

Besides these 2 000 000 acres, there will be no demand for irrigation, except on high mesa lands where the return from agriculture will not justify the expense of an excessive pumping lift.

TABLE 22.—ULTIMATE AREAS POSSIBLE OF IRRIGATION BELOW CANYON SECTION.

Imperial Valley, Mexico (on both sides of the Colorado River)	740 000 acres
Imperial Valley, United States, within the present irrigation district	448 893 "
Imperial Valley, outside lands, East and West Mesas	323 000 "
Coachella Valley and Dos Palmos	100 000 "
Yuma Project	100 000 "
Palo Verde Project, including Cibola Valley	65 000 "
Above Palo Verde Valley, including Parker Project	90 000 "
Total	1 866 893 acres

Assuming a water duty of 2.8 acre-ft., with a 25% allowance for seepage, evaporation, and carrying losses to the points of delivery, there may be a total maximum demand in the Lower Basin, including Mexico, of 7 000 000 acre-ft. per annum. Considering that the greater portion of the additional lands that may come under irrigation in the Lower Basin are more difficult and expensive to reclaim, it is not likely that they will be brought under cultivation as quickly as the 731 000 acres now irrigated. However, assuming that the agricultural demand will necessitate the same rate, it will be probably forty years before the Lower Basin will demand the entire 7 000 000 acre-ft. of water per annum.

The Colorado River Compact, between six of the seven Basin States, provides 7 000 000 acre-ft. of water for the States in the Upper Basin. The maximum usage possible as determined in the paper is 4 500 000 acre-ft. plus 500 000 acre-ft. possible to withdraw into water-sheds other than the Colorado. It is doubtful whether such a quantity of water can ever be put to beneficial use in the Upper Basin States; but presuming a final usage of 5 000 000 acre-ft., the period over which this will be developed will be considerably more than the forty years necessary to complete the usage in the Lower Basin.

In spite of the withdrawal from the tributaries of the Colorado from the upper water-shed, of water to irrigate approximately 1 500 000 acres, as found by the U. S. Reclamation Service, the annual discharge of the Colorado River at Yuma for a period covering the past forty-four years indicates no traceable depletion of supply. The history of irrigation in Southern California and elsewhere during the past twenty-two years reflects a similar condition. As long as the water is not withdrawn from the water-shed, the quantity returned to the river after irrigation may be expected to more than offset any shortage caused by usage on any acreage contemplated. The speaker's experience on the projects in the Lower Colorado, in Imperial Valley, Mexico, and the Palo Verde Valley, especially the latter, where the return water was measured to some extent in a drain canal constructed along the river near the protective levee, indicates the tremendous return of irrigation water to the stream. With a completely regulated Colorado River, whatever the flow, or whether the complete allotment provided for in the Colorado River Compact can be utilized by the Upper Basin States, the Lower Basin projects will never suffer from water shortage as long as no considerable quantity of water is withdrawn from the water-shed. The following outstanding facts sum up the situation:

First.—Under complete regulation, there will be ample water for any future needs.

Second.—On account of the comparative slow advance of irrigation, and the apparent rapid advance of power demand, complete irrigation of all the lands available in the Colorado River water-shed will, without doubt, follow complete regulation of the river for power; power demand will stimulate a regulation of the river from which irrigation will later profit in ample time for its needs. As long as the power dams are designed and regulated by the Government to the ultimate end that all the water of the river can be properly conserved for irrigation usage at the times of irrigation demand, the one dam built immediately for partial flood control, and the additional dams built to meet the growing power demand, will ultimately completely solve the Colorado River problem and attain all the results sought in the Swing-Johnson Bill.

Third.—With an excess of water for irrigation, international disputes over the water are needless and a complete treaty understanding between the United States and Mexico is easily attainable.

All-American Canal.—To February 29, 1924, the Imperial Irrigation District had expended $511 357.60 for All-American Canal surveys, Boulder Cañon Dam surveys, lobbying and conference expenses, and in the Laguna Dam connection to the Imperial Valley Water System; by far the larger part of this expense was incurred through the desire on the part of politicians within the Imperial District to create an All-American Canal.

The argument for an All-American Canal dates from the execution of the contract of October 23, 1918, referred to by the author, between the Secretary of the Interior and the Imperial Irrigation District. Contrary to the interpretation placed on it by advocates of the All-American Canal, this contract does not provide for the construction of such a work; it provides principally for a connection of the Laguna Dam above Yuma with the Imperial Valley Canal System at the International Boundary Line to avoid the necessity of further temporary dams in the river at Hanlon Heading, the intake of the Imperial Canal System that is objectionable to the water users in the Yuma Project directly across the stream. It provides, secondarily, for a survey of the All-American Canal which, if found practicable by the Secretary of the Interior, was to be built by the Imperial Valley System, work commencing within a period of two years. The late Secretary Lane, the author of this contract, positively disapproved of building the All-American Canal on account of its impracticability, as found by the survey; hence, the contract in this respect is of no effect.

Colonel Kelly's misunderstanding of the contract of October 23, 1918, does not differ from that of a great part of the public interested in the project. The voters at the election on its ratification were voting for a connection with Laguna Dam to avoid a threatened water shortage and further disagreement with the Yuma water users; they were not voting for an All-American Canal.

The Engineering Profession is making a grave mistake in sanctioning, without protest, the building of a nationally known work on the location adopted for this so-called All-American Canal, especially without a more complete understanding of the necessities making such an enterprise even worthy of consideration. Although the engineers engaged in the design of this work have protested its limitation within the United States, their protest has not been so strong as to prevent the politicians and selfish interests from passing quickly over it and proclaiming the location of the canal as one freely chosen and sanctioned by the Engineering Profession. Thus, they have gained the confidence of the public and through this confidence have nearly succeeded in securing Government financing through what is known as the Swing-Johnson Bill. Just as surely as the promotion of the project has been tied to the engineers of the country, just that surely will its construction failures be fastened to the engineers unless they examine forthwith in detail all phases of the project and proclaim their findings in no uncertain terms. Then, if such a work is ever financed and built, it may be known as a political necessity and not as a sound engineering structure.

Colonel Kelly's position with regard to the building of the connection between Laguna Dam and the Imperial Valley Canal at the International

Boundary Line, is shared by the speaker. However, the so-called All-American Canal, designed to replace the main canal of Imperial Valley now running through Mexico, should not be built on any of the hypotheses set forth by its sponsors for the following reasons:

1.—It does not add one acre of land to irrigation that cannot otherwise be added at much less expense per acre and in greater acreage.

2.—It does not add one drop of water to the available supply, but, on the other hand, represents an extravagant waste through seepage and evaporation losses.

3.—It does not add one unit of power, but develops less electrical energy for the uses of the American lands than can be developed by the other means suggested herein.

4.—If at all a necessity, it must be a political necessity, and this political necessity is set up by its advocates as the principal reason for its construction. The fact of the present canal being in Mexico is the main reason advocated for the building of a duplicate canal on American territory. The principle, however, is unsound because, as will be shown, Mexico as a water customer is of strict financial value to the American users of water, and, as an ally and neighbor in the use of water, is of great political value in the project. As a matter of fact the new project does not in any sense relieve the owners of the present Mexican Canal from maintaining their flood and irrigation works.

5.—Above all, the construction and the maintenance difficulties and the prohibitive expense of the All-American enterprise warrants a most careful examination before it shall receive the endorsement of the Society in any form. The reasons for this statement will now be discussed.

It is proposed under the All-American project (shown on Fig. 19) to bring water from the Laguna Dam (after raising and modifying the dam to care for the additional diversion) through an enlarged canal located along the route of the present Government canal as far as what is known as Siphon Drop; thence continuing along the foot-hills between the mesa and the river bottom-lands as far as Pilot Knob, where it is to divert westerly along the International Boundary Line and plunge directly into the forbidding territory between Pilot Knob and the Imperial Valley. The plan calls for the abandonment of the gravity system now supplying Imperial Valley through Hanlon Heading at Pilot Knob by way of Mexico. This present supply flows entirely below the surface of the ground at Hanlon Heading and affords a safe delivery of water to Imperial Valley through all seasons of the year. Any desert rain storms along the route of the proposed canal from the Laguna Dam to Pilot Knob can, without difficulty, break it and divert its entire supply back into the Colorado River. The storm regulators provided by the engineers are inadequate to cope with the inevitable cloudbursts draining from the mesa lands along the foot of which the canal is to run. Although the new canal from Laguna Dam should be constructed as far as Pilot Knob, as projected, still the diversion through Hanlon Heading, directly from the river and into the Valley by its present route, should be maintained as a safeguard.

The Imperial Irrigation District, with a population of 60 000 dependent entirely on the flow from the river, cannot be subjected to the possibilities of delays in water service.

It is proposed, from Pilot Knob westerly, to construct the All-American Canal in a cut ranging from 40 to 160 ft. in depth, through 20 miles of high mesa land and 12 miles of the most extensive drifting sand-hills in America (Fig. 14) along the approximate route of the spectacular California State Highway between Yuma and Imperial Valley (Fig. 15), which is built of portable plank board sections, for raising and lowering the grade and regulating the route with the drifting of the sand. Along this same approximate route is constructed the power line of the Southern Sierras Power Company; its experience alone in maintaining 12 miles of line should be enough to weaken the determination of the most enthusiastic supporters of an All-American Canal. One day 30-ft. power poles are covered to the wires with sand and the next day undermined by a 24-hour sand storm.

To build a canal through this section is in itself a most infeasible exploit, not only because of the difficulties of excavation and original construction, but also on account of the hazards and maintenance expense afterward.

Fig. 16 shows a cross-section of this work at one of the deeper cuts. It is proposed to make this excavation with suction dredgers at a cost of 20 to 30 cents per cu. yd. Experience shows conclusively that heavy sands and gravels cannot be pumped at this figure even with low lifts, let alone through the gigantic lift of 150 ft. and more which will obtain when the spoil banks are built up along the edges of the cut. No consideration is given the fact that it is an impossible feat to excavate with hydraulic machines, maintaining such a slope as is estimated; probably 50% of excess materials must be moved if this means of excavation is utilized. Should even 20% of the excavated materials be waste, the cost of the cut will be increased by between $2 000 000 and $3 000 000. Should the engineer's estimate be exceeded by 5 cents per cu. yd., the cost of the work will be increased $3 000 000. Not only is the work itself a dangerous experiment, perhaps an entirely impossible task, but the estimates themselves of such an experiment are undependable, as the whole project is at the mercy of the elements.

The velocities that will obtain in the canal as planned range from 2½ ft. to 3½ ft. per sec.; these velocities are as high as the engineer dared risk in the loosely knit sand and gravel through the mesa, yet a velocity of 4 to 5 ft. per sec. will not keep in suspension the surface sands which blow in from the surrounding country. In other words, if a velocity is maintained sufficient to keep the drifting sands in suspension and avoid the clogging of the canal, then, at certain seasons of the year, when the silt content from the river water is light, this same velocity will erode the banks in a manner that will ruin the entire section of the canal.

A canal all on American territory, designed to serve the western slope of Imperial Valley, would pass along the boundary line north of the City of Calexico, crossing New River on an extensive viaduct, costing $915 000 with its wasteway, and enter the West Side Main Canal, which is on the high ground

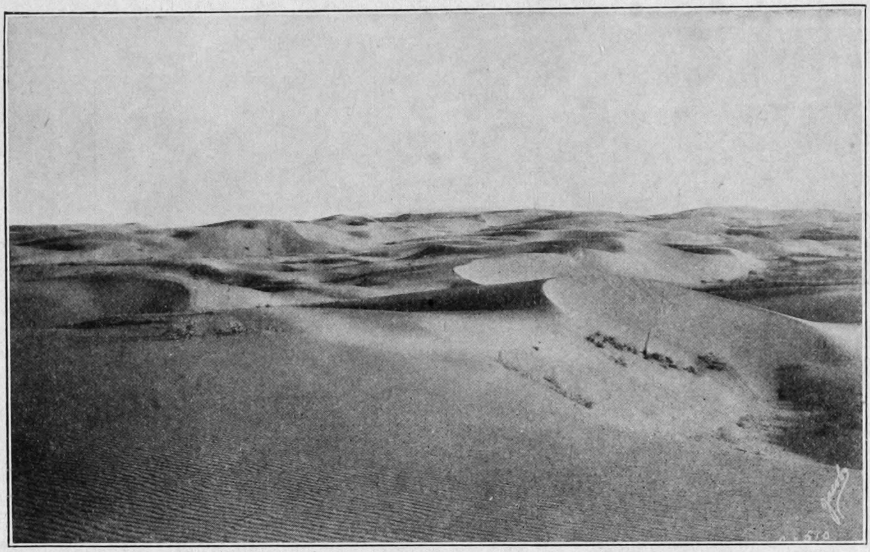


FIG. 14.—DETAIL OF SAND-HILL REGION TRAVERSED BY ALL-AMERICAN CANAL, SHOWING "BARCHAN" FORMATION.

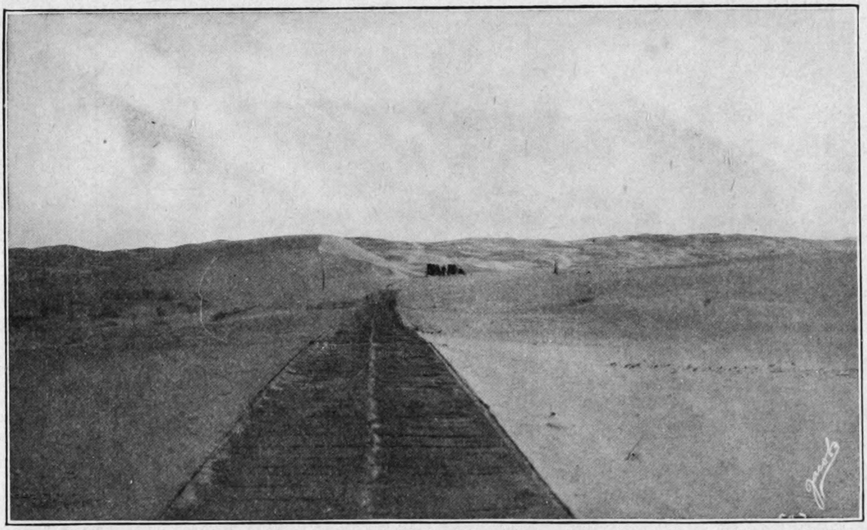
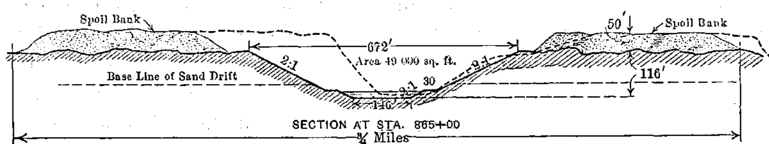


FIG. 15.—LOCATION OF ALL-AMERICAN CANAL THROUGH THE SAND-HILLS, SHOWING ALSO THE CALIFORNIA STATE PLANKED HIGHWAY ALONG ITS APPROXIMATE ROUTE.

of the western slope of the Valley. The fills required crossing the western section of the Valley to attain the altitudes necessary on the western slope, would be as high as 15 ft. above the natural ground. This section of the country is already menaced by ground-water due to seepage from the local canals and if the All-American Canal were carried across this same territory, at such an extraordinary height, this section would be ruined from ground-water. A considerable area of land west of the present West Side Main would be left in its present condition permanently, on account of the low elevation of the All-American Canal.



CROSS SECTION OF CUT THROUGH SAND RIDGES
SHOWING PROBABLE CHANGE IN SECTION AT END OF ONE YEAR

0 100 200 300
SCALE IN FEET

FIG. 16.

Assuming the All-American Canal to be built, the next consideration concerns its future maintenance. The very fact that the stream is in a cut 50 ft. below the floor of the mesa itself, with crowning sand-hills of heights ranging to 100 ft. above the floor, makes it absolutely certain that the cut itself will receive and hold the entire volume of sand drifted to it by each storm. Where the sand-drift passes across the country without interruption, ofttimes a pass through the sand-hills, such as the Government Pass in which part of the canal is located, can remain fairly open; but where the passage is deliberately interrupted by a cut having a flowing stream at its bottom, then all the sands must necessarily enter and remain in this excavation.

Here, again, Imperial Valley must depend on its present canal system through Mexico if interruptions in the delivery of water are to be avoided—interruptions that unquestionably will be fatal on account of the huge quantity of drift involved.

The borings taken along the route of the proposed canal indicate porous strata in the canal prism. Especially with the Boulder Canyon Dam built and with some relief from the silt thrown into the canals as at present, this prism cannot possibly seal itself. The water losses from seepage, as estimated from the losses occurring in the present East High Line Canal through similar sections of material, will amount to 27%, unless the canal is lined with concrete. This loss is prohibitive not only because of the interference in regulating the supply to the land about 150 miles distant, but more particularly because the very water lost to the All-American Canal will mean the ruination, from saturation, of all the low-lying lands along the section of the country through which it passes.

As an alternative, lining the canal with concrete or tunneling the sand-hills is impractical, principally because the section must be constructed for the maximum irrigation requirement immediately, as it will be difficult to enlarge. As it may be twenty years before the entire capacity will be demanded for irrigation, the additional investment at present is prohibitive.

However, the main objection to the location of such a canal is the uncontrollable elements injected into the problem in deliberately cutting and maintaining a waterway through the very heart of a desert mesa region, capped with drifting sand dunes. By means of studies herein discussed, these mammoth sand dunes are easily recognized as similar in size and construction and in the phenomena governing their movement, to the most extensive types the world over. As the welfare of thousands of souls in the oasis of the great Sahara Desert, where prosperous settlements have been overwhelmed and blotted out of existence, is intimately connected with the rate of movement and the mode of accumulation of wind-borne sands, so is the fate of one of the greatest irrigation regions of the world coupled inseparably with a similar movement of great sand-hills on the route of the All-American Canal. The lessons taught by engineers and geologists of England, France, and the United States, in their years of study and observation of the sand dune regions of the world, must be applied in this case to avoid disaster in attempting to build the All-American Canal.

In addition to the difficulties of construction, there is the question of determining from experiments elsewhere whether or not the sand-hills through a 12-mile section of the All-American Canal can be prevented from drifting into the canal; secondly, it remains to determine the rate of movement in the sands of the character found in this case; and, thirdly, having projected a determined quantity of sand into the canal, it is important as to whether or not conditions can be set up in the canal itself enabling the water to transport the sand without resorting to mechanical means.

Although in localities of lesser sand-drifts, fences, trees, and the oiling of the ground surface are useful in stopping their encroachment, under conditions of such overwhelming drift, as in the case at hand, no such means would be successful. The only effect of oiling or planting vegetation is to create other sand dunes. Trees, brush fences, and such obstacles placed in the path of such extreme drift are most readily submerged, emerging, however, as the dunes move on. In the case of the All-American Canal, as the sand rolls over such obstacles, it next encounters the running stream of water which is the only effectual means of stopping it. It follows that the most general method of checking the encroachment of blow sands is to promote the growth of sand dunes; and a sand dune is best promoted by a running stream. Sand-hills on the western shores of the Holy Land, and in a district extending almost from the borders of Egypt, including the neighborhood of Alexandria, are stopped only by the Nile. Sand dunes are invaders far more dangerous than the waves of the sea and only a stream that will carry off the particles will effectively stop them.

In determining the capacity of the canal to carry off the sands injected into it, it is necessary to examine the mechanical elements of the materials involved and to determine the quantity to be removed. Table 23 indicates the remarkable similarity in the grading of sand from dunes scattered over the United States. The similarity of sands taken along the route of the All-

TABLE 23.—MECHANICAL ANALYSES OF SANDS.

SAMPLES FROM THE ROUTE OF THE ALL-AMERICAN CANAL.

SAMPLE NO. 1* TAKEN NEAR STATION 800 FROM BOTTOM OF SAND-DRIFT.			SAMPLE NO. 3* TAKEN NEAR STATION 800 FROM TOP OF SAND-DRIFT.			SAMPLE NO. 7* TAKEN NEAR STATION 980 FROM SAND-FLAT.			Average percentage of three samples.
Diameter, in millimeters.	Percentage.	Proportion, in ounces.	Diameter. in millimeters.	Percentage.	Proportion, in ounces.	Diameter. in millimeters.	Percentage.	Proportion, in ounces.	
2 — 1	......	......	1 — 2	......	......	1 — 2	3.10	2.50	1.03
1 — ½	21.25	17.00	½ — 1	5.62	4.50	½ — 1	55.60	44.50	27.49
½ — ¼	40.00	32.00	¼ — ½	46.25	37.00	¼ — ½	19.40	15.50	35.21
¼ — ⅛	38.75	31.00	⅛ — ¼	48.13	38.50	⅛ — ¼	21.90	17.50	36.26

SAMPLES FROM SIMILAR SAND-DRIFTS IN DIFFERENT PARTS OF THE UNITED STATES.†

Diameter, in millimeters.	Rear slope of a dune, Alliance, Nebr.	Rear slope of a dune, Tampico, Ill.	Rear slope of a dune, New Boston, Ill.	Rear slope of a dune, Alliance, Nebr.	Rear slope of a dune, Alliance, Nebr.	Rear slope of a dune, Hooppole, Ill.			Sand-drift, Griggs Company, North Dakota.	Sand-drift.	Average percentage.
16 — 8	......	......	......	......	......	......	......	......	.....	.....	.....
8 — 4	......	......	......	......	......	......	......	......	.....	.....	.....
4 — 2	......	......	0.20	......	......	......	......	......	.....	.....	Tr.
2 — 1	9.00	3.90	1.80	0.20	0.10	......	0.20	......	.....	0.30	1.55
1 — ½	80.	43.80	22.00	37.10	33.70	12.40	9.70	6.20	19.30	14.00	27.84
½ — ¼	6.60	28.60	46.20	50.90	49.40	34.60	44.40	39.20	45.20	42.90	38.80
¼ — ⅛	5.00	22.00	26.20	18.90	15.00	33.00	40.70	29.40	30.70	37.90	25.88
⅛ — ¹⁄₁₆	0.10	1.70	2.80	1.70	0.10	17.20	4.00	23.40	2.40	2.50	5.59
¹⁄₁₆ — ¹⁄₃₂	......	......	0.20	......	......	2.00	0.30	1.20	0.40	1.80	0.59
¹⁄₃₂ — ¹⁄₆₄	......	......	......	......	......	......	......	......	Tr.	0.30	Tr.
¹⁄₆₄ — ¹⁄₁₂₈	......	......	......	......	......	......	......	......	.....	.....	.....
¹⁄₁₂₈ — ¹⁄₂₅₆	......	......	......	......	......	......	......	......	.....	.....	.....

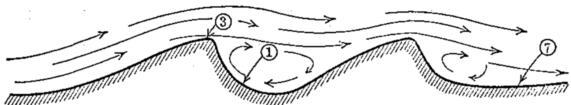
COMPARISON OF AVERAGES.

Diameter, in millimeters........	1 — 2	½ — 1	¼ — ½	⅛ — ¼
All-American Canal..............	1.03	27.49	35.21	36.26
Similar sand-drifts..............	1.55	27.84	38.80	25.88

* See Fig. 17 for position of samples. Five pounds of each sample used. Analyses by J. C. Allison, M. Am. Soc. C. E.

† Analysis taken from "Mechanical Composition of Wind Deposits", by John August Udden, 1898.

American Canal to samples taken elsewhere in the United States, and the mechanical analysis of the sands of the Lybian Deserts and the regions of the Sahara, justify the assumption that the phenomena governing the movement of sands in the older and more carefully studied regions, will be repeated in the case at hand. In Fig. 17 is shown the positions from which the speaker's samples on the All-American Canal were taken.



WIND ACTION ON SAND DUNES OR "BARCHANS"
Figures indicate location from which samples of Table 23 were taken

FIG. 17.

The scouring action of fluids varies theoretically as the square of the velocity and so does the diameter of the particle transported. If the velocity is doubled, the diameter of the particles transported may be increased four times. The transporting power of wind varies approximately with its erosive force, that is, as the square of the velocity, as in fluids, whereas its lifting capacity changes according to the sixth power. The range of velocity of dune-making winds certainly exceeds twice the normal, and hence it might be expected that the bulk of sand, in some places at least, would consist of grains many times as large as in others, were it not for scarcity of the larger material.

Size alone may make a dune a permanent hill even if it is composed of loose sand throughout. Given a constant climate, a large desert dune might easily outlast the highest mountains, for the denuding agency continually renews the surfaces. On the other hand, there is necessarily a limitation of the process whereby dunes grow, which prevents their attaining heights equal to those of mountains formed by erosion. Winds have greater power at considerable elevation than at the surface so that more sand is removed from the summits than is replaced by the wind and thus the lowering of the summits is not offset by the deepening of the trough; action on the summits of dunes is hastened, and in the trough hindered, by gravity, and should a trough be created by excavation through the sand dunes, the phenomena mentioned would continue until the point was reached by the filling of the trough where any deepening would be compensated by the lowering of the summits.

Obstacles, such as a wall, affect the distribution of sand by wind in two ways, directly as obstacles and indirectly by affecting the motions of the air. Wind evokes eddies on each side of an obstacle. These eddies on the weather side pick up the finer grains which those on the lee side capture, throwing away only the finest of them. Sand, therefore, deposits against both sides of the wall. A high canal spoil bank, even though wetted, oiled, and grown with shrubs, acts merely as a wall, the sand being deposited both on the outside and on the canal side. If the sand is fine and the wind strong, the principal deposit is on the lee side or in the canal; if the wall or embankment is high, nothing at first will get over it, except dust wafted in the air. In time, however, the mechanical obstacle offered by the bank results in building up a sloping platform on the weather side and when the platform reaches sufficiently near the top of the embankment, the winnowing action described commences. The deposit on the lee side being formed by sedimentation takes its angle of repose, usually quite steep. If, however, by favoring conditions, the sloping platform on the windward side should in time surmount the bank or wall, so that the large grains could roll over, a proper dune or "barchan" profile is produced (Figs. 14 and 17), and the movement of the dune or barchan into the canal corresponds with the movement of the dune of similar character without the area of the canal prism.

In the observations made by Mr. H. J. L. Beadnell, formerly of the Geological Survey of Egypt, on the dunes of the Lybian Desert, the following results were obtained with an air meter under different conditions of wind in the dune belts (from personal observation, corresponding results are obtained in the sand-dune regions of the All-American Canal):

1.—On the dunes, the sand commences to move when the winds attain the velocity of a light breeze, or 13 miles per hour.

2.—On the open plains, the wind becomes visibly charged with sand as soon as the velocity of a moderate breeze (23 miles per hour) is obtained.

3.—Sand-storm conditions obtained when the wind exceeded a moderate breeze, the maximum velocity actually recorded being 34 miles per hour.

The following experiments correspond in general to those made in an attempt to trace the annual movement of a sand dune through the section of the proposed All-American Canal:

1.—According to Dr. Franz Czerny, dunes on the Baltic Coast in the Province of Courland moved at the rate of 18 ft. per year.

2.—Bromontier measured the movement of the dunes of Gascogne at the rate of 25 m. per year.

3.—Cornish found the average rate of advance of a crest of a dune near Ismailia to be about ¾ in. per hour.

4.—Mr. C. R. Enock estimated the movement of barchans in South America to be as much as 2 ft. per hour in a brisk breeze.

5.—On the Lybian Desert, the movement of barchans is as much as 25 m. per year.

6.—In the sand dunes along the route of the All-American Canal, movement of barchans as great as 85 ft. per year has been recorded.

Fig. 18 shows a profile of that section of the proposed All-American Canal through the sand-dune region. It is reasonable to expect from the experiments mentioned that the sand dunes through which the canal is cut will shift an average of 80 ft. per year. The cross-section of the canal (Fig. 16), indicates as nearly as possible, what effect this shifting will have on the canal prism. A calculation of the quantity of sand shifted per year into the canal, as reflected in the cross-section, gives 3 136 000 cu. yd.

The mechanical analysis of the sands shifted into the canal corresponds to that of materials dragged along the bottom of Colorado River and like streams. These materials form themselves on the bottom of the streams into dunes and anti-dunes and move as such in sand waves down the stream. It is due to the dragging rather than to the suspension faculties of the stream that these types of sands are transported. The first movement begins at a surface velocity of 1.3 ft. per sec.

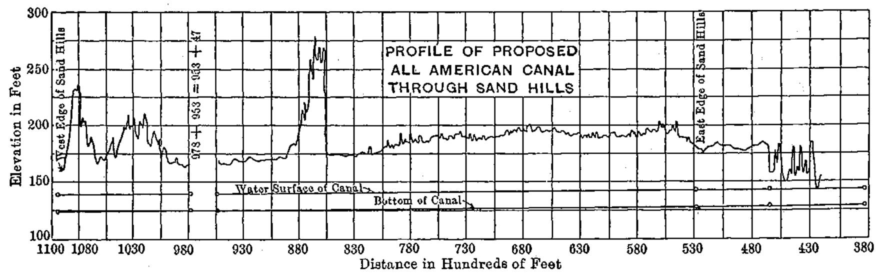


FIG. 18.

From the tabulated data on movement of sand waves,* the following cases are recorded where velocities and sand weights correspond to those of the All-American Canal: In the Mississippi River at Helena, Ark., crests of sand waves moved 17.17 ft. per day with a stream velocity of 3.58 ft. per sec. In the Loire, for corresponding velocities the movement was from 16.4 ft. to 36 ft. per day. Measured by M. Sainjon, in the Loire, under a surface velocity of 1.33 m. per sec., the crests of sand-bars moved from 0.000056 m. per sec. to 0.000087 m. per sec.

From the foregoing experiments it is safe to assume that materials of like nature injected into the All-American Canal will be dragged along the bottom of the canal in sand waves under the prevailing velocities of 3 to 4 ft. per sec., a distance of approximately 6 000 ft. per year. Of the materials presumed to have been thrown into the canal by the wind, only one-tenth will be thus scoured from the critical section through the sand-hills, leaving 2 800 000 cu. yd. to be removed with dredges each year. As a matter of fact, even the small proportion that passes through the critical section in sand waves will only be distributed through lower reaches of the canal, as there are no sluiceways available near the sand-hill section. Any neglect in the yearly dredging of the canal or any accumulation of sand deposits in one section will result in a complete blocking of the water supply, unless the Mexican Canal is maintained as a stand-by. The effect will be to demoralize the living conditions of the 50 000 to 60 000 people in the Imperial Valley, who are dependent entirely on the Colorado River for their water supply.

Practical Substitute for the All-American Canal.—The outlying lands in the Imperial Valley Basin, including the East and West Mesa and the Coachella Valley, can secure a water supply from the Colorado River. However, this must be attained without overburdening the already too heavily taxed users of water in the Imperial Irrigation District. This can be done in a practical manner and at much less expense than the All-American Canal

* "The Suspension of Solids in Flowing Water", by Elon Huntington Hooker, *Transactions*, Am. Soc. C. E., Vol. XXXVI (1896), p. 239.

route, for the new mesa lands and the Coachella Valley. These new Government lands can then be acquired and farmed successfully by the returned soldier, or by any other entrymen who can finance and build their own canal systems at the proper time, in the same manner as the settlers of the other districts within the present Imperial Irrigation District and in Coachella Valley without the necessity of Government appropriation.

Fig. 19 shows the proposed route of the All-American Canal and lateral canal system for the new lands, as covered in the report referred to. Delineated also on the same map is the system proposed hereunder, to irrigate the same lands, except in greater acreage. Briefly described, this proposal is as follows.

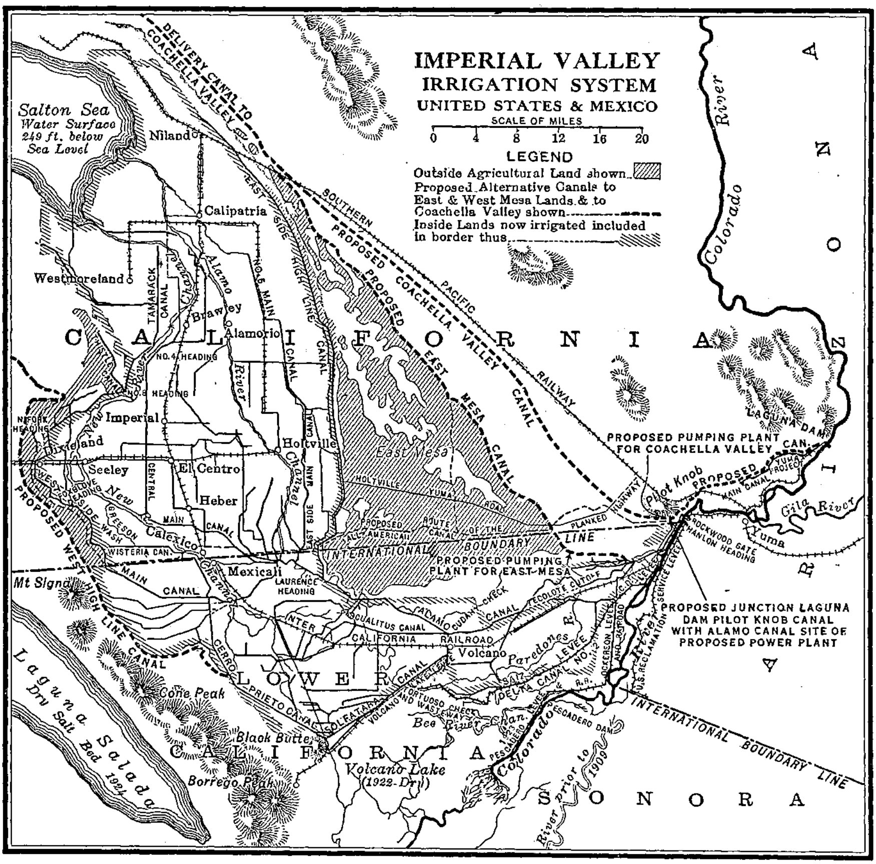


FIG. 19.

Laguna-Pilot Knob Canal for Imperial Irrigation District.—Construct the canal and works from Laguna Dam to Pilot Knob as provided in the All-American Canal report. At Pilot Knob, empty the entire flow of the canal into the Alamo Canal, utilizing the present main channel through Mexico.

Construct a power plant at the point of delivery into the Alamo Canal to utilize the Mexican, as well as the American, water to generate 43 700 h.p. This power is calculated from the following factors: Delivering water from Laguna Dam to Pilot Knob at an elevation of 143.87 ft. and dropping 13 000 cu. ft. per sec. 37 ft. into the Alamo Canal. This water can shortly be sold to American and Mexican lands during part of the year and used to sluice the Imperial Valley Canals during the remainder of the year. The power developed will be delivered as follows:

8 500 h.p. to the Yuma project, as per contract of October 23, 1918;

7 500 h.p. to lift 1 300 sec-ft. of water from the new canal to the floor of the mesa at Pilot Knob to irrigate 100 000 acres of land in Coachella Valley and at Dos Palmas;

21 500 h.p. to lift 2 600 sec-ft. of water from the Alamo Canal to the floor of the mesa at the west end of the sand-hills to irrigate 200 000 acres of East Side Mesa lands in United States and Mexico.

This proposed canal and power plant will cost the District $5 600 000.

The advantages in this proposed work, over the All-American proposal, are that the Hanlon Heading Diversion, and the Alamo Canal through Mexico, will serve as a stand-by for the water system to Imperial Valley in case of mishap to the Laguna Dam connection. The power development is immediately greater than that developed by the All-American Canal, and the market for it is at hand, with little transmission loss and expense. As the irrigated acreage increases on either side of the International Boundary Line, so will the power development increase, while with the All-American Canal no future increase can be had and the Mexican water power is lost to the District entirely.

Canal for Coachella Valley.—Lift from the Laguna-Pilot Knob Canal 1 300 sec-ft. of water for Coachella Valley and Dos Palmas. This water is to be lifted from an elevation of 143 ft. to the floor of the mesa at an elevation of 183 ft. and carried in a canal on top of the mesa in a normal cut along the northeasterly side of the sand-hills (Fig. 19), at a distance to avoid sand-drift or encroachment, to the main line of the Southern Pacific Railroad, at an elevation of 128 ft. Here, it crosses and follows a grade contour to Coachella Valley 37 ft. higher than that reached by the All-American sand-hill route. The route on this location is 13 miles shorter than by way of the sand-hill route and its higher elevation places it to greater advantage as far as storm drainage is concerned. The higher contour irrigates 23 000 acres more in Coachella Valley than the sand-hill route, making in all 100 000 acres of agricultural land in place of 77 000 acres as contemplated. The costs would be as follows:

Pumping plant at Pilot Knob................	$ 500 000
52 miles of canal, Pilot Knob to Iris...........	1 200 000
Iris to end, including laterals................	6 474 000
Total	$8 174 000

For 100 000 acres this would be at $81.74 per acre, as compared to $102.00 per acre, estimated by the All-American Canal report. The saving in maintenance on the pumping route will more than pay for the power and operation of the pumping plant.

Canal for East Side Mesa Lands.—Lift from the Alamo Canal in Mexico, at Elevation 93, 2 600 sec-ft. to the top of the mesa west of the sand-hills, at Elevation 160, to irrigate all the East Side Mesa lands, as contemplated in the All-American sand-hill route (160 000 acres in the United States and 30 000 acres in Mexico), together with 10 000 acres not reached by the All-American route. To lift this flow from the Alamo Canal, a 20-ft. head pumping plant would be required, the water would be carried in a Mexican canal for a distance of 5 miles to the foot of the mesa, where it is lifted in two or more lifts 47 ft. to the top of the mesa; the canal on the mesa follows along the westerly edge of the sand-hills (Fig. 19) to Iris, on the approximate route of the pumping canal lateral contemplated in the All-American program. The cost would be as follows:

Pumping plant, 20-ft. lift	$ 500 000
Pumping plants, 47-ft. lift	850 000
Main Canal to Iris, plus 100 000 acres of lateral system	4 466 800
Plus additional 100 000 acres of lateral system at $16	1 600 000
Total	$7 416 800

Under the All-American sand-hill route the cost per acre is $85.20, with a cost for maintenance which will operate the pumping plants under the Mexican route.

Canal for West Side Mesa Lands.—Construct a canal from the Cerro Prieto Canal in Mexico, at Tule Check, following a grade contour along the western slope of the valley above the line contemplated by the All-American Canal System, irrigating agricultural land as follows:

Lands covered by All-American Canal System	20 000 acres
New lands above All-American Canal System	10 000 "
Pump lands covered by All-American Canal System	23 000 "
Total	53 000 acres

The cost of this project would be as follows:

Enlarging Solfatara and Cerro Prieto Canals in Mexico, 28 miles	$105 000
Head-works at Tule Check	80 000
New canal to International Boundary Line (19 miles)	200 000
Building "B" Line Canal on new location plus enlargement for additional acreage	641 000
Total	**$1 026 000**

For 53 000 acres	$19.35 per acre
Plus distributing system	16.00
Total cost for gravity lands	$35.35 per acre
Plus pumping system	50.50
Total cost for 23 000 acres of pumping lands	$85.85 per acre

Under the All-American Canal System, the corresponding costs are $106.00 per acre for the gravity lands on the West Side and $156.50 per acre for the pump lands.

The advantage of the Mexican route for the West Side lands, is the saving in cost per acre, the saving in maintenance, and in more direct and simple routing, over the prohibitory expense and impossible location of the All-American Canal System as proposed.

Mexico.—As has been pointed out, supporters of the All-American Canal must necessarily create a plausible reason for building it. They cannot well use the merits of the canal itself which are by comparison negative. Therefore, the only remaining argument for the canal is Mexico, the "bogey-man". There being no grounds in truth for an argument they and their supporters have recklessly resorted to imaginary accusations which have no bearing on the situation whatever, and, in their attacks on Mexico, have exposed the interests of American farmers in the Imperial Valley to the possibility of a retaliation that might do irreparable damage to the Nation.

Among other accusations, the supporters for the All-American Canal contend that Mexican lands have not paid their proportion of the expenses necessary in maintaining the canal and flood-control works of the Imperial Irrigation District. Mexican lands are not owners of these works as are the purchasers who happen to be the Imperial Irrigation District, but are merely customers, having no representation in the control of water affairs and having no participation in the possible earnings from the Canal System. Tables 24 and 25 indicate the amounts which Mexico has overpaid in the past five years in the water and flood-control affairs of the Imperial Irrigation District.

In Table 24 the entire financial distribution of the funds of the Imperial Irrigation District has been studied and, from the figures presented by the Auditor of the District, extracts have been taken. The four years of Irrigation District affairs ending December 31, 1922, have been chosen, as those years will properly emphasize the financial relationship between the Mexican and the American sides of the line; the first 1½ years of the financial history of the District (previous to 1919) reflect approximately the same relationship, but the actual distribution of figures is not dependable as to segregation between Mexican and American expenditures.

In the four years covered by Table 24, to avoid the risk of dispute as to expense and disbursement, all the expenses of the Imperial Irrigation District, on both sides of the line, have been taken into account, and Mexico has been charged with its proportion of these expenses. In reality, Mexico is simply a water customer of the Imperial Irrigation District and of its Mexican Branch, known as "Compania de Terrenos y Aguas de

TABLE 24.—IMPERIAL IRRIGATION DISTRICT—STATISTICS FROM FINANCIAL REPORTS, 1919-1922.

	1919	1920	1921	1922	Total.
Acreage irrigated, United States	417 000.00	417 000.00	414 000.00	415 000.00	1 663 000.00
Acreage irrigated, Mexico.......	136 560.00	190 000.00	122 000.00	150 000.00	598 560.00
Total acreage irrigated.........	553 560.00	607 000.00	536 000.00	565 000.00	2 261 560.00
Mexico irrigated 26.47% of entire acreage for 4 years. In the same manner, Mexico irrigated 26.55% of entire acreage in 1922.					
Total interest paid by Irrigation District on all District bonds and warrants, together with all discounts, taxes, and other similar charges paid, except discount on fourth issue of bonds sold for purchase of Mutual Water Companies and drainage in United States part of District.............	$451 025.73	$534 552.97	$458 316.09	$408 555.00	$1 852 449.79
Mexico's proportion of total interest charge is 26.47% of $1 852 449.79, or $490 843.46. In the same manner, Mexico's proportion of interest charge in 1922 is 26.55% of $408 555, or $108 471.35.					
Water sales, United States......	$699 782.20	$814 867.54	$699 690.60	$788 952.59	$3 003 292.93
Water sales, Mexico............	340 710.66	499 000.00	360 702.33	469 740.64	1 670 153.63
Total water sales, United States and Mexico..................	$1 040 492.86	$1 313 867.54	$1 060 392.93	$1 258 693.23	$4 673 446.56
Mexico paid 35.74% of all water revenues for 4 years. In the same manner, Mexico paid 37.32% of all water revenues in 1922.					
Total operating costs of District on both sides of Boundary Line for both canal and levee systems, includes superintendence, maintaining canals, levees, bridges, structures, buildings, fixtures, grounds, power and telephone lines, insurance, maintenance of all machinery, including depreciation; cost of distributing water; salaries and expenses of Irrigation District directors, officers, clerks at all points, law expenses, advertising expense, etc..................	$932 221.68	$1 001 776.53	$623 683.50	$898 795.63	$3 456 477.34
Profit in water rentals over operating costs...............	108 271.18	312 091.01	436 709.43	359 897.60	1 216 969.22
Other profits, exclusive of tax assessments, certificates of redemption and interest on same, or any other profit paid by taxation on assessment by United States side of line.....	54 040.61	99 245.00	59 701.36	93 356.64	306 344.01
	$162 311.79	$411 336.41	$496 410.79	$453 254.24	$1 523 313.23

TABLE 24.—(*Continued.*)

Mexico's proportion of total profits based on the amount of money she paid in to secure said profits, is 35.74% of $1 523 313.23	$544 432.15
Mexico's proportion of all interest as per above	490 343.46
Mexico's over-payment of all operating costs and interest for four years	$ 54 088.69
In the same manner, Mexico's proportion of total profits for 1922 is 37.32% of $453 254.24	$169 154.49
Mexico's proportion of all interest charges for 1922 is	$108 471.35
Mexico's over-payment of all operating costs and interest for 1922 is	$ 60 683.14

la Baja California, S. A."; the original costs and maintenance of all the canals and structures north of the International Boundary Line, with the exception of the Hanlon Heading and Laguna Dam structures, should not be charged against Mexico. If this were done, the overcharge which Mexico has paid on operating expenses, principal, and interest on bonds, etc., would be more than double that shown by Table 24.

The investigation summarized in Table 24 indicates the following facts:

1.—During the four years considered, Mexican lands paid in cash not only their acreage proportion of the operating costs of all work and expense incurred by the District, but also $54 088.69 in excess of their acreage proportion of all interest on bonds, warrants, taxes, and every other expense incidental to the capital investment of the District on both sides of the line.

2.—Again, for the year 1922, Mexico has paid in cash all its share of the operating costs on both sides of the line, together with its share of all the interest items for capital investment of the District on both sides of the line, and has paid in excess, $60 683.14. There should be added to the latter item, the sum of $68 020.06, paid in cash by the Colorado River Land Company, S. A., in 1922, on the levee work of the District in Mexico, making an over-payment by Mexico of more than $128 703.20.

To the total of both these items should be added a differential arrived at, as follows:

The Irrigation District virtually delivered water to the individual user on the American side of the Line, inasmuch as it allowed an average of 10% for seepage and evaporation losses in the Canal System, besides maintaining most of the main canals. In Mexico, the water charge is made directly at the main canal of the District, with no allowance for seepage and evaporation and for canal maintenance. Another item to the advantage of the American side, is the fact that none of the Water Companies paid the District in advance for the water; in fact, most of the Water Companies have been in arrears several months at a time, whereas the Mexican users pay in advance, before water is put into the Mexican Canals. Therefore, to equalize the differential in water charges alone, there should be added to the water payment of Mexico in four years the sum of $167 015.36, making Mexico's total over-payment for the four years, $221 104.05. In the same manner, the over-payment made by Mexico for 1922 should be $128 703.20 plus $46 974.06, or $175 677.26.

It will be noted that the expense per acre for water used in Mexico greatly exceeds that for the United States; for instance, the total cash cost to Mexico per acre irrigated for 1922 was $3.13, while in the United States it was $1.09. This is not because Mexico used more water per acre than the United States, but because of the 10% differential allowance for seepage and evaporation in the United States and because the water charge by the District in Mexico was greater than that in the United States until the time the Water Companies were absorbed. The highest rate paid in Mexico for water is $2.08 per sec-ft.; the lowest rate in Mexico is 75 cents per 1 000 cu. m., or $1.83 per sec-ft., both without any allowance for losses. In the United States, the highest rate paid, until the date of absorption of the Water Companies, was $1.70 per sec-ft. It is true that since then this rate has been raised to $2.00 per sec-ft., but the water is delivered to the individual irrigator, eliminating all losses of whatever nature in canal transit; besides this, it is the practice now, and has been for some years, for the District to furnish water on the American side for canal sluicing, washing out alkali lands, and generally for helping out the individual farmer. No such courtesy is now or ever has been extended to the Mexican water user. The cash allowance, besides water, to the Water Companies by the District for 1920, 1921, and 1922, was $202 674.23.

As stated in the foregoing, none of the canal systems in Mexico, other than the main canal of the District, is maintained by the District. The amount of the assessment against a Mexican acre is the same or more than the average water assessment of the Mutual Water Companies in the District for the same purpose in the United States. As matters now stand, since the District has absorbed the Mutual Water Companies, to equalize the maintenance and water charges the District should also assume the obligation of maintaining all canals in Mexico. It should pay at the rate of $9.09 per acre for each acre irrigated in Mexico, together with the cost of the dredgers and other operating equipment of the Mexican Canal Companies and should assume the delivery of water to the individual Mexican user in the same manner that it has done with the Mutual Water Companies on the American side. To the water user on the American side, the District, in 1923, paid in cash the sum of $4 724 612 to cover the items of canal systems, equipment, etc.

The advantages to the American water user in the present system of selling water by the District to Mexico have never been properly presented by the District. Were the All-American Canal to be built, for instance, and should the District discontinue the usage of its Mexico main canals and the sale of water to Mexico en route, the American water user would not only have the increased bonded debt on his land, created in the financing of such canal, but he would bear the burden of the decreased revenues of the District. The District, in that case, would be identical with a large department store, having all the departments idle except the top floor; in other words, a store supplied with goods and equipment to do business on all ten floors, but only selling and creating a profit on the top floor. The expense of carrying water from the Heading on the river for fifty miles through Mexico, or through an All-American Canal on the American side, without creating any business until it reaches the upper portion of the Line, or the irrigable area on the East Side Mesa in the United States, is a similar example.

The tax rate on the American side for the four years under discussion is, as follows: $1.67 in 1919; $2.35 in 1920; $1.85 in 1921; and $1.90 in 1922; or an average of $1.95. Should there be wiped out the revenues collected in advance from Mexico for the four years, in the total sum of $1 670 153.63, then the tax rate per acre to the American land and property owner would be nearly doubled.

In the studies which have been made of the entire question, the relationship of capital investment between Mexico and the United States has also been investigated. In the building of the canal and levee systems there has been constructed and utilized for the benefit of American lands, a total of 67 miles of canal and 55 miles of levee on the properties of the Colorado River Land Company, S. A., alone, totaling an acreage right of way (exclusive of lands lost by seepage damage, etc.) of 30 000 acres. This taken with the right of way occupied on the remainder of the Mexican lands other than those of the Colorado River Land Company, brings the total usage of property up to 50 000 acres, which, at $50 per acre, has a total capital value of $2 500 000, equivalent to more than Mexico's proportion of the bonded debt of the Imperial Irrigation District.

Table 25 is a summary taken from the figures furnished by the Imperial Irrigation District showing the over-payment by Mexico of its share of expenses for 1923. Summarizing, the actual amount of money expended to deliver water to the International Boundary Line, at the various points of diversion into the United States, for agricultural use, is as follows:

All diversion works at Hanlon Heading, etc.	$122 095.78
All costs of delivering Mexican water, and carrying American water through Mexico	185 986.50
All river protective work of every nature	197 966.68
Total cost to the Irrigation District to deliver water at the various canal points along the International Boundary Line for usage in the United States, and to deliver Mexican water	$506 048.96
Total water sales in Mexico	$526 971.56
Difference between money received from Mexico and total monies expended by the District	$20 922.60
Plus cash paid by the Colorado River Land Company for river protective work, not included in the above	$39 855.65
Total net profit to the Imperial Irrigation District, after delivering all Mexican water, and delivering American water to the various canals at the International Boundary Line	$60 778.25

In other words, during 1923 the Imperial Irrigation District furnished water to its American water users at the International Boundary Line absolutely free of cost and with an added cash profit of $60 778.25. Were the All-American Canal built and functioning in 1923, the same operating costs as those given, in the total of $506 048.96, would have to be met by the American water user in addition to all the other taxes, water costs, and expenses he paid in 1923.

Besides, the abandonment by the District of its 137 miles of canals through Mexico, and its 71 miles of protective levees and railroads, together with the rock quarries and properties pertaining thereto, amounting in all to a total capital value of approximately $6 000 000, would be lost.

Furthermore, in considering Tables 24 and 25, it should be remembered that at the time the Mutual Water Companies on the American side were absorbed, they owed the District a total sum of $573 109.23. The Mexican water users owed the District nothing; in fact, they paid in advance on a great deal of their water. Of the sum owing the Imperial Irrigation District by the American Mutual Water Companies, $202 674.23 was written off by the District, and this bonus, granted the American users, is charged in the financial statements proportionately against Mexico also.

The supporters of the All-American Canal contend that the restrictions placed on them and on the construction and operation works by Mexico are prohibitive. The restrictions in Mexico are far less severe than those in the United States wherever the public interest is involved. At no time in the history of irrigation of the Imperial Valley have the Mexican engineers been anything but helpful in the construction and maintenance of the System.

In addition to the innumerable other objections to having the canal system in Mexico, the supporters of the All-American Canal urge their desire to control the quantity of water Mexico shall receive from the Colorado River, in order that Mexico shall be the one to be deprived of water when a water shortage comes on them. The position alone of Mexico's irrigable lands in the Delta of the Colorado River assures them of an ample supply of water even if the entire regulated flow is utilized in the projects above them, as long as the waters are not withdrawn from the water-shed of the stream. The return waters from the irrigation of 6 000 000 acres in the projects above will furnish the comparatively small area of Mexican land with an ample supply of water forever. As there is a surplus of water for irrigation requirements, there should be no strife between the two countries in the division of the water, and a treaty arrangement whereby American water can be passed through Mexico under complete control of American owners should be made easy.

Conclusion.—Summarizing the whole situation, it must be evident after a careful study of the Colorado River problem from an unselfish and unbiased point of view, that outside of political considerations and ambitions there is no logical reason for the present agitation.

TABLE 25.—THE IMPERIAL IRRIGATION DISTRICT—STATISTICS FROM FINANCIAL REPORT FOR 1923.*

	1923
Acreage irrigated, United States	350 000
Acreage irrigated, Mexico	180 000
Total acreage irrigated, United States and Mexico	530 000
Mexico irrigated 33.96% of entire acreage in 1923.	
Total interest paid by Irrigation District on all District bonds and warrants, together with discounts, taxes, and other similar charges paid, except discount and interest in 1923, on fourth issue of bonds sold for purchase of Mutual Water Companies and drainage in United States part of District	$437 500.00
Mexico's proportion of total interest charge is 33.96% of $437 500, or	148 575.00
Water sales, United States	914 832.15
Water sales, Mexico	526 971.56
Total water sales, United States and Mexico	$1 441 803.71
Mexico paid 36.55% of all water revenues in 1923.	
Total operating cost of the Irrigation District for 1923, including diversion work from the Colorado River to the International Boundary Line, all expense and maintenance costs in Mexico for both American and Mexican water, all river protective work, all expense of the Board of Directors and General Administration on both sides of the Line, all storage and All-American Canal expense, all telephone and power-line expense, etc., the above includes every expense of every nature, except only construction cost of the drainage system in the United States, plus construction costs and costs of delivering water to the individual American ranchers, after the water crosses back into the United States in the various American lateral canals	$799 177.89
Profit in water rentals over operating costs for 1923	642 625.82
Other profits entering the Mexican "Compania" funds, but excluding profits entering "General Funds", such as interest on bank deposits, property sales, etc	61 848.77
Total profits from operation for 1923	$704 474.59
Mexico's proportion of total profits based on the amount of money Mexico paid to secure said profits, is 36.55% of $704 474.59, or	257 485.46
Mexico's proportion of all interest and discount charges on bonds as per this statement	148 575.00
Mexico's over-payment on operating costs and bonded debt costs for 1923 is	$108 910.46
Add to the above, cash payment to the Imperial Irrigation District by the Colorado River Land Company for its proportion of river protective work, in 1923, as per agreement (this sum not shown in the District's 1923 Financial Statement because it was paid in the early part of 1924)	39 855.65
Mexico's total over-payment of its proportion of all costs for 1923	$148 766.11

* All charges for maintenance and operation of every nature (including All-American Canal expense to date), have been taken into account and charged proportionately to Mexico, except only (*a*) interest and discount on fourth issue of District's bonds sold to purchase Mutual Water Companies and to build drainage works on the American side; (*b*) monies expended in distributing water to individual American water users after it passes into the United States; (*c*) monies expended in building drainage works in United States; and (*d*) capital purchase of buildings, fixtures, and equipment for use in distributing water to individual water users in the United States.

If fully conserved there would be more water in the Colorado River watershed than is needed by the practical agricultural land on both sides of the International Boundary Line. It does not require an All-American Canal to serve the remaining agricultural lands in Southern California. A flood-control dam, built forthwith at some point on the river by the Government will solve the immediate flood problem, leaving the Federal Power Commission free to act in granting power permits to complete the development of the river after the Colorado River Compact between the States has been ratified.

FREDERICK H. FOWLER,* M. AM. SOC. C. E.—Present engineering information on the Colorado River problem has been ably summarized by the author. Several of his conclusions are diametrically opposed to a plan that has received wide publicity and has secured a firm hold on the popular imagination, the so-called "Boulder Canyon Project". Although the speaker does not regard this project as the best solution of the Colorado River problem, he admires most heartily its bold conception as an individual development.

In its final form, the Boulder Canyon Project proposes a dam rising 605 ft. above low water, capable of storing 34 000 000 acre-ft. behind it, the dam itself to cost at least $50 000 000. The power rights are to be leased to political sub-divisions or to others on a basis that will amortize the cost in fifty years. The power plants have been estimated to cost $36 000 000, and the transmission lines leading to the market, $46 000 000; a total of $132 000 000, or more, without the All-American Canal that has been appended to the project in pending legislation. According to its proponents, this project would:

(*a*) Reduce the maximum flood flow to 40 000 sec-ft.;

(*b*) Furnish a regulated irrigation supply to all irrigable lands below it; and

(*c*) Produce 660 000 continuous horse-power with a surplus even more than this at certain times.

The author holds that the development is not justifiable, because:

1.—No marked economic gain will result from reducing the flood flow below 75 000 sec-ft., and regulating the discharge of the Colorado River proper to 40 000 sec-ft. will result at times in increasing its flow during the winter months when floods may be expected from the Gila, and, in this manner, greatly increase flood danger between Yuma, Ariz., and the Gulf.

2.—The irrigation supply for lands below the Grand Canyon will ultimately be insufficient even with the tremendous storage proposed; and, for all lands in the basin to be irrigated until 1940, 2 300 000 acre-ft. of storage will suffice.

3.—The large block of power made available immediately on the completion of the dam cannot readily be absorbed by the prospective market, and there will be, therefore, a serious accumulation of interest charges on the unproductive part of the investment.

4.—The construction of the project will result in the permanent loss of 300 000 h.p. and of an irrigation supply sufficient for 50 000 acres.

The radical difference in these two sets of conclusions is due primarily to the differences in the plan of development as proposed in the Boulder Canyon

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Project and by Colonel Kelly, and, secondarily, to the author's reduced estimate of available water supply.

As regards the difference in plan: The Boulder Canyon Project qualifies as desirable under the Reclamation Act, and is actually covered by a Special Act, but does not qualify under the Federal Power Act. Colonel Kelly's plan, however, will qualify in every particular under the Power Act by giving the maximum beneficial development of the entire river.

The Federal Water Power Act was passed by Congress on July 10, 1920, after nearly ten years of debate. If it is permitted to function properly, it should prove in the long run a most valuable piece of legislation. It is far more than the mere "Water Power Act" its name would imply, for it was drafted to accomplish the well-ordered development of rivers, not only for power, but for the joint maximum benefit from irrigation, power, flood control, and navigation. One of its many requirements is that any project adopted shall be such as will be best adapted to a comprehensive plan of improvement and utilization of a stream for the purpose of navigation, of water-power development, and of other beneficial uses (including, of course, irrigation and flood control). It provides further that, if necessary in order to secure these results, the Federal Power Commission shall have authority to require the modification of any project.

Certain other provisions of the Federal Water Power Act have direct bearing on the question of State or municipal *versus* public utility ownership—the issue that is being fought out on the Colorado. These provisions are:

1.—That licenses under the Act are not given in perpetuity, but have a limited term.

2.—That the Act gives preference to municipalities, provided their plans are equally adapted to the best ultimate development of a stream.

3.—That adequate rentals are to be charged for developments made by individuals, public utilities, or by States and municipalities (when operated for a profit), and part of the Government rentals are to be returned to the State or States within which the power development is located.

All these items bear directly on the "public *versus* corporate ownership" phase of the controversy and show that the Special Act confers only one important "benefit" not included in the Federal Water Power Act, namely, an initial appropriation of $70 000 000 from the United States Treasury. Moreover, there is nothing in the Act which prevents the Federal Power Commission from including, as part of the terms of any license, the so-called "Colorado River Compact" or any part thereof.

It is to be hoped that, after long years of discussion, having passed a comprehensive Act, Congress will allow it to function properly and will not hamper its operation by passing special legislation affecting the Colorado, as well as other important streams such as the Columbia, St. Lawrence, and Tennessee Rivers, all of which fall in the same general class.

The inadvisability of special Federal legislation for a situation better covered by general legislation is only the first objection to the proposed Act; the second is that the financial plan is not sound.

It was originally proposed that preliminary expenses in connection with the Boulder Canyon Dam be "charged on a basis of 85% against the interests that might consume power or for power purposes; 10% against flood control; and 5% against irrigation." This distribution was made arbitrarily, but its general theory was correct. Later, it was recommended as not only possible, but desirable, that the expense of the dam itself be carried entirely by the power interests—a proposal that naturally received more hearty popular support than the former, but was by no means as sound economically. In other parts of California land is being irrigated, drained, and protected from floods on a basis requiring payment in proportion to the benefits received. This principle is sound, and it follows logically that the lands on the Colorado should also pay in proportion to the benefits received from the storage of water. The same careful methods could be used in assessing such benefits as are now being used by the California Reclamation Board on the Sacramento and San Joaquin Drainage District. The various users of the stream would then be shouldering their own burdens.

Under the present Boulder Canyon plan, the power users are expected to pay the entire cost, and although it is reasonably certain that they can, there are grave doubts as to whether they should be required to do so.

"The cities and irrigation districts of Southern California" were referred to in the original Boulder Canyon report* as the most important market for Boulder Canyon power. Of the other possible outlets for power listed therein, the most important and readily accessible appear to be the mining regions of Arizona with the principal towns adjacent, and possible railway electrification on the Santa Fé, Salt Lake, and Southern Pacific Railways. Railway electrification is, however, entirely in the future, and its extent is dependent chiefly on the policy of the respective railroad companies. It is generally understood that the management of the Santa Fé System is in favor of electrification at the earliest possible moment, whereas the management of the Southern Pacific is distinctly antagonistic to all such plans. The immediate market for any large amount of power, therefore, is reduced to general uses in Southern California and mining uses in Arizona.

Assuming that "the cities and irrigation districts of Southern California" do buy most of the power, what will be the proper charge?

Why, for instance, should the irrigator of the Riverside region or the Lower San Joaquin Valley pay a price for Colorado River power that will vouchsafe both flood protection and free irrigation supply to his fellow irrigator who happens to be operating in the Palo Verde, Yuma, or Imperial Valley Districts?

Part of the power will go to Arizona. Why should the mining industry of Arizona pay a higher price in order that the limited areas along the river may receive free flood protection and irrigation supply?

It may be argued that the development of these lands will be of benefit to the nation, but it is obvious that, under the existing plan, owners of these

* Senate Document No. 142, p. 19.

lands will reap the benefit—and at the expense of other parts of the community.

Among the strongest engineering counts against the Boulder Canyon Project are:

1.—That it will curtail the ultimate development of the stream.

2.—That, until its large block of power is absorbed, it will continue to pile up carrying charges.

3.—That, after its power is absorbed, the part of the investment chargeable against regulative storage must be duplicated by expenditures for head-water storage unless the upper stream is to remain unregulated. Such duplication would lead to great economic loss.

The best plan of development on any stream is to concentrate the regulative storage as near the head-waters as it can be made effective, except in so far as this program has to be altered on account of local conditions. The burden of proof is squarely on the shoulders of any one who desires to depart from this basic rule, and no adequate justification has been made for the departure proposed on the Colorado.

Two very distinct flood control and storage problems are found on the Colorado:

1.—Reduction of the high and long sustained floods resulting from melting snows in the basin above the San Juan, and the storage of these waters for power and irrigation.

2.—Control of the high, but short or torrential, floods originating in the basins of the San Juan, Little Colorado, Virgin River, and minor tributaries of the plateau region. (The Gila is excluded from this list as it is below all proposed storage.)

It has been generally assumed in certain former studies that large storage for flood control and irrigation combined must be established at the lowest possible site on the Colorado in order: (*a*) To give protection from torrential floods of the San Juan, Little Colorado, and Virgin Rivers; and (*b*) to give closer regulation for irrigation than could be secured from head-waters storage.

Colonel Kelly's demonstration that little economic gain can be secured by reducing flood flows below 75 000 sec-ft. permits a considerable reduction in the flood-control storage needed on the lower river; and installation of head-water storage for control of the main Colorado flood would permit still further reduction in the capacity of the down-stream reservoir.

In view of the interesting flood records secured during September, 1923, it appears that the flood danger from torrential tributaries (other than the Gila) has been greatly exaggerated. As nearly as can be judged from combined stream-flow and rainfall records, it appears that on September 17 and 18, 1923, heavy precipitation occurred on the head-waters of the San Juan and over practically the entire basin of Little Colorado River. Two flood peaks resulted, as shown in Fig. 20. These floods were measured by river observations at Goodridge, Utah, on the San Juan River, and at Lees Ferry, Bright Angel, Topock, and Yuma, Ariz., on the Colorado. No flood was recorded at the stations above the San Juan. The flood from the San Juan reached a peak at Goodridge about 6 A. M., September 19, and this peak traveling down stream reached Lees Ferry 23 hours later, or at about 5 A. M., September 20. Continuing down stream, it caused a secondary peak at the Bright Angel Gauging Station in a flood already discharging from the Little Colorado.

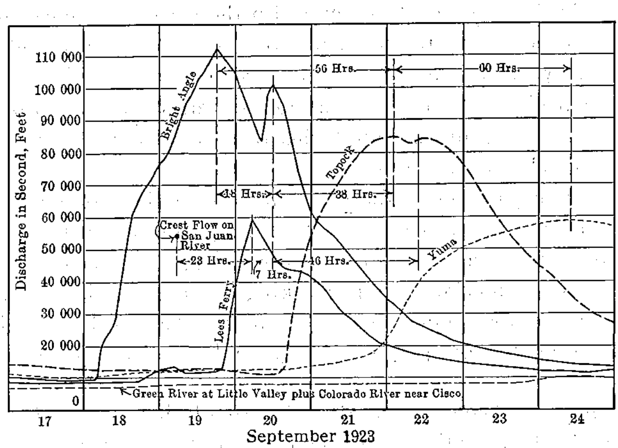

FIG. 20.

No observations are available showing exactly when the flood from the Little Colorado reached the main stream, but its peak had traveled down the main river and had reached the Bright Angel Station on September 19, at 6 P. M., 18 hours before the peak at the same station due to the San Juan flood. The discharge of the first peak at Bright Angel was about 111 500, and that of the second, 101 000 sec-ft.

The hydrograph at Topock shows that the first peak arrived at 2 A. M., September 22, or 56 hours later than at Bright Angel, and amounted to only 85 000 sec-ft.—a reduction of 25 500 sec-ft. The second peak was reached at 10 A. M., September 22, or 46 hours after the second peak at Bright Angel, and was 84 000 sec-ft., or 17 000 sec-ft. less than at the upper station. The records of both these stations were for fractional parts of a day.

The record for Yuma is based on daily averages, but the two peaks had probably flattened into one general rise, reaching a maximum discharge at about 10 A. M., September 24, or 60 hours later than the first peak at Topock. The Yuma record must be corrected for diversions at Laguna Dam and for inflow of the Gila,* but it happened that on the peak day these two discharges

* The mean daily discharges of the Gila and the diversions at Laguna Dam, September 20 to 25, 1923, were, as follows:

		Discharge of Gila, second-feet.	Diversions at Laguna Dam, second-feet.
September	20	200	2 072
"	21	8 000	2 020
"	22	3 900	1 091
"	23	3 000	954
"	24	2 000	2 237
"	25	1 500	2 155

practically balanced. It is probable, therefore, that the Yuma peak did not exceed 60 000 sec-ft. in any event, 25 000 sec-ft. less than at Topock. It appears, therefore, that with no regulation whatever a flood flow of 111 500 sec-ft. at Bright Angel was cut 26 500 sec-ft. by the time it reached Topock, and 51 500 sec-ft. by the time it reached Yuma.

Considering the great distance between the junctions of the San Juan, Little Colorado, Virgin, and Gila, and also the great difference in topographic conditions and elevations in the basins of these tributaries, and the different seasons of the year during which they are normally subject to floods, it is difficult to conceive of any combination of circumstances that would produce a flood from the upper tributaries reaching Yuma at the same time as an extensive flood from the Gila.

It would seem justifiable, therefore, to reduce the storage capacity of the flood reservoir on the lower river to a minimum far below that generally advocated to date, and to secure corresponding control in the head-waters. Even with this reduction, when working in conjunction with head-water storage, the reservoir would certainly supply sufficient local irrigation regulation and water for all projects likely to be completed in the immediate future.

Arguments have been advanced on behalf of the Boulder Canyon location which are really (especially when taken together) strong arguments against it and in favor of head-water regulation. For instance, in the first report on the Project, it was stated that "any large reservoir on the Colorado must depend for its financial feasibility upon the availability of an adequate market for not less than 500 000 h.p. electrical energy within economic transmission distance." The logical conclusion is that a large storage at Boulder Canyon will absorb the ready market for power, and that as all down-stream needs will be safeguarded, adequate regulation of the middle and upper river will be delayed until the dim and distant future.

In the same report the relative advantages of a great reservoir and power plants at Boulder Canyon as against Glen Canyon were carefully compared, and the Glen Canyon Project was condemned on account of its remoteness from the market, as well as for its less effective control of the flood and irrigation supply. No adequate program was advanced, however, for up-stream regulative storage operated in conjunction with down-stream power development and minor re-regulation.

This plan is now advanced by the author, who has shown clearly that it will furnish flood control and an irrigation supply for the same area as the Boulder Canyon Project, and that it will furnish a regulated power discharge through three times as much river descent. It will also reduce the hazard and cost of construction of the five or more dams necessary to develop the fall in the Canyon Section of the river—this last advantage is no small item in its favor. Under his plan, head-water storage and power development on the middle and lower stream can proceed gradually as conditions demand, the first step being only that necessary to give, in conjunction with minor storage on the lower river, the necessary flood-control and irrigation supply.

The functions of the lowest reservoir may be merely supplementary to the major storage in the head-waters, and its size, therefore, should be kept at a minimum, otherwise the investment will be so great that the reservoir must be operated independently of the head-water regulation, in which case, instead of adding to, it will detract from, the flexibility of the entire system.

Eliminating the Glen Canyon Project from consideration for the present by no means exhausts the possibilities of head-water storage. Flaming Gorge, Dewey, and Juniper Reservoir sites offer excellent opportunities. Their combined storage capacity would be 6 940 000 acre-ft., the average annual run-off past the dam sites, 10 300 000 acre-ft., and their total cost, $31 200 000. The prospects are good for the early development of Flaming Gorge without cost to the Government. The Dewey site could be developed by the Government, or by other agencies, at an estimated cost of $11 200 000, and would serve for power regulation throughout the Canyon and for control of floods from the Grand River. The development of the Juniper site for combined irrigation, power, and flood control, might be made at a later date.

The possibility of storage at the Mohave site is a comparatively new but important factor in the Colorado River problem. The Boulder Canyon site was formerly believed to be the lowest point on the river where large storage could be obtained, and this was properly advanced as a particularly desirable feature both because it gave additional flood protection and made possible closer regulation and avoidance of waste in the irrigation supply. It is now found that the original information was not complete, that there is ample storage at the Mohave site, providing the foundation conditions are satisfactory. It must be admitted that any advantages of position claimed for the Boulder site will apply with much greater force for the Mohave site. The Mohave site is 120 miles nearer the principal irrigation diversion, and its construction, according to the plans proposed by Colonel Kelly, will eliminate the necessity of constructing a re-regulating reservoir at Bulls Head. It will flood certain railway improvements, but, even allowing compensation for these, it is attractive financially. It will also flood certain irrigable lands, but these too are covered by the estimated damages, and, as the water supply is now shown to be inadequate for the full development of all available acreage, the elimination of this relatively small portion will not result in an ultimate reduction of the total area served.

The importance of securing more detailed information on the Colorado, before adopting a final program of development, was recognized and emphasized in 1924 by a plank in the Republican platform. It is to be hoped that at an early date funds will be provided, the investigations completed, and the development of the stream started on a comprehensive plan under the Federal Water Power Act.

E. C. La Rue,* M. Am. Soc. C. E.—Because of his investigations along the Colorado River during the past fourteen years, and his publication of considerable engineering data on the subject, the speaker is especially interested in all papers which deal with a plan of development for this great

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river system. The author has analyzed the engineering data resulting from recent investigations on the river without fear or favor. His conclusions regarding a plan of development appear sound. In his discussion, the speaker will deal only with the physical facts as they relate to the various plans of development, and will not express opinions as to the agency which should develop the water-power resources of the river.

During the past thirty-four years, engineers of the U. S. Department of the Interior have been investigating the water resources of the Colorado River Basin. Including its work in the Grand Canyon in the fall of 1923, the U. S. Geological Survey has mapped 1 800 miles of the river and its tributaries. All known dam sites on the main river, between Wyoming and Mexico, have been surveyed. Investigations made both by the Geological Survey and the U. S. Bureau of Reclamation, show that, with complete development, nearly 6 000 000 acres of land can be reclaimed in the American part of the Basin, and about 6 000 000 h.p. can be developed.

It is also well known that property in the Lower Basin, valued at more than $100 000 000, is menaced by the annual floods of the Colorado River. Practically every one agrees that the flood menace should be removed by providing storage somewhere on the lower river. A report that is being prepared by the U. S. Geological Survey, will show the relative value of all dam sites on the lower river, their relation to each other, and to the full utilization of the water resources.

Some fundamental facts should be recognized by all. The resources of the Colorado River are not unlimited. When its millions of horse-power have been developed, the end of water-power production in the southwestern part of the United States will have been reached. All the water resources of the Basin will be required for the irrigable lands within, or adjacent to, the Basin in the United States. If these resources are to be developed without waste, it is necessary that a comprehensive plan be made and agreed on before construction work is started.

As explained by the author, the Boulder Canyon Project does not conform as a unit to the full development of the river. This is not surprising, for this project was selected and approved before field investigations were made to determine the proper plan of development. However, the Boulder Dam has not been built, and it is not too late to prepare a comprehensive plan for the development of the river, with the idea that the first dam built will be properly located.

In his study of the subject the speaker has reached the following conclusions:—

1.—As shown in the paper, the water supply of the Colorado River and its tributaries is not sufficient to irrigate the lands susceptible of irrigation lying in or adjacent to the Basin in the United States and Mexico.

2.—There are in round numbers, 1 000 000 acres of land in Mexico, which may be irrigated with the waters of the Colorado River. If these lands are irrigated, it will be necessary to dedicate to the desert forever about 1 000 000 acres of irrigable land in the United States.

3.—Any development on the river that will increase the low-water flow before such increase can be used in the United States, will enlarge the irrigated area in Mexico.

4.—If the Boulder Dam is built as planned, and 600 000 h.p. is developed at the dam, the low-water flow will be increased far in excess of the quantity that can be used for irrigation in the United States for many years to come. Long before this time, it will have been put to beneficial use on approximately 1 000 000 acres of land in Mexico. Although it is physically possible for this water to be diverted at a later date in the United States, it is not conceivable that this Government would dry up 1 000 000 acres of land in Mexico without first entering into negotiations with the Mexican Government. The time to deal with Mexico is before and not after its lands have been placed under irrigation, before and not after a large dam is built in this country, which will result in the irrigation of such a large acreage in Mexico.

5.—In the distant future it may be desirable to obtain from the Colorado River a domestic water supply for the Coast cities of Southern California. There is an excellent dam site in the Lower Grand Canyon which could be used as a point of diversion for a gravity system. Although a long tunnel would be required, such a system might be the most economical. The plan for a gravity system should not be rejected by engineers who never have seen the dam site. The plan now being advocated calls for a pump lift of 1 200 ft., which requires the use of 200 000 h.p. With the Boulder Dam Project preventing the development of 300 000 h.p. (according to the author), and the domestic water supply project forever dedicating 200 000 h.p. to pumping, it must be apparent that these plans should be carefully studied before any money is made available for construction purposes.

6.—There is urgent need for flood control, and this problem should be solved as quickly as possible. For more than a year the speaker has recommended that a thorough investigation be made of the Mohave flood-control reservoir site. As a result of his preliminary studies, he has reached the following conclusions regarding this site:

(*a*) It is the lowest known site on the river where adequate storage capacity can be obtained for flood control.

(*b*) It would surely form a unit of a comprehensive plan for the development of the whole river.

(*c*) It would probably cost less than any other storage site of equal capacity on the river.

(*d*) It would not destroy other valuable dam sites. The Boulder Dam, if built as planned, would destroy certain dam sites in the Lower Grand Canyon, and prevent the full development of the water resources of this section of the river.

(*e*) For the same storage capacity, a dam in Mohave Canyon would have about one-tenth the volume of masonry of a dam in Boulder Canyon.

(*f*) The Mohave Canyon site is accessible, being only 2½ miles from the railroad.

(*g*) Considerable quantities of sand and gravel, suitable for concrete, are available close at hand, and the granite in the abutment walls will provide excellent material for crushed rock.

(*h*) The depth to bed-rock is probably not great; the center pier of the Atchison, Topeka and Santa Fé Railway Bridge, 2½ miles above the dam site, is resting on bed-rock 70 ft. below the water surface.

(*i*) With the flood problem solved by a dam at Mohave Canyon, there will be ample time for studying the river and no necessity for proceeding except in conformity with its orderly economic development.

The speaker would make the following recommendations:

1.—A thorough investigation should be made of the Mohave Canyon flood-control reservoir site, including detailed surveys and diamond-drill borings. If suitable foundation is developed, a flood-control dam should be built at this site and operated in such a manner as to prevent any increase in the irrigated area in Mexico.

2.—While investigations are being made at the Mohave Canyon flood-control site, and during the construction of a flood-control dam, negotiations should be carried on with the Mexican Government with the idea of definitely fixing the quantity of water which is to be allotted to the lands in Mexico.

3.—Prior to a definite settlement with the Mexican Government, it would not be good business to permit the construction of a power dam on the Colorado River, which would increase the low-water flow of the river in excess of the quantity necessary to supply the land now under irrigation.

4.—While the flood-control dam is being built, and negotiations are being carried on with Mexico, the investigation of the Colorado River Basin should be continued, with the idea of evolving a comprehensive plan for the development of this river.

5.—If the resources of this great river system are to be developed in an orderly manner, a comprehensive plan of development must be made and agreed on by the Interior Department, the War Department, and the Federal Power Commission. Each development on the river should be a unit of this plan.

Arthur P. Davis,* Past-President, Am. Soc. C. E.—In this interesting paper the author presents some pertinent facts, and reaches important and far-reaching conclusions, some of which, if carried out, would result in the unnecessary destruction of large natural resources of land, water, and power. For this reason the speaker feels compelled to dissent from these conclusions and to give his reasons therefor.

The speaker is in accord with several of the author's maxims, as follows:

1.—No complete and inexorable plans for the development of the Colorado River should be adopted until more is known about the river, and the requirements of the future.

2.—No unnecessary evaporation should be involved.

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3.—No power head should be sacrificed unnecessarily.

4.—Agriculture should be given preference over power uses.

The plan proposed by the author violates all these maxims.

Importance of Storage.—The most outstanding and important feature of the Colorado River is the great fluctuation of its flow. The low-water years yield less than 9 000 000 acre-ft. below the canyons, and the high-water years yield about three times this quantity. The seasonal fluctuations are still more striking; autumn flows of 4 000 sec-ft. and less are common, and the high-water peak often reaches 150 000 and sometimes exceeds 200 000 sec-ft.

The low-water flow is already appropriated and used in irrigation, and an unusually dry season produces a shortage. Without regulation, the stream will produce only about 25% as much primary power as with proper regulation, and the effect of storage on irrigation is similarly important.

In addition, the great volume and long duration of the spring floods are such as to constitute an annual menace to all the valleys of the lower river, especially to the Imperial Valley, which, if entirely submerged, would be permanently destroyed, as it is largely below sea level.

These conditions make indispensable a large volume of storage capacity which fortunately Nature has made possible and feasible, with proper conservation and utilization. This, however, is not all.

Heavy Silt Content.—Nature sends down the river an annual average of about 100 000 acre-ft. of silt, which will fill to that amount any reservoir built within or below the canyon region. This silt clogs the channel, obstructs irrigation canals, and adds greatly to the flood menace and to the cost of irrigation operations. It makes the river unfit for municipal uses, for which it will be required extensively in the near future; all these conditions will be remedied by storage, as the silt will settle in the reservoirs, and the desilting of the river is one of the major requirements in changing it from a menace to a valuable asset. The average annual volume of this silt, however, is 160 000 000 cu. yd.—a greater amount than the total excavation performed by the Isthmian Canal Commission in digging the Panama Canal.

Desilting the river by settlement in reservoirs, fills those reservoirs to the extent of the volume of the silt deposited. Obviously, the time will come when all the reservoir space will be occupied by silt, unless some means of removal is applied. Any known method of accomplishing this is troublesome and expensive—many times as expensive as constructing additional reservoir capacity, as long as other good reservoir sites are available. It thus becomes necessary to conserve reservoir space to the greatest practicable extent.

The amount of storage necessary to equalize the flow of the river through all the years would be enormous, and hardly practicable. To just what extent it may pay to hold the water of extraordinary floods for use in dry years is a question about which the best engineers may differ, but all will agree that hold-over storage to a large extent is necessary if the river is to be properly used. It is necessary to retain a large amount of this storage in the Lower Basin, where most of the flow can be intercepted, in order to desilt the river and to control and utilize the floods of the lower tributaries.

Herman Stabler, M. Am. Soc. C. E., estimates the storage capacity necessary to maintain reasonable uniform annual flow between 10 000 000 and 20 000 000 acre-ft. The U. S. Geological Survey places it at 18 000 000 acre-ft.,* which latter figure may be used for present purposes. To this must be added a large quantity for flood control, and another for the storage of silt, to prolong the usefulness of the reservoir. At the very least, 25 000 000 acre-ft. is necessary to solve the problems presented. A much greater quantity would be useful in saving the water of abundant years, but is, perhaps, not justified at present.

Storage in Upper Basin.—The author states that the reservoirs above the canyon region should be used to regulate the river for use below. This is impossible, because they have not sufficient capacity, and are situated so that they intercept only a part of the flow, leaving a large area of water-shed unregulated.

The Ouray site, the largest of those listed in the paper, should be eliminated, as the Secretary of the Interior has promised in writing to dedicate this site to the construction of a railroad when required. The Kremmling site already has a railroad through it. This leaves as the principal known feasible sites in the Upper Basin, those given in Table 26.

TABLE 26.—COLORADO RIVER RESERVOIR SITES.

River.	Reservoir.	Capacity, in acre-feet.	Average run-off, in acre-feet.	Cost.
Green	Flaming Gorge	3 120 000	2 300 000	$16 000 000
Yampa	Juniper	1 550 000	1 200 000	4 000 000
Colorado	Dewey	2 270 000	6 800 000	11 200 000
San Juan	Bluff	1 400 000	2 300 000	8 800 000
Total		8 340 000	12 600 000	$40 000 000

These reservoirs aggregate an insufficient capacity and would be relatively inefficient as two of them, if put to use, would seldom fill for lack of water, and a third is too small to control the drainage into it. Far more important, however, is the fact that these reservoir sites are needed for local use, for which they would not be available if operated to accommodate the needs of the Lower Basin. This program would be an economic blunder of the first magnitude.

Their use for the needs of the Upper Basin may be of incidental benefit to the Lower Basin, but to dedicate them to the needs of the Lower Basin would destroy their local usefulness, and could be justified only in part, even if storage opportunities were not available in the Lower Basin; but this is not the case. The opportunity for storage in the Lower Basin is much larger, cheaper, and more efficient than in the Upper Basin. Boulder Canyon Reservoir can be built to a capacity five times as great as all the reservoirs noted in Table 26 combined, and at much less cost per acre-foot. If desired it can be built to a smaller size, at much less unit cost than the upper reservoirs and, later, can be enlarged when the encroachment of silt deposits makes it necessary.

* *Water Supply Paper No. 395*, U. S. Geological Survey.

Evaporation Should Be Minimized.—The author objects to Boulder Canyon as a large reservoir, because of alleged excessive evaporation. Curiously enough he proposes to substitute the Mohave Reservoir which has much larger area per unit of storage exposed to evaporation.

The author's curves show the comparison given in Table 27.

TABLE 27.—COMPARISON OF MOHAVE AND BOULDER RESERVOIRS FOR SIMILAR CAPACITIES.

Capacity, in acre-feet.	Surface Area, in Acres.	
	Mohave.	Boulder.
10 000 000	112 000	69 000
15 000 000	136 000	90 000

In addition to having an area about 60% greater for a given capacity, for the height proposed, the Mohave Reservoir is 100 miles farther south, 500 ft. lower in altitude, much shallower, so it will become more heated, and is on an open plain, where the winds would have freer sweep than in Boulder Canyon. All these factors would have a tendency to increase the relative evaporation at Mohave; thus, for a given capacity, Mohave would probably have more than 75% more evaporation than Boulder Canyon Reservoir, if devoted to similar uses. Certainly, this new favorite cannot qualify on the score of economy of water.

Colonel Kelly seeks to justify this waste, by claiming a very large evaporation from the Mohave Valley in its present state. It is true that this valley now overflows, and, of course, experiences evaporation losses in proportion to the overflowed area; but if it is reclaimed, as it should be, the water applied to it would be usefully consumed in irrigation, and not wasted like that evaporated from a reservoir. Water evaporated from Mohave Reservoir is as truly wasted as if lost from any other reservoir in the Basin, and such evaporation is much greater in proportion to storage capacity than from any other proposed reservoir in the entire Basin, on account of its relatively broad, shallow character. As far as loss of water is concerned, it is by far the poorest site proposed.

The author charges that the height of dam proposed by the Reclamation Service—605 ft.—would make impossible the development of an 80-ft. fall between its back-water and Diamond Creek. This is not the case, for the dam in Boulder Canyon might be built 80 ft. higher whenever the additional capacity is needed in the future. This would have the merit of concentrating the power development at one plant instead of two, and save 80 to 100 miles of transmission line to the Coast. This height of dam, backing the water to Diamond Creek, is one of the alternatives presented by the Reclamation Service. On this fallacious claim, the author has based most of his condemnation of the proposal of the Reclamation Service.

The fact is, the Reclamation Service presented five alternative heights of dam, one of which is nearly that which the speaker prefers, 570 ft., backing water to the dam site at Bridge Canyon and creating a capacity of about

28 500 000 acre-ft.; it would cost about $43 000 000, and develop nearly 600 000 continuous h.p., or 900 000 on a two-thirds load factor. Marketed at 4 mills per kw., it would amortize the investment in about 40 years, meanwhile taking care of flood control and irrigation.

The author states that the water supply of the Colorado is insufficient to irrigate the land available for irrigation, yet he objects to a large reservoir capacity on the ground that it would waste water by evaporation, and insists on providing for passing the surplus at the rate of 80 000 cu. ft. per sec., rather than storing and using it for power and irrigation.

It should be emphasized that a dam of the height here proposed will develop power at a lower unit cost than any dam of less elevation, so that the additional storage for irrigation and the additional security against floods cost nothing. It is certainly better to hold the floods by storage, even if part of the water does evaporate, than to let them run to the sea, and fight them en route as demanded by Colonel Kelly.

Power Market.—Concerning the market for power, the author says: "It it not extravagant to conclude that all the power in the Canyon Section of the Colorado may be absorbed in the next 25 or 30 years." This is a higher rate of demand than was assumed in the estimates of the Reclamation Service, but evidently it is justified.

The Southern California Edison Company has repeatedly expressed willingness to expend from $30 000 000 to $40 000 000 per year to develop power in the Canyon if given the privileges.

The City of Los Angeles offers to take all the power allocated to it from the Boulder Canyon Dam after States and other municipalities are satisfied, and the electors recently voted by a large majority to authorize the City Council to negotiate such a contract. The city is certainly a responsible customer, and with all this evidence there need be no doubt that a ready market will be found for the power.

If the storage capacity allocated to flood control is too great, as implied by the author, a part of it can be used for power head and a part for storage, and the duty and consequent revenues of the reservoir increased.

Mohave Reservoir Wasteful and Destructive.—The alternative reservoir strongly advocated by the author is at Mohave Canyon. Not only is the Mohave Reservoir extremely wasteful of water by evaporation, but will require the removal of about 20 miles of double track on the main line of the Santa Fé Railroad, increase its length about 3 miles, destroy the great bridge at Topock, submerge the large railroad hotel, roundhouse, machine-shops, icing plant, 24 miles of yard tracks, and the entire City of Needles. It will also require the reconstruction of part of the Santa Fé Trail Highway. These damages have been included in the estimate, and the cost will be about as much as the dam itself. There is not included, however, the important fact that this reservoir would also submerge the whole Mohave Valley containing nearly 30 000 acres of rich, irrigable bottom-land for which there is an ample water supply when storage is provided, and that this water cannot be used elsewhere except in Mexico, because the regulated water supply is ample for all lands feasible of irrigation in the United States, including the Mohave Valley lands.

Nature has provided two feasible dam sites that will utilize all the head available here, without submerging the Mohave Valley. One of these sites is above, at Bulls Head, and one below, near the mouth of Williams River. The latter is necessary for a high diversion dam for the Parker-Gila Valley Project, the construction of which the author assumes. It would be built to the greatest height possible without damage to the City of Needles, or about 100 ft. The proposed dam in Mohave Canyon would conflict with this, and would also submerge the dam site at Bulls Head, just above the Mohave Valley. It would leave undeveloped 40 ft. of power head below Boulder Canyon, which would thus be lost.

The dam site in the Mohave Canyon was examined twenty years ago and at intervals since by various engineers, including William Mulholland and J. B. Lippincott, Members, Am. Soc. C. E., and on account of the destruction of land, water, and other property, was unanimously regarded as infeasible, and for this reason, its foundations were not explored. Any money spent thereon would be wasted for reasons already given. It was never seriously advocated until it became necessary to kill the proposal to build a dam in Boulder Canyon and develop enough power to repay the cost. This emphasizes the real point at issue, that is, whether the immense resources of the Lower Colorado are to be retained in the control of the Federal Government or turned over to private corporations. This is a question on which engineers and others may honestly differ, and which the speaker will not discuss. It should be considered on its merits, and not combatted indirectly to the great sacrifice of the natural resources of land and water.

Wanton Destruction of Valuable Storage.—Perhaps the most destructive feature of the author's plan is the proposed building of a high dam at Devils Slide, thus restricting the height of the Boulder Dam to 387 ft., and its storage capacity to about 10 000 000 acre-ft. Such a reservoir would rapidly fill with sediment, and thus be destroyed much earlier than necessary.

It has been shown that large storage capacity is necessary to convert the Colorado River from a destructive torrent into a source of vast wealth, and that this storage will steadily be destroyed by silting. Yet, here is a proposal to build a high dam in the middle of the best reservoir site in the Basin, and thus wantonly destroy its value. It is idle to reply that other reservoirs can be provided above, because these are of limited capacity, and, therefore, of limited life; moreover, they do not intercept all the water nor all the silt.

Proper Plan of Development.—The plan of development proposed herein is shown on Fig. 21(*a*) as compared with that proposed by the author on Fig. 21(*b*).

The speaker's plan would be to build the Boulder Dam to a height sufficient to back up water to the dam site at Bridge Canyon. This dam would impound about 28 500 000 acre-ft. of water, control floods more perfectly than any smaller reservoir, and develop power more cheaply than any smaller dam, in sufficient quantity to repay its cost with interest.

Next, the Parker site should be improved to serve as a diversion dam for irrigation and municipal supply. With complete regulation at Boulder Canyon it will be a good power site.

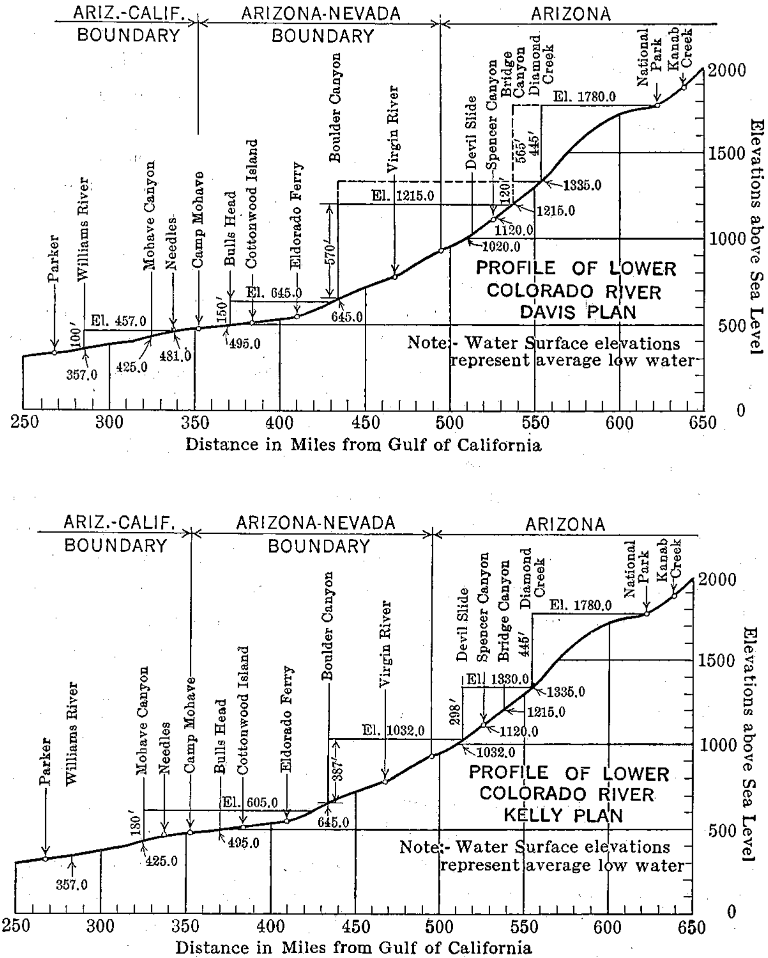

FIG. 21.

A dam at Bulls Head will back the water to the base of Boulder Dam, and with the regulation of that dam, will constitute a good power site. This leaves three alternatives for the development of the power head above Boulder Canyon, between Bridge Canyon and the National Park Boundary, as follows:

1.—If on that future day it is decided that more storage is necessary, the Boulder Dam can be raised 120 feet, its gross capacity increased to 48 000 000 acre-ft., less the accumulated silt, and the water backed to Diamond Creek, where a dam would be built to back water to the National Park.

2.—If it is then definitely decided that no more storage will ever be needed a dam can be built at Bridge Canyon to back water to the Park Boundary.

3.—If the decision is that additional storage may be needed some day, the dam at Diamond Creek can be built, and the space between this and Boulder Reservoir can be left open for still further consideration, that is, whether to build Boulder Dam higher, or to build a dam 128 ft. high at Bridge Canyon.

In any event, the construction of the dam at Devils Slide, as proposed, would be a serious economic blunder, as it would destroy the best reservoir site in the Basin, and seriously limit the usefulness of the river.

The plan proposed herein would utilize every foot of head between Parker and the National Park, except 38 ft. in the Mohave Valley, which would thus be preserved for agriculture, complying with the fourth maxim mentioned previously, as to the preference given to agriculture over power.

It complies with the first maxim, leaving several alternatives open for decision in the light of future information. It likewise complies with the other maxims. Contrasted with this, is the plan to issue corporate licenses for Diamond Creek, Devils Slide, and Boulder Canyon, and build a Government dam at Mohave Canyon, as proposed by the author, and shown on Fig. 21(*b*) for comparison. The two plans would have the results given in Table 28.

TABLE 28.—COMPARISON OF PLANS.

Site.	Head, in feet.	Surface area, in acres.	Capacity, in acre-feet.
		DAVIS' PLAN.	
Williams	100	90 000	2 900 000
Bulls Head	150	20 000	1 600 000
Boulder	570	138 000	28 500 000
Bridge Canyon	570	16 000	3 000 000
Total	1 390	264 000	36 000 000
		AUTHOR'S PLAN.	
Mohave	180	130 000	13 000 000
Boulder	387	69 000	10 000 000
Devils Slide	298	4 000	400 000
Diamond	445	13 000	1 900 000
Total	1 310	216 000	25 300 000

It will be noted that the plan here proposed develops 80 ft. more head, and uses this head far more efficiently than the author's plan because its regulation is both greater and higher up the stream. Its power output would be greater by several hundred thousand horse-power.

The evaporation surface by the latter plan would be greater by about 22%, but owing to differing conditions already enumerated, the evaporation would be only slightly greater and the storage afforded would be 10 700 000 acre-ft. greater, and would endure more than 100 years longer. It does not submerge Mohave Valley, as proposed in the author's plan. In every respect, therefore, it is better.

A further comparison may be made by omitting the dam near Williams from Table 28. This produces the exhibit shown in Table 29.

TABLE 29.—COMPARISON OF PLANS—WILLIAMS RESERVOIR OMITTED.

	Head, in feet.	Surface area, in acres.	Capacity, in acres.
Davis' plan	1 290	174 000	33 100 000
Author's plan	1 310	220 000	25 800 000

By this comparison over the same stretch of the river, the author's plan develops about 1½% more head, but owing to better regulation, higher on the stream, the speaker's plan would develop far more power. The latter would expose 46 000 less acres to evaporation, in a region where the rate of evaporation would be less, and afford more than 7 000 000 additional acre-feet of storage capacity, and, hence, would last 70 years longer; and it would not submerge the fertile Mohave Valley. It is clear, therefore, that the plan proposed by the author does not conform to the best development of the river and that it violates each of the maxims enunciated.

For irrigation and flood control, the Mohave site has no advantages over the Boulder site, as there are no tributary streams between, but the Boulder Reservoir would protect the Mohave Valley from floods, provide it with irrigation storage, and facilitate its reclamation, while a dam in Mohave Canyon would submerge and destroy that valley forever.

Storage in Boulder Reservoir would be beneficial for power development at Boulder Canyon, Bulls Head, and Williams, a total fall of 820 ft., while that at Mohave could be of no benefit for power except at its own site, which is so unfavorable that none of the power companies has applied for it. Storage at Mohave, therefore, would require duplication somewhere above, for power development.

Poor Rock in Glen Canyon.—The author expresses disagreement with the Consulting Board that examined the dam site above Lees Ferry in Glen Canyon and advised limiting the pressure on the rock to 20 tons per sq. ft. on account of its soft, friable character.

This Board included four experienced engineers all of whom have borne the responsibilities of designing and building some of the world's greatest dams, including the Don Pedro, Arrowrock, and Roosevelt Dams, and an eminent geologist, who made a very careful examination of the site and the material. It seems rather bold for one who has made no such examination to overrule them summarily on the strength of three samples of drill cores. Any one experienced in diamond drilling knows the persistent tendency of the core fragments to grind each other to powder in the rapidly revolving core-barrel, so that the soft parts are washed out and only the hardest survive. So great is this tendency, that the recovery of 100% of core even in the hardest rock is rare.

The rock in Glen Canyon is so soft that it is difficult to break off a sample without crushing it; and such a sample carried in one's luggage for a few days is apt to yield more fine sand than rock. The caution of the Consulting Board was clearly well founded.

Increase of Low-Water Flow.—The author opposes the increase of the low-water flow of the Colorado. He says:

"The Boulder Project would provide water in the Lower Basin at all seasons far in excess of present irrigation requirements. This water will pass into Mexico and there be used for irrigation. Once used, its withdrawal for use in the United States will be difficult, if not impossible."

The opposition to development is entirely unfounded. The proponents of the Boulder Project suggested the insertion of a clause in the bill reserving the benefits of storage to the United States. Legally and morally such a reservation is not necessary, but it would be good policy. Having provided the storage facilities, the United States would have both legal and moral rights to its benefits. The American lands being higher on the stream, these rights are easy of enforcement.

On the other hand, the regulated water being subject to appropriation on American lands would facilitate development in Arizona and California, and the feasible irrigation projects in those States would just about absorb those waters as they come from the power plants. To irrigate additional lands, as those in Mexico, it would be necessary to re-regulate the waters, which would be entirely in the hands of the American authorities.

Time of Construction.—The author states that flood control can be obtained more quickly by a dam in Mohave Canyon, than by one in Boulder Canyon, and compares the estimated time of constructing a large reservoir in Boulder Canyon with a much smaller one in Mohave Canyon. The investigations of Boulder Canyon have occupied nearly three years, and Colonel Kelly states that they are not sufficient. No investigations of Mohave Canyon have been made, and after these are completed, it would be necessary to take up negotiations with the railroad and hotel companies and hundreds of property owners for the removal of the railroad and the City of Needles. Such measures afford endless opportunity for delay whether carried out under private negotiation or by condemnation proceedings.

No such difficulties are found at Boulder Canyon, and it is believed that a reservoir of any given capacity can be built there more quickly than anywhere else, if all reasonable precautions are observed.

The Upper Basin's Interest in Boulder Canyon.—Four times in recent years, beginning in 1915, the irrigators of Imperial Valley have required and have taken from the Colorado River all the water flowing therein; each time it was less than the actual needs and a shortage occurred. As development progresses, this condition will be more frequent and intense, and if with present development, another series of low-water years should happen, such as occurred before and after 1902, the water shortage would be prolonged and disastrous.

Under the principles of the Supreme Court decision in the Wyoming-Colorado Case, the farmers of Imperial Valley would have the right to cause to be closed during the period of shortage the head-gates of all canals above them, that are junior to their appropriations of 1900 and earlier. This would include all three of the Government projects in the Upper Basin, two in Colorado and one in Utah, and many private enterprises as well which have hard enough struggle without adding water shortage and litigation.

The irrigators in the Lower Basin do not desire litigation, as is shown by their avoidance of it during the past shortages. If a large reservoir is built and the water regulated, there will be plenty of water for them so there will be no litigation. The representative from Imperial Valley has testified that the District is willing to yield all claim to the low-water flow in exchange for a right in the reservoir, and no doubt the other irrigators served from the reservoir would do the same.

Without storage in the Lower Basin, the junior rights in the Upper Basin are in continual jeopardy, and the situation must become more and more a handicap to the financing of new irrigation enterprises in the Upper Basin. A large reservoir at Boulder Canyon will correct all this, and make water rights above secure from molestation. A small reservoir would not have this effect.

The author proceeds throughout the paper on the theory that a reservoir of, say, 4 000 000 acre-ft. capacity, would be as efficient for flood control as an equal capacity on the top of a reservoir six or eight times as large. This is not the case.

If a reservoir with a capacity of 25 000 000 or 30 000 000 acre-ft. were provided to regulate the river, it would, by constant use and discharge of the stored waters, enter the flood season with its storage depleted to an extent exceeding 8 000 000 acre-ft., and any capacity held especially for flood control would be added to this. Therefore, the available storage for controlling floods would be several times the total capacity of the small reservoir proposed by the author, and its efficiency correspondingly multiplied.

It is conceivable and possible to provide a reservoir at Boulder Canyon of such magnitude that the stream would be equalized through a series of years to a discharge of about 20 000 cu. ft. per sec. to be used for the development of power or some other beneficial purpose. Although such complete control might not be justified, any large reservoir approaching a capacity of 30 000 000 acre-ft., would approximate this result, and assure beginning the flood season in April with more than 10 000 000 acre-ft. of available space at the top of the reservoir to receive and regulate the summer floods. Any surplus received could be discharged during the flood season or soon after and not carried on to February, as alleged by the author.

Colonel Kelly ignores the great fundamental fact that the larger the reservoir provided, the more complete will be the control of floods and the more water will be available for power and irrigation; and the larger the reservoir, up to 35 000 000 acre-ft., the cheaper the unit cost of power developed, so that the added value for other purposes costs nothing.

He also ignores the fundamental fact that a deep reservoir of a given capacity with a moderate surface area will lose less water by evaporation and furnish more head for power than a broad shallow reservoir, which although it might require only a small amount of masonry for its dam, requires a vast outlay for damages to cities, railroads, and other property, and costs about the same per acre-foot stored, besides destroying a great alluvial valley susceptible of high development.

The author deserves thanks for the frank official declaration of the settled policy of the Federal Power Commission, in his statement that:

"All the development needed on the Colorado will be built by private capital under adequate Federal and State regulation if the river is given over to development under the Federal Water Power Act."

This declaration is in the face of the mandatory provision of the law that the Commission shall give preference to applications from municipalities, such as are on file for the privileges of the Colorado power sites. That this defiance of law is a settled policy of the Power Commission is an important fact in considering legislation affecting not only the Colorado, but any other stream under its jurisdiction.

If the author really believes his statement that the Mohave is a good power site, and should be the first development, why does he not require the power companies to begin their development by building the Mohave Reservoir? None of the power companies has applied for this privilege, and they would probably spurn it, as the results would not pay for the damages caused to railroads and other property. The mere mention of such a proposition should be considered absurd, as it really is.

C. E. Grunsky,* Past-President, Am. Soc. C. E.—The Colorado River presents one of the nation's largest and most pressing domestic problems—a problem which, however, has its international aspects, that, through inaction on the part of the Federal Government, are annually growing more serious. As Adviser to the Secretary of the Interior in 1907, the speaker called attention to the anomalous situation which had resulted from the operations of the California Development Company, whose canal located in part in Mexico was supplying irrigation water from the Colorado River to the lands in Imperial Valley, California, and suggested a plan of procedure to prepare the way for a comprehensive treatment of the river problem which would be advantageous both to the United States and to Mexico. Nothing came of the suggestion, however.

The problem cannot be solved without giving consideration to the fact that the Colorado is an international river. The interstate pact formulated by a Commission headed by Herbert Hoover, Hon. M. Am. Soc. C. E., now ratified by all the interested States, except Arizona, will be, when consummated, only a first step toward the solution of this problem.

If State boundaries are to be considered and conflicting interests between upper and lower groups of States are to be recognized, as indicated in the pending pact, then, too, the States within the two groups may well ask, as does Arizona, "What will be the situation 40 or 50 years from now?" Each of the States in the upper group wants to know what proportion of the water which is to be left in the river for use of the lower group of States it will be expected to furnish—just as each of the States of the lower group may desire

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to know at the outset what proportion of the water and what proportion of the power output will ultimately fall to its share.

It is not surprising, therefore, to find Arizona with only a limited area that can be brought under canal at reasonable cost, in the attitude of inquiry. There is some basis for the fear, for example, that if a dam is constructed at or near Boulder Canyon and a power plant is placed in operation, the predominating benefit will go to those regions where industries are already well established—that the southern part of California will absorb an undue proportion of the energy made available, at the cost of Arizona's future. A similar fear is expressed in the matter of the use of water for irrigation. Who, if there be no understanding on this point in advance, shall prevent the extension of irrigation to the most favorably located lands regardless of State, or even of National, boundaries, thereby possibly depriving one State or another of opportunities within its boundaries which, although perhaps not immediately attractive, may yet be of equal or greater value in a broad plan based on the ultimate greatest good to the greatest number.

No reasonable regulation of the flow of the Colorado River by storage appears to be feasible except with the approval of and under the control of some higher authority than that of the individual State. This principle has already been recognized in the creation of the Commission which formulated the interstate pact. The Federal Government is the agency which, logically, should effect the regulation and apportion the output. As a possible alternative, the suggestion of Governor Scrugham, of Nevada, in an address at a meeting of the Pacific Coast Electrical Association, deserves consideration. He suggested that an interstate power and irrigation district be formed to plan and carry out the Colorado River project. If those who are directly concerned prefer district to Federal control, why should they not have it, provided, always, that the international phases of the problem are not overlooked?

An interstate district, however, any more than the United States, could not prevent development along lines of least resistance, regardless of State boundaries, unless there be some pre-arranged plan of development, with power and water allotments adjusted in some measure to political sub-divisions. The time element should be taken into account and the desirable ultimate conditions should be forecast and carefully weighed. Although the ideal solution of such a problem as that of the Colorado River might ignore State boundaries, it must be submitted that their recognition may aid in securing desirable widespread, rather than concentrated, utilization of both water and power.

In Mexico extensive areas have already been brought under irrigation with water from the Imperial Canal. There is satisfaction in the knowledge that the water in the Colorado River originates in the United States and that were it all retained and used within these borders, if possible, the nation's neighbor to the south would have to be content with a protest. This will never happen. Thus far, however, there has been no limit set to the quantity of water which is ultimately to be allowed to flow into Mexico, and the irrigated area in Mexico has been growing apace. On this subject the United States Government was warned, as already stated, in 1907, at a time when Colorado River water was used in Lower California on less than 10 000 acres. At present, the irrigated area in Lower California is about 200 000 acres. What shall be the limit and what agency other than the United States can fix the limit?

There is plenty of land in Mexico to use the water—about 800 000 acres in the river delta and, on the mesas of Sonora, an additional 500 000 acres or more. The ultimate extent of irrigation in Mexico need not then be regarded as limited by the physical features of the country, but solely by the quantity of water temporarily and ultimately available.

It should be noted in this connection that the engineers of the U. S. Reclamation Service, who have given much thought and study to the Colorado River problems, report that, after all the lands in each State of the upper group that can be supplied with water from the Colorado River at reasonable cost have been brought under irrigation, there will still be an ample supply, not only to meet the compact requirement of the lower group of States, but also for a fair delivery of water to Mexico.

Again, the Colorado River menaces certain areas in the United States and other areas in Mexico, whenever at flood stages it runs wild in Mexico. The great menace is to the lands which lie below sea-level, partly in Mexico, but mainly in the United States. The places where this flood menace must be fought are in Mexico. To be sure the frequency of floods can be reduced materially, and channel deterioration by silt deposits can be decreased materially with such works as the contemplated Boulder Reservoir, but occasional floods originate in parts of the river's water-shed below Boulder Canyon, and even after the construction of a Boulder Reservoir or its equivalent, these floods would still remain a problem feature in the river delta south of the boundary. The fact should be recalled, in this connection, that the discharge of the Gila alone may bring the Colorado River at Yuma to a full flood stage as it did in November, 1905, when the river broke from its channel and took a course into Salton Basin.

The flood control problem, therefore, involves not only the retention of the flood waters of the upper river in reservoirs, but also a proper treatment of the lower river to care for the high stages that will still occur occasionally after up-river reservoirs have been built.

The United States should arrange all matters pertaining to flood control, not only in so far as the construction and operation of storage reservoirs are concerned, whether these be built by an interstate district, by a single State, by a group of States, by a private corporation, or by the United States, but also in the matter of providing a direct permanent channel for the Colorado River from the southern boundary of California to the Gulf.

In other words the United States must maintain itself in a position to keep the flood menace for all time at a minimum and to assure respect for interstate and international obligations. When the United States, however, either by direct action or through selected agencies, reduces the flood menace and conserves the waste water of the river for use in generating power and for irrigation, the resulting benefits, both in this country and in Mexico, should be ascertained and the cost of the works, or better, the cost of the service rendered, should be charged in some equitable manner to those who use the output of power and water and to those who benefit by the flood-control works.

Surely there should be no difficulty in reaching an understanding on this point with Mexico, neither should there be any difficulty in agreeing with Mexico on the project for flood control within that country, nor yet as to the limit beyond which a delivery of Colorado River water to Mexico cannot be assured.

F. E. WEYMOUTH,* M. AM. SOC. C. E. (by letter).—The writer would like to point out discrepancies in data which, in the paper, have been credited to the U. S. Bureau of Reclamation. For example, Table 11 does not appear in any report of the Bureau of Reclamation, as far as the writer can learn; the equivalent information as it appears in a report which he made in February, 1924, is as given in Table 30.

TABLE 30.—IRRIGABLE AREAS AND WATER REQUIREMENTS.
(Areas, in Thousands of Acres; Consumption of Water, in Thousand Acre-Feet.)

	PRESENT:		IMMEDIATE FUTURE.		NEAR FUTURE.		DISTANT FUTURE.		TOTAL.	
	Area.	Water.	Area.	Water.	Area.	Water.	Area.	Water.	Area.	Water.
Above Boulder	*	*	773	1 349	1 063	1 958	989	1 879	2 825	5 186
Between Boulder and Laguna	40	120	166	498	47	141	216	937	469	1 696
Below Laguna in United States	469	2 111	430	1 935	.....	.....	.....	.....	899	4 016
Total for United States	509	2 231	1 369	3 782	1 110	2 099	1 205	2 816	4 153	10 928
In Mexico	190	855	300	1 350	310	1 395	†	.....	800	3 600
Grand total	699	3 086	1 669	5 132	1 420	3 494	1 205	2 816	4 993	14 528

* Not shown, as Table 30 shows only anticipated future demands on present stream flow.
† 200 000 acres not dependent on Colorado River discharge is not included.

A part of Table 19 is designated "U. S. Bureau of Reclamation Plan", and contains in its heading an assumption of up-river storage development, which, to the writer's knowledge, no report made by the Bureau of Reclamation has ever embodied. Even if this heading were changed, the data presented as to power head, evaporation, irrigation storage, and flood-control storage, do not conform to similar data presented in that report covering development to Elevation 1 250, which Table 19 is probably intended to present. Further, this table contains no reference to the alternative plan presented at the same time, contemplating development to the elevation of the Bridge Canyon site. These discrepancies should be borne in mind in considering the discussion following Table 19.

* Pres., Brock & Weymouth, Inc., Philadelphia, Pa.

Investigations of the Colorado River Basin were started by the Reclamation Service in 1904 with the view of augmenting the water supply for irrigation in the Lower Valley and of controlling the ever-present flood menace in the Delta region. Extended investigation of the Upper Basin indicated a lack of the requisite storage at reasonable cost, therefore, studies of storage sites in the lower river were undertaken. After a preliminary study of the problem and a reconnaissance of the river below the mouth of the Virgin River, work was concentrated, in 1919 and thereafter, on the better dam sites in Boulder and Black Canyons.

The primary object was the regulation of the river for irrigation and flood control. As these investigations progressed, it became evident that a large amount of power could be developed without interfering with the primary use of the reservoir for irrigation and flood control, and that at the dam sites considered it would be possible to develop power which could be sold at a price sufficient to repay the cost of construction. In all these studies, the power problem was considered only as incidental to that of irrigation and flood control. Studies were largely concentrated at the Boulder Canyon Reservoir site where the requisite storage could be obtained at the lowest cost and where the development could be made without interfering with other uses of the river.

A preliminary report on this subject under the title, "Problems of the Imperial Valley and Vicinity," was made in 1922 by Arthur P. Davis, Past-President Am. Soc. C. E., then Director of the Reclamation Service. The studies were continued after that report was completed and the results embodied in a voluminous report, containing nearly 2 000 typewritten pages, submitted by the writer in February, 1924, under the title, "Report on the Problems of the Colorado River Basin." When this report was written, the data available on dam sites above Boulder Canyon were practically limited to the Glen Canyon and Diamond Creek sites.

In 1923, the U. S. Geological Survey made some topographical surveys and a general geological examination of the Colorado River Gorge from Lees Ferry to Las Vegas Wash, the latter being between the Boulder and Black Canyon Dam sites, which were investigated by the Bureau of Reclamation for the Boulder Canyon Reservoir site. A few days prior to the completion of the writer's report, the Geological Survey furnished an approximate elevation of some of the dam sites below Diamond Creek. Brief studies, therefore, were made in the time remaining and led to the submission of an alternative plan limiting the height of the Boulder Canyon Dam to the level of the Bridge Canyon Dam site. It was pointed out that the success of this plan would depend on the feasibility of the Bridge Canyon for a high dam and power plant.

Since then the Geological Survey has provided a preliminary profile of the Colorado River through the stretch investigated in 1923, as well as the topography of the principal dam sites noted by the survey party below Grand Canyon National Park. These data, in addition to those obtained from investigations by the Bureau of Reclamation, have made it possible to extend the previous studies and to determine the best plan for the development of the lower river, having in mind at all times the paramount importance of irrigation and flood control. Some of the results of these studies are embodied in this discussion. The section of the river through the Park has been disregarded, because of public aversion to its development, while the part above the Park is so far distant from large power markets that its development will not be economical until the entire power possibilities below the Park become fully utilized.

The more important factors involved in the proper development of the entire section below the Park in the order of importance are, as follows:

1.—Adequate storage capacity for irrigation and flood control with a minimum of evaporation loss.

2.—Construction cost.

3.—Maximum power output with maximum flexibility.

4.—Minimum destruction of developed and undeveloped property.

Adequate Storage Capacity for Irrigation and Flood Control.—This factor is by far the most important, as the use of water for irrigation must take precedence over that for power in the Colorado River Basin. The object of the development should be first, the protection of present irrigated lands from the ever-present dangers of inundation and water shortage and thereafter the provision of adequate storage capacity to permit the utmost development of the water resources of the Colorado River Basin. Other waters cannot be substituted to irrigate lands in the Colorado River Basin, but other sources can provide power.

Under present conditions less than 1 000 000 acre-ft. of active storage are required to insure an adequate irrigation supply for the Lower Colorado areas. With further development throughout the Basin, this volume will soon increase rapidly. In the writer's report of February, 1924, it was estimated that 25 000 000 acre-ft. would ultimately be required for this purpose alone if up-stream developments did not create material hold-over storage. Undoubtedly, considerable storage of this type will materialize, but it is believed that 15 000 000 acre-ft. of storage will be required for this purpose on the lower river.

The present silt inflow at Boulder Canyon is estimated at 80 000 acre-ft. annually. It will gradually decrease as up-stream reservoirs are constructed. To prevent the encroachment by silt on the storage needed for irrigation purposes for a long period of years, an additional capacity of 5 000 000 acre-ft. is needed.

Floods should be limited to not more than 40 000 sec-ft. at Yuma, as discharges of more than 50 000 sec-ft. are difficult of control and seriously endanger the present levees. The uncertainties attending any change in the regimen of a stream like the Colorado River dictate that ample provision should be made to meet contingencies. Under present conditions, such control will require 8 000 000 acre-ft. of storage, decreasing to 5 000 000 acre-ft. when the up-stream development becomes considerable.

From the foregoing it will be seen that a total capacity of 25 000 000 acre-ft. should be provided to meet future conditions. That such a capacity is not needed to care for irrigation, flood control, and silting in the immediate future is apparent. The provision of this or even a greater capacity at the present time is not an economic blunder, however, as the full control of present flow for the prevention of waste and, therefore, the maximum power output requires a storage of more than 30 000 000 acre-ft.

The location of this storage is also an important factor. From the standpoint of flood control and avoidance of irrigation waste, storage should be as near the point of use as possible. To restrict evaporation losses, the reservoir should be deep and located in the Canyon Section.

Construction Cost.—Even with the cost of the dams added to the power feature, power can be developed more cheaply at Boulder Canyon for the market available than at any other point on the Colorado River, or elsewhere. Modification of plans for purely storage development to include power development must provide power at a minimum cost per unit, in order that the additional investment may be justified and the burden on the power users reduced to a minimum. The more recent studies have assumed that the cost of storage for irrigation and flood control should be saddled on the power development.

Power Output.—Although adequate provision must be made for irrigation and flood control, any accepted plan must offer no avoidable interference with the maximum possible power development. Maximum power output is desirable as the presence of a market in the near future for all power that may be developed below the Park is generally conceded. As power depends on head and quantity of water, it follows that the maximum possible output would be obtained with stream control at the upper reaches of a section and utilization of the entire head below. As no feasible storage possibilities with sufficient capacity exist above the Boulder Canyon Reservoir site, it follows that, in order to obtain a maximum product, the plan adopted must be a compromise between a sacrifice of operating head and of storage capacity.

A considerable portion of the energy used in Southern California at the present time is devoted to irrigation pumping, which varies greatly from year to year with the stream flow. No doubt such pumping will continue to take a considerable part of all power marketed there. Some of the power systems with which the Colorado River development would be interconnected are less fortunate in storage possibilities. The best use of Colorado River power is possible only with a large storage reserve at strategic points, that will permit a flexible power output.

Destruction of Property Values.—The Mohave Valley Reservoir, if developed to Elevation 600, as proposed by Colonel Kelly, would require the reconstruction of about 26 miles of double-track main-line railroad (Santa Fé). The Town of Needles, Calif., with a population of more than 2 500, would have to be moved to a new site, together with extensive terminal facilities of the railroad company. Irrigable land, to the extent of 40 000 acres, much of it Indian reservation, would be submerged. A school would also have to be moved. Parker Valley Dam, if developed to Elevation 425, would not destroy any property of value. Developed to Elevation 458, the lower part of Mohave Valley would be submerged to the extent of possibly 10 000 acres.

Field Data Available for Designing Work.—

Diamond Creek Dam Site.—The topography and drilling data were obtained from Mr. J. B. Girand, applicant before the Federal Power Commission for this site.

Bridge Canyon, Spencer Canyon, and Devils Slide Dam Sites.—The topography at the dam sites was obtained in 1923 by the U. S. Geological Survey, but in most cases in insufficient amount to cover the sites for power houses as well. No data are available on foundations. The estimates of cost are based on assumed depths to rock of 60, 90, and 120 ft., the middle depth being used for a general comparison of plans. The accessibility of the sites has been assumed without actual knowledge of this condition.

Boulder Canyon Reservoir Site.—Detailed topography of the reservoir area and dam sites has been obtained; surveys made for connecting railroads indicate a readily accessible site. The two most favorable dam sites indicated by detailed geological investigations have been thoroughly drilled. Concrete materials have been located and subjected to practical tests to determine their suitability with gratifying results. This work was carried on from 1918 to 1923.

Bulls Head Reservoir Site.—The topography for this site was obtained in 1902 and 1903. The location was diamond-drilled in 1903 by the U. S. Reclamation Service as reported in the Second Annual Report of that Service.

Mohave Valley Reservoir Site.—The general topography of this reservoir site was made by the Reclamation Service in 1902 and 1903 and that of the dam site by the U. S. Geological Survey in 1923. No drilling has been done. Estimates of the depth to rock are based on conditions existing at the railroad bridge a few miles above and at other dam sites on the river. The cost of necessary changes in railroad trackage and facilities is computed from information furnished by the Railroad Company.

Parker Dam Site.—The general topography was taken in 1902-03. Additional topography was furnished by Fred A. Noetzli, Assoc. M. Am. Soc. C. E. The site has not been tested for foundations.

Designs and Estimates.—Designs and estimates for the Black Canyon Dam have been worked out in great detail for various heights, based on complete field data.

Information on the Diamond Creek, Bulls Head, and Parker sites is in such shape that the designs and estimates can be considered little better than preliminary.

The foundation conditions and right-of-way difficulties at the Mohave Valley site are unknown. There are so many uncertainties connected with the cost of this development that any estimates made with available data may be misleading. Under no circumstances should this site be developed.

The Bridge Canyon, Spencer Canyon, and Devils Slide sites have only incomplete topography from which estimates can be made.

Although an infinite number of plans for the development of the Grand Canyon-Parker Section may be advanced on the basis of known and assumed dam sites, it is believed that the layouts presented in Figs. 22 and 23 cover all the more favorable plans.

TABLE 31.—STATISTICS OF PLANS FOR COLORADO RIVER DEVELOPMENT.

Plan.	Conditions with Present-Day Water Supply.				Conditions with Full Up-Stream Development and Complete Up-Stream Storage Control.				Total storage capacity for silt, floods, and equating stream flow, in acre-feet.
	Total head utilized in feet.	Total horse-power available.	Total cost.	Cost per installed horse-power.	Total horse-power available.	Total cost.	Cost per installed horse-power.	Average evaporation loss, in second-feet.	
A	1 353	3 080 000	$339 000 000	$110	2 810 000	$316 000 000	$111	1 400	32 700 000
B	1 283	3 155 000	359 000 000	113	2 620 000	312 000 000	118	1 550	38 900 000
C	1 338	2 665 000	331 000 000	122	2 810 000	336 000 000	119	1 100	20 700 000
D	1 338	2 350 000	303 000 000	128	2 825 000	331 000 000	116	940	14 900 000
E	1 352	3 280 000	388 000 000	116	2 900 000	341 000 000	117	2 110	41 600 000
F	1 282	3 317 000	398 000 000	119	2 715 000	335 000 000	123	2 260	47 800 000
G	1 337	2 967 000	370 000 000	126	2 905 000	354 000 000	121	1 810	29 600 000
H	1 337	2 770 000	356 000 000	126	2 920 000	356 000 000	121	1 650	23 800 000

In comparing these plans as regards their most important features (Tables 31 and 32), two conditions of water supply have been assumed, namely, present supply without up-stream control and possible future supply with stream flow fully equated. Neither condition will ever fully materialize. By the time the entire river below the Park can be put to power use, much irrigation and power development may take place above. Full control of the river by up-stream storage is impracticable. Actual conditions will gradually leave the "present" status and approach that of full up-stream development.

TABLE 32.—COMPARISON OF PLANS FOR COLORADO RIVER DEVELOPMENT.

Conditions with Present-Day Water Supply.								Conditions with Full Up-Stream Development and Complete Up-Stream Storage Control.											
Plan.	Total horse-power available.	Plan.	Total cost.	Plan.	Cost per installed horse-power.*	Plan.	Total horse-power available.†	Plan.	Total cost.	Plan.	Cost per installed horse-power.	Plan.	Average evaporation loss, in second-feet.	Plan.	Total‡ storage capacity for silt, floods and equating stream flow, in acre-feet.
F	3 317 000	D	$303 000 000	A	$110	H	2 920 000	B	$312 000 000	A	$111	D	940	F	47 800 000
E	3 280 000	C	331 000 000	B	113	G	2 905 000	A	316 000 000	D	116	C	1 100	E	41 600 000
B	3 155 000	A	339 000 000	E	116	E	2 900 000	D	331 000 000	E	117	A	1 400	B	38 900 000
A	3 080 000	H	356 000 000	F	119	D	2 825 000	F	335 000 000	B	118	B	1 550	A	32 700 000
G	2 967 000	B	359 000 000	C	122	A	2 810 000	C	336 000 000	C	119	H	1 650	G	29 600 000
H	2 770 000	G	370 000 000	G	126	C	2 810 000	E	341 000 000	G	121	G	1 810	H	23 800 000
C	2 665 000	E	388 000 000	H	126	F	2 715 000	G	354 000 000	H	121	E	2 110	C	20 700 000
D	2 350 000	F	398 000 000	D	128	B	2 620 000	H	356 000 000	F	123	F	2 260	D	14 900 000

* Based on estimates for installations using convenient power units with total power approximating available power.

† Based on complete equation of stream flow by up-stream storage.

‡ Total capacity behind dams, except lower 67 ft. of Parker Dam.

The evaporation from the reservoirs is based on an estimated loss of 5 ft. per year over the mean exposed area in each case. This value may be con-

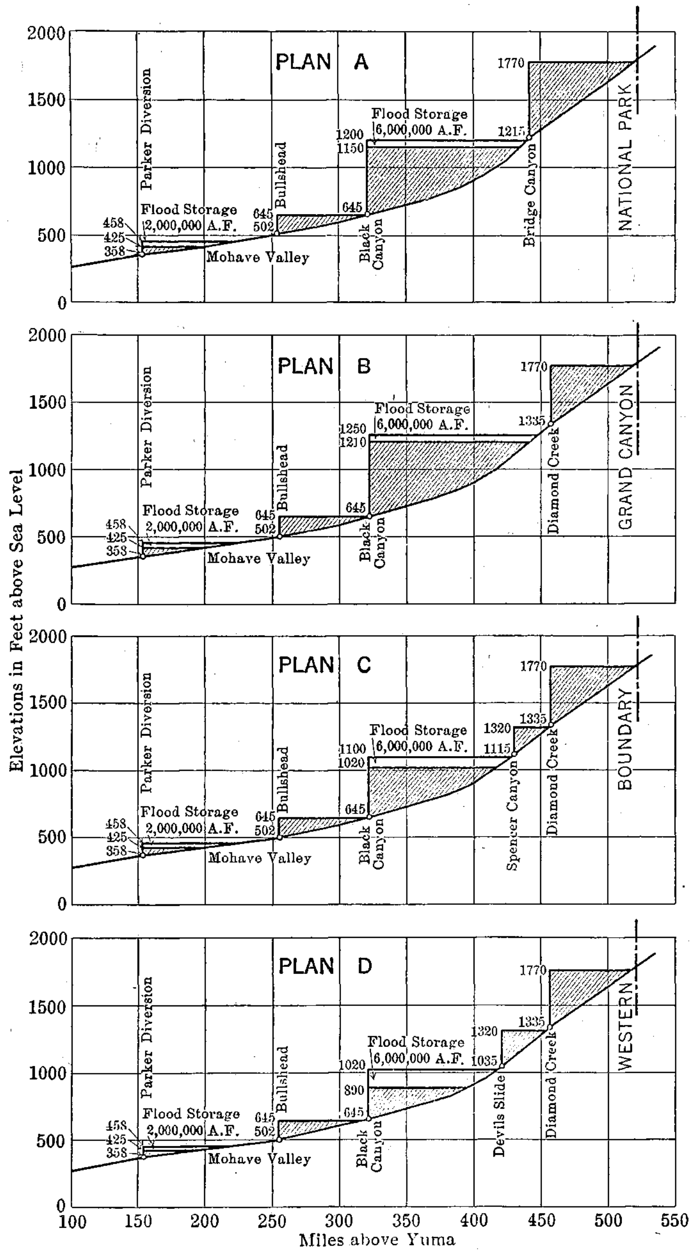

FIG. 22.—DEVELOPMENT OF COLORADO RIVER BELOW GRAND CANYON, PLANS A TO D, INCLUSIVE. FLOOD STORAGE INDICATED IS THAT REQUIRED UNDER PRESENT CONDITIONS.

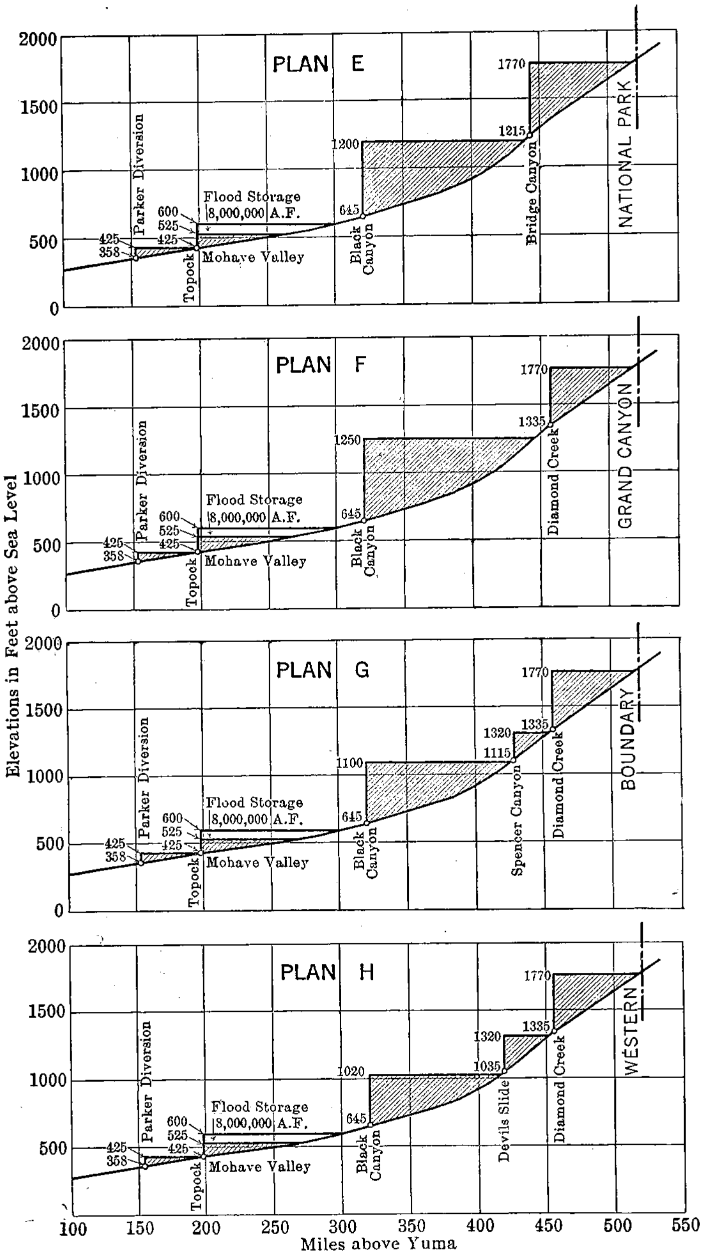

FIG. 23.—DEVELOPMENT OF COLORADO RIVER BELOW GRAND CANYON, PLANS E TO H, INCLUSIVE. FLOOD STORAGE INDICATED IS THAT REQUIRED UNDER PRESENT CONDITIONS.

sidered an average. Actual losses will be higher in the lower desert region below Boulder Canyon than in the Canyon Section proper.

Plan A, Fig. 22, exclusive of the Parker Dam, was first suggested by the writer in his February, 1924, report. That plan, with the Parker Dam included, presents the best scheme of development for the lower river as a whole. Its outstanding advantage is that it supplies the needed storage capacity with a minimum evaporation loss. It provides superior flood control by regulating Williams River, and it entails a minimum destruction of irrigable areas. The cost of construction is the lowest of all the plans, both under present and future conditions. With only partial control, such as will actually exist, the power output for these plans with small storage capacity would suffer far more severely than Plan A. The cost of the Parker Dam is included in the total cost of this plan. It would provide a much needed diversion for Parker Valley and for contemplated irrigation of the higher lands below.

G. E. P. SMITH,* M. AM. SOC. C. E. (by letter).—There is no subject more timely, especially to the Southwest, than the one under discussion. Perhaps no other great undertaking, of immediate concern, involves so many engineering problems of a controversial nature, and none is more worthy of the assistance which results from open discussion by the Society. The author is to be thanked for presenting clearly the viewpoint of the staff of the Federal Power Commission.

Among those who have studied the problems of the Colorado, is the U. S. Reclamation Service, which has carried on investigations and studies of the highest importance, including the testing of many foundations, for twelve years. Likewise, the pioneering and other investigations of E. C. La Rue, M. Am. Soc. C. E., have been most valuable.

The State of Arizona has been somewhat laggard in this regard. However, it organized, in 1922, the Arizona Engineering Commission to make a reconnaissance study of the irrigation possibilities from the Colorado River within the State. This Commission, of which Mr. La Rue was Chairman, reported in July, 1923. The Legislature of 1923 made a special appropriation of $14 000 for hydrometric work on the Colorado for the biennium 1923-25; an initiated measure authorizing extensive studies of the Colorado and appropriating $100 000 for the purpose, was also voted on in the November, 1924, elections.

As a large part of the potential water power of the Colorado lies within Arizona, this State will exercise considerable control over the development program. Within its boundaries, the State has control over the appropriation of water for irrigation and other uses, and, also, has control over the stream and its bed in all matters not related to navigation. The Federal Government, by reason of its ownership of abutting lands, also can exercise control over the proposed developments, which control is exercised through the Federal Power Commission. The State and the Federal Governments, therefore, must co-operate in the control of the power development of the river. Inasmuch as

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about 90% of the power development in the canyon region will be within partial control of Arizona, it is desirable that the State should be represented in the studies and conferences which must precede any further construction on this important stream.

Water Supply.—It has been assumed that the extensive records of stream flow on the Colorado and its tributaries were adequate as a basis for study. However, Herman Stabler, M. Am. Soc. C. E., has added material of great value by extending the records backward more than 20 years, as given in Table 5. The net result of this study is to indicate that the safe water supply of the river may have been over-estimated by about 12 per cent. In studying the water resources of the Gila River a few years ago a somewhat similar change in flow was noted, that is, a greatly increased run-off during the past twenty years. The average rainfall at Tucson for the period, 1885-1904, was 10.25 in., whereas the average from 1905 to 1923, inclusive, was 12.91 in. The records of rainfall do not demonstrate any periodic cycle, but they do give warning that the discharge records since 1902 are not an entirely safe basis for planning the utilization of the river.

It has long been apparent that the water supply of the Colorado is inadequate for all the demands that will be made on it, as is the case with many other streams of the West. In the report of the Arizona Engineering Commission, Mr. La Rue pointed out that there is a 1 000 000-acre project with diversion point near Parker, Ariz., the development of which may be feasible in 20 or 30 years, but that there may be no water supply for it. Other projects may yet be found that are comparable with some of those now considered feasible.

The adequacy of the water supply in the seven States will depend in a measure on the quantity of water granted to Mexico through a treaty. Such agreement may be complicated by a situation the reverse of that on the Colorado, which exists on the Lower Rio Grande, where the Conchos River of Mexico is a big factor in the water supply of lands in Texas. The writer agrees with the author that a treaty with Mexico, covering the quantity of water to be delivered at the International Boundary, should be negotiated as soon as practicable. It should require, also, the payment of a part of the cost of storage by the holders of the Mexican lands, in proportion as they are permitted to share in the benefits of storage.

It must be confessed, however, that the use of water in Mexico may increase rapidly to more than the quantity agreed on by treaty, and the probable result would be another treaty granting a larger quantity.

Comparing Mr. Stabler's estimate of dependable supply with Table 11, it is apparent that ultimately the shortage may approximate 6 000 000 acre-ft.

In California, the City of Los Angeles has filed application for a diversion of 1 500 sec-ft. in the vicinity of Blythe for use in Los Angeles and vicinity. It would add to the value of the paper if the author would state whether allowance has been made in Table 11 for such a diversion.

The Division of the Water Supply.—As between the seven States that are interested in the use of the Colorado River for irrigation, the greatest care should be exercised to take no irrevocable steps that will prevent the highest use of that portion of the water supply remaining to the United States. It is impossible to state at present just where and how the last residual unappropriated water should be used, or where it will be most needed.

Six of the seven States are so-called priority States, that is, States where the water laws are based on the doctrine of beneficial use according to priorities and where riparian rights do not exist. The seventh State, California, since the time limit for asserting riparian rights expired in December, 1923, is also a priority State, at least so far as the Colorado River is concerned. The decision of the Supreme Court in the Laramie River case is applicable, therefore, to the Colorado River Basin—in brief, the doctrine of beneficial use according to priorities is the basis for water division throughout the Basin, regardless of State boundary lines. There is no ownership or permanent control of the water by any project or any State. An appropriator acquires the right to use the water, as far as he can make beneficial use of it, and as long as he does use it. The building of a reservoir is not necessarily an appropriation; actual beneficial application of the water to land, without undue delay, is required also. So much has been said and written in support of this principle of water law and the need for it in States where irrigation is practiced, that it would be superfluous to enter into a discussion of it here.

The author states that the Boulder Project would put to beneficial use for power practically all the water in the Colorado River and would thereby acquire prior rights for it all. This suggests that a treaty between the seven States might be limited to an agreement that the use of water for power should of itself create no rights as against its later appropriation for irrigation, either up stream or down stream. It is an open question as to whether the author's statement is correct. A year ago (1923), the Federal Power Commission proposed to stipulate in the licenses for power that no rights prejudicial to the development of irrigation are acquired by the licensees. Many authorities believe that such a stipulation would protect the Upper Basin States, especially if similar provisions should be made in the power permits to be issued by the States. In the absence of an agreement, a test case should be brought before the United States Supreme Court, to determine whether a power dam can acquire rights as against irrigation. The Imperial Valley should bring such a suit against the permittees of the Flaming Gorge Dam site.

A more comprehensive contract or agreement may be needed between the three States of the Lower Basin and the Federal Government. It should include provisions covering (1) the location of any dam or dams on State boundary lines; (2) the subject of taxation; and, (3) the operation and maintenance of structures built on boundary lines, if built by public agencies, and the allocation of their costs and benefits.

Location of First Dam.—The writer agrees fully with the author that "storage for equalization of flow should be provided above the Canyon Section, and that storage for re-regulation of flow should be provided at the bottom of the Canyon Section"; and also that the storage capacity required at the present time for flood protection and for insuring a late-summer irrigation supply is moderate in amount, say, 4 000 000 acre-ft. exclusive of silt storage. He does not agree as to the importance of locating the reservoir for flood protection as far down stream as practicable, and considers that the author's argument against the Boulder Project should not be taken as conclusive until more is known about alternative projects in the Lower Basin.

Why begin at Topock? The Mohave Valley is the hottest place known, at least so far as the U. S. Weather Bureau reports show, and the evaporation rate must be excessive; the potential power at that site is unequal to the immediate demand, and the foundations have not been drilled. It is likely that bed-rock will be found considerably deeper than at the Topock railroad bridge, where the maximum depth is not known, except that it is in excess of 100 ft. The Bridge Engineer of the Santa Fé Railway System has stated that "the east pier supporting the main cantilever and anchor arms goes down very close to 100 ft. and is founded on a bed of cemented volcanic boulders." It is not reassuring to contemplate laying the foundations at a depth of more than 100 ft. and at the same time contending with the untamed river in a canyon only 240 ft. wide. The writer believes that no attempt should be made to construct this or the Boulder Dam until considerable river control is secured farther up stream at sites where the bed-rock is shallow. The Topock Reservoir, too, would accumulate silt rapidly, especially on the higher levels, and the storage capacity would be reduced seriously in 20 years unless the Boulder Dam is built in the meantime. Of course, it would be a great advantage to the Imperial Valley to have the river desilted, but, likewise, it would be advantageous to those who operate turbine water-wheels in the Canyon Section.

Mindful of the need of quick action in the interests of the Imperial Valley, it seems most untimely for the Engineering Profession to propose a new location for the first dam, and to ask for another year of delay, to permit of determining the foundations at this new site.

The first dam should be at the Dewey site on the Grand River, built by the Federal Government as a regulating dam for flood control. Plans for such a dam were detailed by the U. S. Reclamation Service several years ago. With a height of 215 ft. it would create a storage capacity of 2 300 000 acre-ft. The depth to bed-rock is only 44 ft. below the surface. The rock is hard, Carboniferous sandstone, suitable for building operations. The site is above the silt-gathering area and, consequently, the life of the reservoir will be long. Studies of the effect of this proposed reservoir on flood flows showed that in 1914, a year of exceptionally high June floods, the crests at the mouth of the Grand River would have been reduced from 64 000 to 23 000 sec-ft. The regulation of the river effected by the Dewey Dam would give greater security in the construction of other dams farther down stream, and would double the power capacity at Diamond Creek and at other power sites above the mouth of the Virgin River. The site is below all irrigable areas on the Grand River, so that its use for river regulation would not interfere with the irrigation development of the Upper Basin. Its cost is estimated at $11 000 000.

It can be completed in three years. After other dams have been built on the river, the Dewey Project can be used, in part, for power.

By increasing the height of the dam to 245 ft., the storage capacity would be increased to 3 000 000 acre-ft. This would necessitate moving about 8 miles of the Denver and Rio Grande Railroad. The topography, however, is favorable, and the cost would be not more than 5% of the cost of the dam.

The Dewey Reservoir alone does not provide the 4 000 000 acre-ft. of storage required for flood control. The additional storage can be provided on the Green River, either at Flaming Gorge or at Juniper Mountain and Flaming Gorge. It is almost certain that the Flaming Gorge Dam will be built by the Utah Power and Light Company. The Federal Government should provide for a 30-ft. increase in height of the dam to give 1 000 000 acre-ft. of storage for flood control only. It is within the province of the Federal Power Commission to require this if the funds are provided by Congress or by projects farther down stream that will be benefited.

The most pressing problem of the Imperial Valley is not flood control, but the increase in the late-summer water supply. The shortage was acute and caused much damage in 1915, 1919, and 1922. The flow at present (July, 1924) is lower than on the corresponding date on any one of those years, and forecasts a severe shortage this year. Another year with as little run-off as 1902 would cause a complete loss of summer crops. The Dewey Reservoir alone would provide an ample late-summer water supply for at least 20 years. It would be filled each year in May and June and emptied gradually during the next six months.

It has been claimed that the first reservoir should be on the lower river below the mouth of the Virgin, so as to regulate the floods from the Virgin, the Little Colorado, and the San Juan. High floods on those streams are short-lived and are flattened out before they reach Yuma. The highest flood ever recorded on the San Juan occurred in 1911 and was estimated at 150 000 sec-ft. The maximum flow at Yuma during the period was only 60 000 sec-ft., of which only a part was due to the San Juan flood. The Little Colorado flood of September, 1923, was exceptionally high, but the discharge at Yuma did not exceed 60 000 sec-ft. Of course, those floods might have occurred coincidently, but it should be borne in mind that for a long time to come the levees of the lower river will be maintained for protection against floods of 200 000 sec-ft. from the Gila River. Furthermore, within recent years, an excellent system of flood warnings has been perfected, and track and quarry facilities at Andrade have been made very effective for fighting floods.

The cost of the Dewey Dam, or a part of the cost, should be pro-rated by the Federal Power Commission among the down-stream projects which will be benefited. The Diamond Creek Project could well afford to pay the entire cost, but the Boulder and other projects should each pay a share, because each will be benefited by it. The Federal Government should contribute to the cost of this and other dams on the head-waters of the Colorado under the same theory of government as was exemplified in the building of thirty-three dams on the Ohio River, that is, to secure river regulation and control, to make the stream manageable and utilizable; or as exemplified in the purchase of great areas of land on the head-waters of the Allegheny and Monongahela for reforestation. Navigation is no more vital to the economic and social welfare of the group of six States bordering the Ohio than is the taming and harnessing of the Colorado to the welfare of the seven States along its course. The Federal Government should pay one-half the cost of the Dewey Dam and one-half the cost of securing 1 000 000 acre-ft. of storage for flood protection at the Flaming Gorge site.

It is desirable to have a larger measure of flood control, especially for such years as 1884 and 1909, and it is to be expected that, in time, the stream flow of the Upper Basin will be fully equated, probably at the mouth of the Green River or in the general vicinity of Lees Ferry. It is a disappointment to the writer that the author has not presented a definite plan for complete regulation of stream flow in the Upper Basin, in consonance with the general principles laid down by him. Until a general plan for complete regulation of the flow in the Upper Basin has been adopted, it would be a grave misfortune to give up the Ouray Reservoir site by restoring it to entry and granting a right of way for a railroad to cross it. Test borings that go all the way to bed-rock should be made at the Junction site, and borings should be made at Bluff.

Just now the urgent problem is to hold back somewhere a part of the June flood, and this can be done by means of reservoirs in the Upper Basin or anywhere above Parker. From the standpoint of protection to the Imperial Valley, the location of the storage is not so important as its immediate availability. The Imperial Valley should not be obliged to wait eight, ten, or twelve years for relief.

The development of the Colorado, as here proposed, by a moderate amount of storage, which can be utilized in Utah, Nevada, Arizona, and California, will prevent the early application of water to great areas in Sonora and Lower California and the subsequent claims of priority rights for those lands. It will retard development in Mexico until projects in Arizona and in the Upper Basin can be gotten under way.

The main arguments used by the proponents of the Boulder Project against storage in the Upper Basin are: (1) That it would leave the run-off from a large part of the water-shed unregulated; and (2) that the Upper Basin can make full use of the reservoirs situated above the canyon region. These arguments are not sound as has been shown herein. It is true that in order to prevent waste of water to the sea, there must be some reservoir farther down stream, but it will be many years before close control is required.

The First Power Project.—The Diamond Creek Project, at the mouth of Diamond Creek, 16 miles north of Peach Springs, on the Santa Fé Railway, is strictly a power project. If the Dewey Dam is built at once, the Diamond Creek Project might well be the first power development for the Lower Basin States. This project has a long list of advantages. It has a shallow depth to bed-rock, indeed, the bed-rock is swept bare during high flood stages; it is the narrowest between canyon walls; the walls are of granite;

it is easily accessible from the railroad and has convenient space close by for construction operations; and its distance from the center of gravity of the power market is little more than the distance from Boulder Canyon. The power installation of the Diamond Creek Project with the unregulated river flow will be between 200 000 and 300 000 h.p., depending on the height of the dam. If the Dewey Dam is built, an equal amount of power will be added, and the power possibilities will be further increased by the Flaming Gorge Project. A large part of this power would be marketed in California.

Arizona needs the Diamond Creek Project, but there is no urgency analogous to the situation in the Imperial Valley. Arizona has excellent power projects on the Salt and Verde Rivers and one at Yuma; the development of these projects is under way or is planned. The San Carlos Project of the U. S. Indian Service on the Gila River should include power development. Besides, it is a political question as to who should build the projects on the Colorado, whether private or public agencies, and, in this struggle, each side seems to be very successful in preventing progress by the other.

Assuming that storage for stream regulation has been obtained above the Canyon Section, then the problem in the Lower Basin involves the following desiderata:

1.—Power development at an early date and at minimum cost; each project to be part of a comprehensive plan that will utilize the maximum feasible head.

2.—Silt storage; this is of doubtful importance, as the silt problem will be less acute when the Imperial Canal is connected to Laguna Dam.

3.—Re-regulation; although not essential now, it will become so as the development of irrigation increases.

4.—Minimum loss by evaporation from reservoirs; this also will become important as irrigation development advances.

These conditions are met at the Boulder site far better than at Topock; and, as a first power project, the Diamond Creek location is better than the one at Boulder, assuming, of course, that regulation of the river is effected in the Upper Basin. The importance of making power available at an early date cannot be over-estimated. Despite the generous surplus of power for 1924 shown in Table 14, there is a critical power shortage throughout Southern California now (July, 1924), and it is doubtful whether the supply will again equal the demand until power is obtained from the Colorado. The growth in population, or in use of power, is not the only factor; the amount of rainfall, the price of fuel oil, and other elements enter, many of which cannot be forecast at all. It is unlikely that power from the Boulder Project can be obtained in less than 10 years; power from Diamond Creek can be had in 4 years, if the deadlock between those interests that are seeking to control the development can be broken.

The author has referred repeatedly to the need of conforming to one optimum comprehensive scheme of development. There can be no objection on this ground to the immediate development of the Dewey and Flaming Gorge Projects and probably none to the Diamond Creek Project.

Louis C. Hill,* M. Am. Soc. C. E.—It is generally agreed that the Colorado River must be controlled not only for flood protection but for irrigation and the development of power. As stated by the author, however, protection of the lands along the river and in the Imperial Valley from damage by inundation is of primary importance. No plan that limits this protection should be considered.

The determination of what ultimate development of the Colorado River will give sufficient protection from floods, will irrigate most economically the maximum area, and will return the largest net income from the generation of power, is a problem not yet solved. Any schedule of development leading to such ultimate control and use of the waters of the Colorado River will be greatly influenced by such economic factors as the rate of agricultural development within the Basin and the rate of increase in the use of power throughout the entire Southwest.

As the generation of power will be of secondary importance to irrigation, and as both must be considered in the light of their effect on the control of floods, the speaker will touch on these subjects in that order.

Power Development.—If the entire Southwest were thickly settled and industrially developed it would be logical to create the first storage reservoir on the Colorado near the upper end of the Canyon Section. The regulation of the flow from this reservoir would greatly increase the available power at each site below. Furthermore, this regulation would reduce the cost of foundation work on any dams built subsequently in the canyon.

Before being called by the U. S. Bureau of Reclamation and by private power interests to study the control of the Colorado River, the speaker was of the opinion that the Glen Canyon site should be developed first, in spite of the distance to a power market. However, after personal investigation of this site at the head of the canyon and of the Boulder Canyon or Black Canyon sites at the lower end, he is convinced that, under the physical and economic conditions, the net advantages of the lower site outweigh those of Glen Canyon as the location of the first large reservoir. Glen Canyon is about 100 miles farther from a railroad than Black Canyon and 250 miles farther from the principal power market.

Although the depth to bed-rock at Glen Canyon is about 80 ft. as against 124 ft. at Black Canyon, there is considerable doubt as to the suitability of the Glen Canyon sandstone for the foundation of a dam as high as that required for proper control of the Colorado River. It is no doubt true that tests of dry samples indicate ample compressive strength, but this material will be subjected to high hydrostatic pressure so that its action when wet must be considered. Samples of this sandstone were secured by the speaker himself from an excavation made in the side wall of Glen Canyon by the Southern California Edison Company for the purpose of obtaining fair samples. After one of these rock fragments has been in water for a few minutes, it may be easily broken and crushed into sand particles with the fingers.

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Even if careful and extended tests should show sufficient strength and resistance to percolation to warrant the erection of a high dam, this sandstone is unsuitable for use in the construction of either a rock-filled or a masonry dam. The aggregate would have to be obtained several miles down stream from the dam site.

In his conclusions, the author has stated that a high dam should not be built in Boulder Canyon or Black Canyon because the ultimate power development under the U. S. Bureau of Reclamation plan would be curtailed by 300 000 h.p., due to the loss of 80 ft. of head between the Boulder Reservoir and Diamond Creek. The selection of Black Canyon as the site of a storage dam should not be condemned arbitrarily because the Federal Power Commission believes that too high a dam is provided in the preliminary plans of the U. S. Bureau of Reclamation.

In all the plans proposed by the author, he has considered that the elevation of the head-water above each dam should equal the tail-water level of the next dam. The least lowering of any reservoir must result accordingly in the loss of just that amount of available head in the development of power.

The requirements for irrigation in the Lower Basin will seldom correspond to the quantity of water that will be released from the upper storage reservoirs for the development of power. Consequently, re-regulation of the water released for power must be effected in some reservoir at the lower end of the Canyon Section. As this re-regulation will result in unavoidable fluctuations in the level of the lowest storage reservoir, provision must be made in the ultimate development to prevent a corresponding loss of head and power.

It has been suggested by Mr. R. A. Hill that a dam, which would be sufficiently high to back water to the foot of the power dam at Diamond Creek, should be constructed ultimately across the upper end of Boulder Reservoir, probably at either Spencer Canyon or Bridge Canyon. The normal low-water level in Boulder Reservoir should correspond to the river level at this intermediate dam, and during periods of high water this dam should be partly submerged. In spite of inevitable fluctuations in the level of Boulder Reservoir, it would be practicable to use in the development of power all the head between these reservoirs by the installation of variable head turbines arranged to operate when submerged as much as 100 ft. Furthermore, this plan would eliminate the loss of 80 ft. of head below Diamond Creek, cited by the author as one of the main objections to a high dam at Boulder Canyon or Black Canyon.

It will be many years before the construction of this intermediate dam becomes necessary, but the speaker believes that it should be considered as part of the ultimate development on the Colorado River. It would not be difficult to construct; the flow of the river from above would be under control; and Boulder Reservoir would periodically be low enough to unwater the dam sites in Spencer and Bridge Canyons.

In order that the maximum beneficial use may be made of the waters of the Colorado River, a large amount of storage to equalize the flow over several years must be provided for irrigation as well as for power. Although the author has given some weight to this in his plan for the development of power, he has not provided sufficiently for irrigation, which should be given prior consideration.

Irrigation.—Water storage for irrigation should be as close as possible to the lands to be served. If this were the only consideration, the selection of Boulder Reservoir—to be created by a dam in Black Canyon—would be without material opposition as this reservoir is only 300 miles above the Laguna Diversion Weir, as compared with nearly 700 miles for the Glen Canyon site.

Storage reservoirs above the Canyon Section should be built as the need arises, and should be operated to best satisfy the power demand. These reservoirs, when the ultimate development has been effected, will practically equalize the seasonal variations in the flow of the Colorado and will reduce the annual variations. Elimination of annual variations is of primary importance in the conservation of water for irrigation; consequently, there must be provided below the Canyon Section as much irrigation storage as is economical.

There is no clause in the Colorado River Compact which provides for the release in a year of low flow of water for the irrigation of lands below the Canyon Section, although it does provide that during 10 consecutive years a total of 75 000 000 acre-ft. must be allowed to reach Lees Ferry. Consequently, a large amount of hold-over storage must be available to assure the lands in the Lower Basin of a continuous supply of water for irrigation.

The speaker is of the opinion that a reservoir of sufficient capacity for these purposes can be created most economically at Boulder Canyon. For many years it will be possible to release water from Boulder Reservoir in such quantities and at such times as will satisfy both the power and irrigation demands. Ultimately, the release of water from Boulder Reservoir will approach the variable irrigation requirement of the Lower Basin, except as modified by the regulatory effect of a reservoir farther down stream. The power output of other plants along the Colorado would be so modified as to satisfy that part of the power demand not taken care of by the output at Boulder.

Secondary re-regulation of the normal release from Boulder Reservoir should be provided as close as possible to the lands to be served with water for irrigation. As a comparatively small capacity will be required, the best location, as far as is known at present, would be just below the mouth of Bill Williams River. A dam at this point would also divert water into canals to irrigate large bodies of land between Parker and Yuma, Ariz., and in the Palo Verde Valley. This reservoir would also serve as a settling basin and point of diversion for an additional domestic supply for the cities and towns of Southern California the local water resources of which have been exploited to the safe limit. The value of this reservoir for flood control will be discussed later.

The author has considered that re-regulation can best be effected with a dam at Topock, creating the Mohave Reservoir. The only objection to this site, in his opinion, is that its flowage damages may be high, as it will require moving the Town of Needles, a division point on the Santa Fé Railroad, and re-locating 15 to 20 miles of main-line railroad. He neglected to call attention to the fact that about 100 000 acres of land in the Mohave and Cottonwood Valleys would be submerged and thus eliminated from agricultural development.

The principal advantage claimed for the Mohave Reservoir is based on rather fallacious reasoning. The author states that water for 50 000 acres of land would be saved if Boulder Reservoir were reduced in size and Mohave Reservoir constructed. This assertion is based on apparent differences in evaporation losses.

According to Table 18, there would be, under the U. S. Bureau of Reclamation plan, an evaporation loss at Boulder Canyon of 650 000 acre-ft. per annum, or 600 000 acre-ft. more than at present, while future evaporation loss, under the author's plan, with the same flood control at Mohave, would be 490 000 acre-ft., from which has been deducted 350 000 acre-ft. as the present loss, leaving only 140 000 acre-ft. as the net loss.

It is incorrect to credit all the present loss from the 72 000 acres of flooded area in Mohave and Cottonwood Valleys to the Mohave Reservoir. Flood control in Boulder Reservoir would greatly reduce the area from which evaporation would occur. This inevitable reduction should properly be credited to the Boulder Reservoir and only the remainder should be a credit to the Mohave Reservoir. Unless submerged, these valleys will be irrigated when regulation is provided, consequently the evaporation from this irrigable area cannot justifiably be deducted from the evaporation loss from the reservoir which would submerge these lands. It would be equally logical to create a reservoir out of the cultivated Palo Verde and Parker Valleys in order to eliminate the evaporation loss from these lands.

In Table 33 is shown the manner in which the speaker believes these losses should be considered. For purposes of comparison, the values in Table 18 are taken as correct.

This saving by the elimination of Mohave Reservoir would be about sufficient to compensate for the evaporation loss from the proposed secondary reservoir near Parker. At least the quantity of irrigation storage given must be provided below the Canyon Section, in addition to that needed for flood control and for silt accumulation, even if up-river storage is developed later, as considered by the author. Careful analysis of all the factors affecting the reduction of the water supply by evaporation shows clearly the fallacy of this objection to Boulder Reservoir.

Flood Control.—The ideal reservoir for flood control would be below the last tributary of any consequence. Unfortunately, such a provision on the Colorado River is impossible below the Gila, so that the control of the Gila River floods must be by separate regulating works on that stream. It is generally agreed that reservoirs for flood control on the Colorado should be at, or below, the lower end of the Canyon Section. Consequently, discussion revolves around the selection of Boulder Reservoir or Mohave Reservoir.

There is practically no contributing drainage in the 80 miles along the Colorado River between the Black Canyon Dam site and Topock, hence this factor is negligible in the selection of the proper site.

TABLE 33.—COMPARISON OF EVAPORATION LOSSES.

	Acre-feet, per annum.	
Boulder Reservoir with Maximum Level at Elevation 1 250, Providing 34 000 000 Acre-ft. of Storage, of Which 8 000 000 Acre-ft. are for Flood Control:		
Loss from reservoir surface	650 000	....
Present loss from stream bed	....	50 000
Reduction in flooded area above Topock assumed at only 50% and corresponding reduction in evaporation loss, one-half of 350 000 acre-ft.	....	175 000
Total	650 000	225 000
Additional evaporation loss under Reclamation plan	....	425 000
Mohave Reservoir with Maximum Level at Elevation 605, Providing 13 000 000 Acre-ft. of Storage, of Which 8 000 000 Acre-ft. are for Flood Control:		
Loss from reservoir surface	490 000	....
Loss from Boulder Reservoir with storage capacity of 10 000 000 acre-ft. according to author's Plan No. 3	340 000	....
Allowance of 50% of present loss from flooded area within proposed Mohave Reservoir	....	175 000
Present loss from stream bed at Boulder Reservoir (Plan No. 3)	....	40 000
Total	830 000	215 000
Additional evaporation loss under author's plan	....	615 000
Net evaporation loss chargeable to Mohave Reservoir	615 000	
Net evaporation loss chargeable to Boulder Reservoir	425 000	
Difference in favor of Boulder Reservoir	190 000	

Floods from the drainage area of the Gila River have as great a maximum discharge as floods in the Colorado above their junction at Yuma, but the Gila floods are of short duration. Under present conditions these floods do not tend to coincide, as the Colorado is at its highest stages from May to July, while the Gila floods almost invariably occur during the winter. The former result from melting snow on the mountains in Utah, Colorado, and Wyoming; the latter are from heavy rains in Arizona and New Mexico.

When the Colorado floods are reduced in magnitude by regulation, the flow of the river in the late fall and winter will be increased materially. Provision must be made, therefore, to minimize the probability of a Gila flood being augmented by 40 000 sec-ft. or more from the Colorado.

In this connection, Mohave Reservoir would have an advantage as it is about one day closer to Yuma than Boulder Reservoir. This advantage would be entirely offset if a dam creating the proposed Parker Reservoir were constructed below the mouth of Bill Williams River. Not only would this regulating reservoir be another day closer to Yuma, but it would directly control the flashy floods from the Bill Williams.

When storms were occurring on the head-waters of the Gila River, the normal release from Boulder Reservoir would be curtailed. When it became evident that a flood was imminent on the Gila, the entire flow of the Bill Williams, and that water already released from Boulder Reservoir, could be held back in the Parker Reservoir until the Gila flood had receded. As Parker is closer to Yuma than the last important tributary on the Gila, such a method would be entirely practicable.

The author has resorted to another method of handling the floods of the Colorado River, which does not meet with the approval of engineers long experienced in the actual control of these floods. In order to avoid the possibility of a dangerous coincidence in the flows of the Colorado and of the Gila at Yuma, Colonel Kelly proposes that the stored flood waters shall be released at the rate of about 80 000 sec-ft. By so doing, all flood waters would have been removed from the reservoir before the season for Gila floods. The hydrograph, Plate I, shows that this would be entirely unnecessary in more than half the years.

As intelligent operation of the flood-control reservoir would practically obviate the coincidence of floods from the Gila and the Colorado, the speaker can see no sound reason for disregarding the opinion of those who have personally been combatting the floods of the Colorado. The engineer of the Palo Verde District has stated—according to the author—that if no levees are provided, the lands of this district would be flooded when the flow exceeds 50 000 sec-ft. and that bank protection is required at floods of more than 35 000 sec-ft. It is the opinion of the engineers of the Yuma Project, that floods of the Colorado should be reduced to 40 000 sec-ft. and that a continuous flow of 80 000 sec-ft. would be almost as hazardous as no control whatsoever. The average flow of the Colorado after regulation is effected will be from 15 000 to 30 000 sec-ft. No channel maintained by such a flow will carry a flood discharge of 80 000 sec-ft. unless both levees and bank protection are provided.

Conclusions.—It is the firm opinion of the speaker that when all factors are taken into consideration, it will be found that the Boulder Canyon Project will most nearly satisfy the physical and hydraulic conditions and at the same time will fit in best with existent economic conditions. The U. S. Bureau of Reclamation plan should not be adopted without modification, neither should irrigation be subordinated for power, as would be the case under the plan of development advanced by the author.

The speaker has made no reference to the All-American Canal, as he considers that this matter particularly concerns the Imperial Valley and that it should be entirely divorced from the general development of the Colorado River. From the attitude of the Mexican Commissioner at the time the speaker conferred with him as American Commissioner on the allotment of the waters of the Colorado River and of the Rio Grande, it is quite probable that an equitable settlement can be made which will be satisfactory to both Mexico and the United States. Such a treaty should be negotiated as soon as possible.

All efforts should be concentrated toward the immediate construction of a dam in either Boulder Canyon or Black Canyon that will fit into the ultimate plan of development, while creating for immediate use a reservoir of sufficient capacity for the accumulation of silt, for flood protection, for ample irrigation and domestic supply, and for the development of enough power to satisfy the demand for many years. The selection of the agency or interests which shall effect this construction is a matter entirely foreign to the determination of the proper plan of development of the waters of the Colorado River.

C. S. JARVIS,* M. AM. SOC. C. E. (by letter).—This paper and the discussions that have followed it are so timely and have done so much toward focusing attention upon the outstanding issues, that the main problems are several steps nearer solution.

One of the important points brought out by the author in regard to the feasible irrigation development is that the ultimate depletion of the water supply due to the use in the Upper Basin will probably never exceed 5 000 000 acre-ft., or approximately 1 acre-ft. per acre supplied. Relating this fact to the apportionment of 7 000 000 acre-ft. to the Upper Basin under the terms of the Colorado River Compact as now drawn, it is apparent that although they may divert the prescribed quantity, the return flow should account for nearly 30%, or 2 000 000 acre-ft., to benefit the lower projects. Also, the return flow from the projects in the Lower Basin and above Hanlon Heading will inure to the benefit of the Imperial Valley and lands in Mexico.

There seems to be no possible challenge to the author's statement of principles regarding the desirable locations for storage, and he plainly concedes that compromises have to be made to suit the natural conditions, such as available sites of sufficient capacity, dependable supply, and prior developments and rights. Inasmuch as the triple interests of irrigation, power projects, and flood protection must be served, it is evident that both upper and lower storage sites must be utilized. Most of these sites near the head-waters have such limited capacity as to be well within the scope of private enterprise.

The investigations of the U. S. Reclamation Service during the past two decades furnish the most definite data yet made available as to comparative values of the various plans suggested. However, they were not extensive enough to determine the actual merits of the principal projects now advocated.

It appears advisable to include an extensive examination of the proposed reservoir basins, especially that which would be utilized by the Boulder Canyon Project, because of the known deposits of rock salt and other soluble minerals which might prove harmful to the lands in the lower deltas. Two of the known salt ridges lie somewhat above the proposed high-water level of the plan advocated by the Reclamation Service; but the extent of the saline deposits within the flooded area should be known in advance.

If some large storage reservoir is provided, such as has been suggested at Glen Canyon, Boulder Canyon, or the Mohave site, then, in order to realize on the power feature during the non-irrigating season, water must be wasted. This would make advisable the provision for auxiliary storage at some point down stream. Thus, the Bulls Head or the Parker site would be among those

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examined for the purpose of retaining a relatively small storage, from which no primary power would be obtainable.

The conflicting views as to whether the supply of water is greater or less than required by the available irrigable lands, are evidently traceable to varying judgments concerning lands suitable for reclamation.

Field observations made by the writer on the head-waters and in the intermediate valleys of various tributaries justify the opinion that all the feasible sites at the higher levels should be utilized as rapidly as they can be financed. This is particularly true of the Gila River in Arizona, where the direct benefits to irrigation and the incidental reduction of silt burdens and flood menace for the lower delta will be of immense value.

About twenty years ago field data were collected and designs made for the Gila under the direction of Arthur P. Davis, Past-President, Am. Soc. C. E., and others. The use of this material should prevent the delays and controversies over the Colorado River problem which at present seem to be impending.

E. W. Lane,* Assoc. M. Am. Soc. C. E. (by letter).—The effect of the deposition of silt on the storage capacity of the proposed basins in the Colorado River has been given careful consideration, but has any study been made of the effect of discharging into the river below the flood-control dam of from 40 000 to 80 000 cu. ft. per sec. of water from which the silt has been removed? It is obvious that the water will pick up and carry away large quantities of silt, and although there is probably little, if any, precedent for determining the quantity thus removed, it is easy to show that this may be important.

The silt now passing the Boulder Dam site is estimated to be 80 000 acre-ft. per year. Neglecting the effect of the redistribution of flow and diversions, if it is assumed that before traveling the 459 miles to the Gulf of California, the stream has picked up as much silt as it is capable of carrying, it would remove practically 80 000 acre-ft. of silt per year. Assuming a river bed 1 500 ft. wide, this quantity would be equivalent to an average depth of nearly 1 ft. per year. It would seem more reasonable to expect it to pick up this in the first 100 miles, in which case, the average lowering would be about 4.5 ft. per year; at the upper end it might be twice this, or more. As the silt percentage curve (Fig. 10) given by the author shows that the silt content was nearly the maximum at a discharge of 40 000 cu. ft. per sec., the redistribution of flow might even increase the silt removal more than 80 000 acre-ft. per year.

The quantity of silt removed from the river bed below the dam will be influenced by a number of factors. As the river bed is cut down, the tributary streams will cut down their beds also, bringing into the main stream large quantities of silt which will reduce the rate of lowering of the main stream bed. The fewer and smaller the tributary streams, therefore, the more rapid will be the lowering of the main stream bed.

If bed-rock lies close to the river bottom or heavy gravel deposits exist, such conditions will retard or limit the erosion in their vicinity, but this will only tend to increase it in other parts of the stream. Diversions of water, of

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course, will reduce the lowering, by removing the eroding and transporting agent.

The effect of lowering the bed of the Colorado River, down stream from the storage dam, would be in part harmful and in part beneficial. It would lower the tail-water of the power house at the dam; this would give an increase of head, but it might destroy the effectiveness of the draft-tubes, if they were not designed for such a contingency. This effect may also occur at the proposed power dams on the Colorado.

If the lowering is considerable, it will make the diversion of water for irrigation more difficult and may cause serious undermining of the existing dams founded on silt.

Although it is not possible to predict how much effect this lowering will have in improving flood conditions in the lower river, it will at least be beneficial, and may become, in the course of a number of years, an important factor. It is possible that if engineers knew more of the laws governing this action, by preventing the cutting back of the tributaries, and possibly building a retarding basin on the Gila River, to remove the silt from its water also, the river might be made to excavate its own channel deep enough to carry the flood flow without endangering the surrounding country. In his discussion* of the paper entitled "Flood Problems in China", by John R. Freeman, Past-President, Am. Soc. C. E., the writer has already suggested that this method is worthy of study for the improvement of the Yellow River in China, where the conditions are particularly favorable.

RAYMOND A. HILL,† ASSOC. M. AM. SOC. C. E. (by letter).—The problem of the Colorado River is too complex for arbitrary solution at this time, as the data which are available, or which might be made available, cannot include certain important factors the determination of which is necessary to the proper solution. The extent of flood control which will be needed after storage is provided, and the quantity of water which will be required for irrigation, are two such indeterminates.

The author has made use of certain curves showing the relation between the percentage of silt and the discharge of the Colorado River at Yuma, the relation between velocity and discharge, and the area-discharge relation. These curves were originally prepared by the writer in connection with certain studies to determine the relation between silt content and depth for various velocities. Fig. 24 shows the volume of silt which is transported by the Colorado River at various stages when there is no contributing flow from the Gila River.

It would seem from this that the author is justified theoretically in maintaining that the Colorado River has been more stable at 80 000 sec-ft. than at 40 000 sec-ft. It must be realized, however, that during the years in which these silt measurements were made the river was constantly fluctuating in volume, particularly at the higher stages, and that even with a silt-laden river the proportion of silt would tend to decrease if the discharge were held constant.

* *Transactions*, Am. Soc. C. E., Vol. LXXXV (1922), p. 1558.

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This in itself would alter the stage of equilibrium. Certainly the characteristics of a desilted river cannot be based on data acquired when the river was heavily laden with silt. Before the Colorado River is regulated, no one can predict which rate of discharge from a flood-control reservoir will produce the most stable condition.

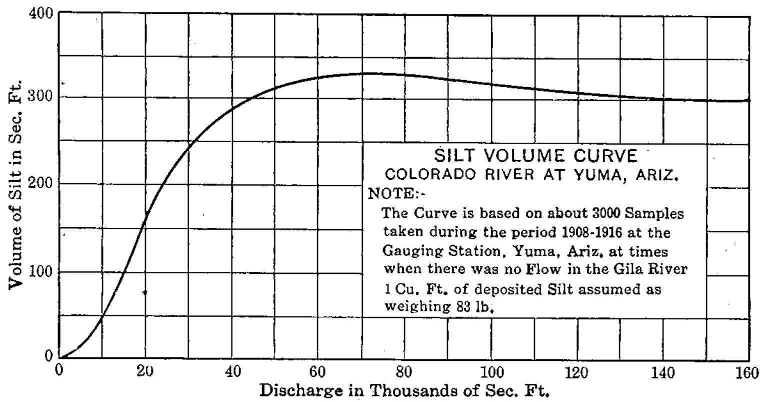

FIG. 24.

Silt which enters the Colorado River above the last reservoir will be intercepted and deposited in this and other reservoirs. The water which is passed down the river will be clear at first, and it will be highly desirable to keep it as clear as possible by reducing scour in the channel. A load of silt, however, will be picked up along the river whenever the rate of discharge is materially increased. As much of this silt will be carried into the irrigation canals, fluctuations in the flow of the Colorado River should be reduced to a minimum. This consideration alone will require that the release from the flood-control reservoirs be held to much less than 80 000 sec-ft., as the irrigation demand will not exceed about 30 000 sec-ft.

Estimates of the available water supply and of the future irrigation requirements naturally differ widely, as these are to a considerable extent matters of conjecture.

The average annual discharge of the Colorado River at Yuma, as estimated by Herman Stabler, M. Am. Soc. C. E., was 30% greater for the last 20 years than the average for the preceding 20 years. It is believed that the run-off for the years preceding 1902 has been computed too conservatively.

Prior to its break into the Imperial Valley, the Colorado River had been lengthening its old channel by deposition of silt at the head of the Gulf of California. This naturally resulted in a continuous raising of the water surface at Yuma, until, as shown in Fig. 4, only about 30 000 sec-ft. were carried at a gauge height of 23.0 ft. Since 1905, largely on account of the change in the river channel below Yuma, the average discharge for the same gauge height has been more than 50 000 sec-ft. The original gauge readings were kept by the Southern Pacific Railroad Company which had little interest in the volume of water in the Colorado River. Consequently, there were not enough actual stream-flow measurements, prior to 1902, to determine the continually changing gauge-discharge relation. As the river bed was steadily rising, calculations based on gauge heights would tend to give results lower than the actual discharge of the river.

Fortunately, records covering many years of measured run-off will be available before the irrigable acreage will have expanded sufficiently to absorb the increase in supply which will come with regulation.

In Table 11 the author shows a compilation and classification of the areas which may be served from the Colorado River. His conclusion that the water supply is obviously inadequate depends on the accuracy of the calculations as to the water supply, on the economic feasibility of agriculture on these lands, and on that use of water assumed as necessary.

So much of the area included is less suited to agriculture than other large undeveloped sections in the United States and Mexico, that the writer, who is familiar with the entire area, cannot conceive of its complete development. In 1907, 190 000 acres were irrigated on all the projects of the U. S. Bureau of Reclamation; by 1921, the irrigated area had increased to only 1 250 000 acres, in spite of the fact that natural and economic conditions were favorable to rapid expansion. It has taken 20 years for less than 500 000 acres to be placed in cultivation in the Imperial Valley of California. When it is realized that these areas were the easiest and cheapest to develop, it should be obvious that a great many years must elapse before the irrigated area below the canyon will exceed 2 000 000 acres.

Conservation of water by the reduction of the gross duty will more than offset any further increases in the irrigated area. The author has assumed that 4.2 to 4.5 acre-ft. of water will be consumed each year on every irrigable acre below the canyon. The actual consumption per gross acre of irrigable area in that part of the Imperial Valley served by the Imperial Irrigation District is shown in Table 34, summarized from the 1923 report of the Chief Engineer of that District.

TABLE 34.—WATER DELIVERY IN IMPERIAL VALLEY, 1923 SEASON.

Division.	Irrigable area, in acres.	Water delivered to farms, in acre-feet.	Acre-feet per gross acre.
Calexico	47 000	99 887	2.12
Holtville	85 000	154 683	1.82
Imperial	130 000	249 630	1.92
Brawley, East	78 000	156 188	2.00
Brawley, West	82 000	149 933	1.83
Calipatria	93 000	109 909	1.18
Total	515 000	920 230	1.79

As about 80% of the irrigable area was actually cultivated in the Calexico Division, 70% in the Holtville, 70% in Imperial, 75% in Brawley, East, 70% in Brawley, West, and 45% in the Calipatria Division, the net duty for each acre actually cropped was approximately 2.7 acre-ft. The gross duty for each irrigable acre of a fully developed area will be almost equal to the net duty on each cropped acre, as the transmission losses are generally counterbalanced by the difference between the irrigable and cropped areas.

Even without further improvement in irrigation and farm methods, at least 1.5 acre-ft. per acre, or about 5 000 000 acre-ft., should be deducted from the estimated total requirement. Projects comprising several million acres in the San Joaquin Valley of California are being carried forward on the basis of 2.0 acre-ft. per acre, and this quantity is considered sufficient in Southern California. As the character of development progresses, the economic advantages arising from the minimum use of water will force a similar procedure in the Colorado River Basin.

Therefore, it is the writer's firm opinion that future experience will disprove the contention that the water supply from the Colorado River will be insufficient for much of the lands, because he believes that the water supply has been under-estimated, that the economically feasible area has been over-estimated, and, finally, that the available supply can serve a far greater area than that claimed by the author.

E. B. DEBLER, ESQ.* (by letter).—According to the paper, little, if any, saving in the cost of bank protection and maintenance will result from reducing the flood discharge of the Colorado to less than 80 000 sec-ft. Porter J. Preston, M. Am. Soc. C. E., Project Manager and Superintendent of the Yuma Project since 1920, and R. N. Priest, Assoc. M. Am. Soc. C. E., Construction Superintendent since 1903, most of the time in charge of river control work through the Yuma Project, advise that the levees begin to undercut at discharges of 50 000 sec-ft. and that overflow of the natural banks below Yuma begins at discharges of 30 000 to 50 000 sec-ft., depending on river conditions. Colonel Kelly states on the authority of the Engineer of the Palo Verde Project that flooding without levees would begin in the Palo Verde Valley with discharges of 50 000 sec-ft. and that bank protection is required for flows exceeding 35 000 sec-ft. These conditions are typical of all the valleys below the canyon region. Mr. Preston further states that the channel capacity is increased by 10 000 to 20 000 sec-ft. by scouring of the river bed with continuation of the flood.

Until the Gila River is controlled, levees will have to be maintained to the present levels, but the Gila floods are of such short duration that they do not require bank protection for the levees. The expenditures on levees have largely been for purposes of revetment and this is required by reason of the continued persistent undermining of levees by extended floods originating along the Colorado. In 1913, a levee was cut entirely through with a maximum flood discharge of 62 000 sec-ft. The advantages of reducing all ordinary floods to less than 50 000 sec-ft. are obvious.

Colonel Kelly recommends a flood-storage capacity of 4 000 000 acre-ft. to reduce recorded floods to 75 000 sec-ft. and to permit the interruption of flow for repairs in case of breaks in levees. His floods refer, however, only to the period since 1902. Reliable records indicate a flood in 1884 far in

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excess of any since 1902, with a maximum discharge for that year at Needles, estimated by Santa Fé railroad engineers on the ground, at 384 000 sec-ft. The maximum discharge at Laguna Dam since 1902 has been 186 000 sec-ft. Herman Stabler, M. Am. Soc. C. E., estimated the annual discharge for 1884 at 27 200 000 acre-ft. as compared with a discharge of 21 100 000 acre-ft. for 1920 on which Colonel Kelly's recommendation of 4 000 000 acre-ft. of storage is based. The difference of 6 100 000 acre-ft. between the discharges of these two years is largely water that would have to be stored if discharges at Yuma are to be maintained at 75 000 sec-ft. as recommended by Colonel Kelly. The required storage capacity to hold the 1884 flood to 75 000 sec-ft. would then be 10 000 000 acre-ft. compared with 4 000 000 acre-ft. recommended by Colonel Kelly and 8 000 000 acre-ft. proposed by the U. S. Bureau of Reclamation.

The problem of flood control is not one of water alone; it contains an element of possibly even greater importance—silt control. It may be granted that power dams, if constructed on the Colorado River in the immediate future, will cause Colorado River waters to leave the canyon region practically desilted. The present topography of the stream bed and valleys below Boulder Canyon is a balance between the silt supply brought by the stream from upper sources and existing channel conditions. When the silt supply is cut off, this balance is disturbed, and the result is entirely beyond the ability of man to forecast with certainty. Will it be safe to turn a continuous stream of 75 000 sec-ft. of comparatively silt-free water into a channel that has adapted itself to heavily silted water? To provide for expected, but wholly uncertain, developments from this change in character of stream flow, liberal allowance must be made for controlling the stream flow to discharges materially less than those proposed by Colonel Kelly.

The paper outlines a permissible development at Mohave Valley in case Congress should deem some provision for flood control and irrigation necessary, and places the cost of the power plant at $35 per h.p., wholly omitting the cost of transmission lines. Estimates for Boulder Canyon indicate a cost of $76 per h.p. for the power plant and pressure tunnels with a plant capacity of 200 000 h.p. With the lower head available at Mohave Valley, the cost at that point would be no less. Adding to this amount the estimated cost of $115 per h.p. for the dam gives a total cost of $191 per h.p. for a power plant nearly 300 miles from the Southern California market as compared with a similar cost for competitive California sites not only nearer the market, but located so that advantage may be taken of transmission lines already constructed and not fully loaded.

To produce this power the normal flow of the Colorado River must be increased very materially. If, for this discussion, it is admitted that the increase in normal flow caused by the construction of Boulder Canyon Reservoir would be a menace to the fullest possible use of Colorado River waters by reason of an immediate impetus in Mexican irrigation, the Mohave Valley plan for all practical purposes is open to the same objection.

The inability of power revenues at the Mohave Valley site to repay the construction cost is probably best indicated by the fact that this dam site is the only one on the Lower Colorado River that has not been plastered with applications before the Federal Power Commission.

Colonel Kelly states that "all development needed on the Colorado will be built by private capital under adequate Federal and State regulation if the river is given over to development under the Federal Water Power Act". There is little reason to doubt that speedy development can be obtained in this way, along lines, however, as favorable as possible for power but with a minimum regard for irrigation and flood control.

The present status of the Flaming Gorge permit of the Utah Power and Light Company is an excellent example. This permit was originally granted, subject to up-stream irrigation use. It is now understood, however, that the Company is reluctant to accept license under these terms and requests irrigation development above the reservoir site to be limited.

The claim that construction of the Boulder Canyon Reservoir will jeopardize up-stream water rights by utilizing the total stream flow applies with equal force to any and all reservoirs and power plans proposed, as even the so-called up-stream reservoirs are below the irrigable areas in the Upper Basin.

Regardless of the amount of storage provided, the flow available for power, whether at Mohave or Diamond Creek, is made up of the normal flow plus a storage increment, the latter alone being affected by the storage capacity provided. The normal flow is of vital interest to power and to irrigation development throughout the basin. Up-stream irrigation development will reduce this plan to the detriment of power development below; it can be safeguarded only by legal and binding agreements which will preclude opposition to such depletion.

In case a plan of private development is adopted, a large development of Colorado River power may come about very quickly in comparison with irrigation development; the provisions for future irrigation development, therefore, must permit wide latitude from any plans that may now be outlined. If inadequate storage capacity is provided for flood control and irrigation before power developments become crystallized, the bar to full irrigation development becomes insurmountable. The proposal by Colonel Kelly and others to inundate a large irrigable area like the Mohave Valley as the first step in irrigation development requires more justification than has yet been advanced. On the other hand, an excess of storage for irrigation and flood control can be converted later to use for power development, resulting only temporarily in a reduction in power output, provided a market then exists for this added power. Although the Reclamation plan is severely criticized, no alternative plan is outlined in sufficient detail to indicate its comparative value or feasibility.

The author enunciates the generally recognized axiom that power development should be based on up-stream storage. Practical plans usually require some deviation from this principle either to obtain the greatest power output or to obtain a near maximum output at reasonable cost. It is in conformity with this practical application of the principle that the plans outlined in the discussion by Mr. Weymouth have been evolved.

It is granted that widespread up-stream storage would materially alter these plans, but thus far no agency has proposed such construction and the prospects thereof within a reasonable time limit are decidedly unfavorable. To hold back feasible developments on the Lower Colorado for fear they may not fit in with some theoretical ultimate plan is likely to cause far more loss from delayed development than the possible cost in the far future of reconstruction to fit in with changed conditions. Had the same principle been adopted in the construction of American railroads there would not be a single line from coast to coast to-day.

WILLIAM KELLY,* M. AM. SOC. C. E. (by letter).—The writer has been much interested in the discussions by Messrs. Allison, Fowler, La Rue, Davis, Grunsky, Weymouth, Smith, Jarvis, L. C. Hill, R. A. Hill, Lane, and Debler, each of whom has contributed valuable data or opinions on one or more phases of the problem.

The writer will give a brief review of these discussions, and close with an expression of his conclusions.

Mr. Allison supports the views expressed in the paper with respect to flood control which, in view of his long connection with Imperial Valley, is very gratifying. He expresses the opinion that there will always be sufficient water for all future irrigation needs and presents data to substantiate this view. Many engineers disagree with him in this respect, but practically all now agree with his further view that power development will precede irrigation development and will materially aid the latter. Mr. Allison's presentation of data on and his discussion of the All-American Canal are valuable contributions, and should prevent the Federal Government from ever taking part in that project.

Mr. Fowler brings out clearly and accurately certain important functions of the Federal Water Power Act and their relation to the Colorado River, which explain the point of view from which the writer has approached the problem. Mr. Fowler's reasoning on the distribution of costs among the various interests instead of inflicting it all on the power consumer, is sound. Finally, he brings out more forcefully than the writer the advantages of a well-balanced progressive development over the single large Boulder Canyon plan.

Mr. La Rue presents data to show that all the resources of the Colorado will be needed and that probably there will not be enough water to irrigate all the available land. Mr. Allison and certain engineers of the Reclamation Service differ with him in the latter view, whereas Arizona and many engineers who have studied the question agree with him. Nobody can be certain what the future irrigation development will be. It may well be slow as predicted by Mr. Allison, but, considering the vast arid territory through which the river runs, the only safe policy is to see that any project built at present shall involve no ultimate waste of water such as will result from duplicate regulatory storage. Mr. La Rue's recommendations at the end of his discussion have great merit, and are worthy of serious consideration.

* Col., Corps of Engrs., U. S. A.; Chf. Engr., Federal Power Comm., Washington, D. C.

Mr. Davis' discussion is a clever composition of facts combined with assertions and partial quotations that misinterpret the writer's views. His arguments appear convincing even to the writer, who knows that many of them are not in accord with the facts. Coming from a man of Mr. Davis' prominence, they will doubtless carry conviction to many. It would be tedious and appear contentious to answer his discussion item by item, but certain additional facts need presentation and certain of his inferences and misinterpretations of the writer's position need correction.

Under the heading "Storage in Upper Basin" (page 384), Mr. Davis discards the Ouray Dam site on account of a railroad right of way granted by the Secretary of the Interior. The right-of way in question was granted in January, 1922, for a period of five years to the Denver and Salt Lake Railroad Company on Mr. Davis' recommendation. It lies entirely on the west side of the river, extending from about the middle of Sec. 18, T. 8 S., R. 20 E., to the Town of Randlett, and is all above the 4 800-ft. contour. Information is not available as to where the proposed railroad will cross the Green River, but there seems to be no reason why it should not follow up the river and cross just south of Split Mountain, somewhat on the line of a right of way granted some years ago. This latter right of way has now expired so that the location of the proposed railroad in the vicinity of Green River is still under Federal control. The water surface at the Ouray site is at about Elevation 4 630. Taken in conjunction with Flaming Gorge and Juniper a storage capacity of about 3 000 000 acre-ft. at Ouray will give full regulation of the Green River at the latter point. This capacity can be obtained by a dam 170 ft. high, that is, with a crest at Elevation 4 800 and a draw-down at 25 ft. A dam of about that height backs the water to the Split Mountain Dam site for the development of which there are now two applications before the Federal Power Commission; it is unlikely that a higher dam at Ouray will ever be built. The Salt Lake Railroad may be a desirable development, but should not be a reason for interfering with a proper development of the Ouray Dam site.

Although up-river storage cannot be used exclusively for carry-over storage for the Lower Basin to the extent at one time contemplated by the Reclamation Service, it will provide seasonal regulation and can be developed for carry-over storage to whatever extent the future may show to be economically feasible. Mr. Davis states that at least 25 000 000 acre-ft. of storage will be needed in the Colorado Basin. In this figure, he duplicates quantities for flood storage and adds a margin for silt storage, but gives no credit for the silt storage that will be provided by power dams. About 86% of the water reaching Boulder Canyon comes from above Glen Canyon, and considering the possibility of storage dams at Glen Canyon and Cataract Canyon in addition to those higher up, this part of the flow can be completely regulated above Grand Canyon. Such regulation can proceed gradually as economic conditions justify and the extent to which it should be developed can be determined by the economic requirements of the future. It will be relatively free from silt deterioration and will have several times the power value of storage at Boulder Canyon. About one-half the remaining flow is a nearly constant increment requiring no regulation, the remainder occurring in erratic flood flows mainly due to fall and winter rains and rarely exceeding 1 500 000 acre-ft. in any year. These flood flows can be largely regulated and absorbed by the power dams in the Canyon Section and the re-regulating dam below. Such being the case the writer can see no justification for creating 34 000 000 acre-ft. of storage at the bottom of the Canyon Section.

The Reclamation Service estimates indicate that the Big Boulder Canyon project is cheaper for power and storage than any other on the river. This may or may not be the case, but even if it be assumed that it is, the project should not be built unless it is made to conform to a plan of development that will get the fullest use of the water. Colorado River power can be developed cheaper than steam power in Southern California. It will all be needed and nobody should be permitted to "skim the cream," leaving a residue that cannot be used.

Referring to use of up-river storage, Mr. Davis asserts that "This program would be an economic blunder of the first magnitude." His views on economics have often differed from those of the writer, but never more than on this point. It is undoubtedly feasible to regulate the flow of the Colorado above Glen Canyon. The advantage of placing regulatory storage as far up stream as possible is generally recognized, and on no other river known to the writer are the advantages so marked as on the Colorado.

Mr. Davis and most of the Boulder advocates disregard the time element in discussing the Colorado. They compare the initial development of a progressive complete project with the very comprehensive results claimed for Boulder Canyon. If only one development were to be made on the Colorado, their arguments should be given considerable weight, but that is not the case, and Mr. Davis himself recognizes that the development of power will proceed rapidly and continuously to its full extent when the present deadlock is broken.

Mr. Davis' statement that, "it is certainly better to hold floods by storage, even if part of the water does evaporate, than to let them run to the sea, and fight them en route, as demanded by Colonel Kelly," is the kind of argument advanced by several of the Boulder advocates. The writer has never demanded any such thing; on the contrary, he has endeavored to ascertain what degree of flood protection can be obtained by storage, and has indicated what he believes to be profitable as a first step, with the definite statement that full regulation will be obtained later as power and irrigation development proceeds.

Under the heading, "Mohave Reservoir Wasteful and Destructive" (page 386), Mr. Davis exaggerates all the difficulties and slights all the advantages. The estimate of the Reclamation Service for flowage damages on the Mohave site is $12 775 000, made up as follows:

Railroad	$8 500 000
Highway	200 000
General property damage................	4 075 000

The railroad damages are based on a letter from an official of the railroad company which bears evidence of an intention to play safe. No allowance is made for the elimination of heavy grades on the present approaches to the bridge and the extra operating costs due to the additional three miles of road are capitalized at about $1 000 000. No allowance is made for salvage on the present division shops, ice plants, and other property. On the other hand, the estimate of flowage damages at the Boulder site, the development of which would cause the flooding of many mining claims, two small towns, and a branch line railroad terminus, is only $500 000. Evidently these two estimates are not made on the same basis and are not comparable.

With respect to irrigable land in Mohave Valley, it should be understood that the river meanders through this Valley in such a way that under present conditions the cost of reclaiming the land by holding the river in place is too great to make the land of any value. What the conditions will be when the river is controlled to a maximum flow of 40 000 cu. ft. per sec., as proposed by the Reclamation Service, is problematical. It should be less expensive to reclaim the land under those conditions, but levees and bank protection will still be necessary, and will cost at least $50 000 per mile. The land is divided by the river into five tracts, as shown in Table 35.

To the cost of reclamation must be added the cost of irrigation and drainage, which will probably be not less than $75 per acre. To the usual operating costs must be added a figure for maintenance of levees and bank protection. Considering these facts, none of this land is economically feasible for irrigation, with the possible exception of the tract at the south end of the Valley. A dam at Parker of the height proposed by Mr. Davis would submerge this tract; a dam at Parker that does not submerge this tract will not materially interfere with a dam at Mohave.

TABLE 35.—IRRIGABLE LANDS, COTTONWOOD AND MOHAVE VALLEYS.
(Acreages from Unpublished Report of U. S. Reclamation Service, 1916. Other Figures Compiled by the Writer.)

Tract.	Area, in Acres.						Miles of revetment and levee.	Estimated cost per acre of levee and revetment.	Remarks.
	Irrigable.		Waste.		Total.				
	Gravity.	Pump.	Gravity.	Pump.	Gravity.	Pump.			
Cottonwood Valley:									
East side.........	2 085	.....	1 551	.....	3 636	.....	5	$125.00	....
West side.........	2 214	.....	703	.....	2 917	.....	7	160.00	....
Mohave Valley:									
Arizona side......	.....	700	2 200	400	2 200	1 100	..	......	All gravity land has been ruined by meandering of river.
Opposite from Mohave.............	1 000	70	4 800	230	5 800	300	10	500.00	....
Arizona side........	22 500	2 425	12 500	1 200	35 000	3 625	28	56.00	....

Mr. Davis states that engineers who examined the Mohave site twenty years ago rejected it. It may be well to record why this site was then rejected.

The flooding of the railroad, of the Town of Needles, and of 40 000 acres of supposedly irrigable land was believed to be involved in developing a reservoir capacity limited to 1 500 000 acre-ft. On these premises, it was concluded:*

"In view of the existence of several reservoir sites below and of the damage which would occur from the construction of a dam at Blue Canyon (Mohave Canyon), it is believed that this valley near Needles (Mohave Valley) can be more profitably utilized by irrigation from diversion canals (than as a reservoir)."

If the premises were correct one could easily agree with the conclusion, which, as it should be, was based on the greatest measure of profit to be obtained from the resources involved. It was not reported as "infeasible" despite Mr. Davis' statement that it was "unanimously regarded as infeasible." For a reservoir, the Valley is unusually well shaped; the floor is quite flat and the banks rise steeply from it so that it can be used without creating much shallow water. With a dam 180 ft. high reserving 4 000 000 acre-ft. for flood control, the depth of water at the upper end of Mohave Valley at maximum draw-down would be about 90 ft., and at the upper end of Cottonwood Valley about 40 ft. This cannot properly be termed a shallow reservoir.

Under the heading, "Wanton Destruction of Valuable Storage" (page 387), Mr. Davis argues that storage at Boulder Canyon must be reserved for silt. On the basis of 100 000 acre-ft. of silt per year, the smaller Boulder Canyon Dam suggested by the writer would hold the entire deposit for a period of 100 years. The power dams above would hold at least as much more. No sufficient study of the silt problem has yet been made; probably storage will always be the cheapest way of taking care of it. If the silt problem were to control, no dam above Boulder Canyon should be built until Boulder Reservoir had filled to the maximum for comfortable operation. Then the next dam up stream should be built and allowed to fill, and so on. Such a program would run over a period of several hundred years and would be intolerable. Although silt will add to the expense of using Colorado water for domestic, irrigation, and power purposes, it will not prevent that use provided sufficient storage can be maintained to regulate the flow. As nearly all the silt enters the river below the San Juan, storage above that point will be little affected. Ultimately, at least in theory, all storage below the origin of silt will fill, and the only regulation of flow will be that which can be obtained above that origin. The silt problem is a strong argument for seeking regulatory storage above the San Juan, but not for excessive storage at Boulder Canyon. It is quite certain that complete desilting at Boulder will greatly accentuate the ever-present tendency to erode banks and to pick up a heavy load of silt from the vast quantities now stored in the bottoms along the 300 miles between that point and Yuma.

Under the heading, "Proper Plan of Development" (page 387), it is encouraging to note that Mr. Davis gives consideration to adapting his Boulder Canyon project to a full development of the lower river. Perhaps he will eventually come to consider also the upper river and to give proper weight to the regulatory storage that can and will be provided there. The only regulatory

* First Annual Report, U. S. Reclamation Service, pp. 113 and 114.

storage needed in the lower river in the final development is in the lowest reservoir that will give sufficient storage, so that no power will be lost owing to the difference in the power and irrigation demands. Mr. Davis' discussion makes it necessary for the writer to point out again that he is not committed to his plan, and that it was used simply as an illustration. A better plan can doubtless be developed when the necessary data are available.

In discussing "Poor Rock in Glen Canyon" (page 390), Mr. Davis emphasizes the writer's presumption in differing with his eminent Board. The writer questions whether there is much difference between his own views and those of the Board regarding the quality of rock at Glen Canyon. The report of the Board which examined this site was signed by Messrs. F. E. Weymouth, F. L. Ransome, L. C. Hill, and A. J. Wiley (three engineers and a geologist), on December 20, 1922. The following is quoted from the report:

"11. The Jurassic sandstone has been fully described by Gregory, Bryan, and others. It is a fine-grained, very uniform quartzose sandstone which appears to owe its reddish tint to the superficial redness of certain individual grains. The grains are imperfectly cemented and the whole resembles in hardness the type of soft brick known to the trade as salmon brick. It crumbles under shock, such as that of ordinary blasting, and small fragments can be crushed to sand between the fingers. Notwithstanding its softness the rock stands remarkably well in the canyon walls, forming large, smooth cliffs that rise for 1 000 ft. or more above the river, and which in places are within 5° of being vertical.

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"13. As pointed out by Dr. Bryan the Jurassic sandstone is too soft and too easily broken on corners and edges to make good building stone, and is entirely unsuitable for use as concrete constituent. In large masses, however, it successfully resists the weight of the towering canyon walls and shows no signs of failure at the base of the cliffs where these come down to the water's edge. Under the atmospheric conditions prevailing at the canyon, moreover, the sandstone in spite of its softness withstands the action of the weather remarkably well. Some of the smooth walls must have stood without appreciable change for centuries.

* * * * * * * * * * * *

"30. The abutments for a gravity type concrete dam are fully exposed, and the foundation is indicated by a diamond drill boring. Both are of a quite uniform soft sandstone which is not hard enough for a building stone, but probably will be found to have sufficient strength to support a concrete dam."

As far as the writer can ascertain, no other Board report on the subject has been made, but apparently one member of the Board expressed somewhat modified views about a year later, for Mr. Weymouth, in his report of February, 1924, quotes from a letter of November 27, 1923, by Mr. Wiley as follows:

"It does not seem feasible to build any type of masonry dam of the necessary height for effective storage on the soft sandstone at Glen Canyon, at least no type or height requiring maximum pressures of more than 20 tons per square foot should be used."

A few years ago the writer spent four days examining this dam site. Evidence of bearing power is furnished by the cliffs which rise nearly vertical to a height of 1 000 to 1 500 ft. It may be well to point out that bearing power is determined by compactness, rather than by hardness and that the rock in question leaves nothing to be desired in the way of compactness. The cementing material is not strong enough to resist heavy erosion; spillway and power tunnels would have to be lined, but in foundations, even with the most ordinary precautions to prevent failure by displacement, the rock will certainly bear more than the load which it is safe to place on concrete in a dam.

It may be interesting to note that common practice considered the safe maximum stress in concrete dams as 20 tons per sq. ft., until some of the high dams of the Reclamation Service were built, when it was found that the cost of maintaining that standard was prohibitive, and the limit was raised to 30 tons per sq. ft. The same experience resulted from the design of the high Boulder Dam; Mr. Davis and his Board of Engineers have designed that dam with a maximum stress of 40 tons per sq. ft., equivalent to 555 lb. per sq. in. The concrete will have to be unusually good to insure an ultimate strength of 2 000 lb. per sq. in. In other words, the factor of safety will be about 3.6 in the concrete. The loading assumptions used by the designers are conservative, but with the tremendous loads available for unexpected concentration in such a high dam, there is a risk in so far exceeding precedent which nothing but positive necessity can justify.

The economic height for power dams in the Canyon Section can be shown to lie between 200 and 400 ft. Dams higher than 400 ft. can be justified only for storage or, perhaps, for the purpose of backing the water up to the next feasible dam site, and should not be permitted unless it can be positively proved that the full development of the river cannot be obtained without them. The writer does not consider it necessary or desirable to build a very high dam at Glen Canyon—probably not over 400 ft., and certainly not over 500 ft.

Referring to the heading, "Increase of Low-Water Flow" (page 391), legal views of eminent authorities are available to prove that Mexico can never profit from the storage of water in the United States, but any one who will study the history of the relations of the United States with other countries, especially with those of the American Continent, will realize that the United States always sets aside legal arguments and settles on a basis of unreasonable liberality. It is certainly a wise precaution to obtain a treaty with Mexico to cover the question. Fortunately, conditions seem favorable at present for negotiating such a treaty and it is understood that preliminary steps are already under way.

Mr. Davis makes two statements in his discussion which cannot be overlooked. In the first he says, "This emphasizes the real point at issue, that is, whether the immense resources of the Lower Colorado are to be retained in the control of the Federal Government or turned over to private corporations." Any one familiar with the Federal Water Power Act knows that it sets forth a complete Federal control—the product of more than twelve years' consideration by Congress. Nobody, as far as the writer is informed, has ever proposed less Federal control except certain advocates of municipal development who do not wish to be burdened by the Federal Water Power Act, and who have called forth the private monopoly specter in their efforts to obtain special privileges for themselves.

The other point is where Mr. Davis states:

"The author deserves thanks for the frank official declaration of the settled policy of the Federal Power Commission, in his statement that: 'All the development needed on the Colorado will be built by private capital under adequate Federal and State regulation if the river is given over to development under the Federal Water Power Act'".

The writer made a simple statement of fact to indicate that no appropriation by Congress is necessary to procure a full and economical development of the Colorado River. In another part of his discussion (page 386), Mr. Davis confirms this, but he proceeds to construe the writer's plain statement of fact into a declaration of the policy of the Federal Power Commission. The policy of the Federal Power Commission with respect to any pertinent subject can always be obtained by application to the Commission or can be deduced from the precedents set up during the past four years. The Commission has administered the Act strictly in accordance with its terms, and all municipal applications have received the preference to which the law entitled them. The only municipal application for power development on the Colorado River is that made by the City of Los Angeles for the Boulder site. The City made it clear to the Commission that it did not wish consideration of its application unless Congress definitely refused to appropriate for the Boulder Project. Judging by precedent, the City of Los Angeles can feel assured that it will get all the preference contemplated by law if and when any application for the Boulder Canyon Section of the river is considered by the Commission. Mr. Davis' statement is an accusation that the members of the Commission have acted in defiance of the law entrusted to their administration. Such an accusation has no place in an engineering discussion. It may be noted that a similar accusation has been made recently by certain municipal ownership advocates who claim that the Commission is not carrying out the law because it has subjected their projects to the same examination as private projects and has not granted the applications "sight unseen". Mr. Davis seems to be convinced that opposition to his project is due entirely to objection to public ownership. That is not the case; the writer's opposition is and always has been based solely on engineering and economic grounds.

Mr. Grunsky emphasizes the need for a treaty with Mexico. He also discusses the division of the resources of the Colorado among the various States and proposes, as a solution, Federal control. The tendency to mould economic laws to fit political boundaries has always been prevalent; it probably will never be entirely overcome, although it is dangerous and has been responsible for most of Europe's troubles. All the developments on the Colorado thus far proposed involve power and occupy public lands, and, therefore, in the absence of new legislation, will come under the Federal Water Power Act, which provides a Federal control that is adequate. The Act does not provide Federal funds for construction, nor does it give the upper States a treaty guaranty of water rights, but, judging by experience under the Act to date, it will give them all the protection they need.

With reference to Mr. Weymouth's discussion, the writer had no intention of misquoting or misrepresenting the data presented by the Reclamation

Service. Table 11 does not purport to be taken from any report of the Bureau of Reclamation. It is quoted from a report by Herman Stabler, M. Am. Soc. C. E., and is a compilation of data made available to him by Mr. Weymouth. Evidently the same data, slightly modified, were compiled in Table 30 by Mr. Weymouth in the report to which he refers. The essential differences between the two tables are explained in the footnotes to Table 11. The text of the footnotes is based on statements in the report made by Mr. Weymouth in February, 1924.

In Table 19, the term, "U. S. Bureau of Reclamation Plan", was used in a general sense as referring to a high dam at Boulder Canyon, and the data used in the table were computed by the writer. There should be no misunderstanding on this point because all the figures are based on up-river regulation which Mr. Weymouth and the Reclamation Service have declined up to the present to consider as available. Mr. Weymouth cites the historical development of the investigation conducted under his direction. Conditions have changed materially since this investigation was commenced. Mr. Weymouth's willingness to consider an ultimate plan of development as evinced in February, 1924, together with the general trend of his discussion, might be taken as an indication that if he had continued in charge of the investigation he might have spread it sufficiently to get the broader scope which the writer deems necessary. About the only material difference between his views and those of the writer is in regard to the feasibility of storage elsewhere than at Boulder Canyon. The data available on storage sites may be sufficient to have convinced Mr. Weymouth that up-river regulation is infeasible, but it has failed to convince many others, including the writer.

Professor Smith points out the interests of the State of Arizona in the Colorado River. These interests have been fully recognized by all Federal authorities. Unfortunately, there is divided opinion in Arizona as to what should be done with its interests so that much delay in getting started on any project for the Colorado is likely to result. Professor Smith discusses the question of water rights. The writer does not pose as an expert on that subject, but whatever the law may be it is certain that representatives of the upper States have persistently refused to accept anything short of an interstate treaty as protection of their future needs. Professor Smith's suggestion that the matter be settled by the Imperial Valley suing the permittees on Flaming Gorge does not seem to be practicable, because Flaming Gorge cannot in any way infringe on the rights, present or future, of the Imperial Valley, and there is no ground on which to base a suit. Professor Smith's suggestions with respect to up-river storage are sound, but as yet no one has shown a practical way of financing a dam at Dewey in advance of a certain amount of power development below. Professor Smith might with justice point out that the same objection exists against the Mohave site. The Federal Government has considered such projects only in connection with the improvement of navigation or under the terms of the Reclamation Act. It is stretching the point rather far to consider that Boulder Canyon or a substitute comes under either category, and it is doubtful whether Congress will set a new precedent by undertaking any project on the Colorado unless there is a strong public demand and practically no opposition.

The people who might be expected to support a proposition for a flood-control dam at Dewey are supporting Boulder Canyon and opposing everything else. Under the circumstances, the only prospect for early development of up-river storage appears to the writer to be in connection with power development.

Mr. Jarvis' discussion comprises a brief résumé of the Colorado problem and expresses his views on certain phases of the problem.

Mr. L. C. Hill discusses the Glen Canyon site as a power site. The writer has never considered such a development probable. If the Glen Canyon Dam is built it will probably be as a storage dam to regulate the flow for projects lower down. Eventually, it might be feasible to develop power at Glen Canyon, but that is hardly likely to be economical in the early stages. Mr. Hill seems to appreciate the desirability of making all the units fit into a plan for full development. He misunderstands, however, the writer's views with respect to the relation between power and irrigation, namely, that power development will proceed more rapidly than irrigation but not that power should be allowed to curtail irrigation. On the contrary, construction at power sites can and should progress so that it will permit and aid the fullest practicable irrigation development. The writer does not agree with Mr. Hill that storage for annual hold-over will be necessary or advisable at Boulder Canyon.

Mr. Hill states that about 100 000 acres in Mohave and Cottonwood Valleys would be submerged by a dam near Needles. The total area submerged by the highest dam proposed will be about 75 000 acres and, as shown under the writer's reply to Mr. Davis' discussion, of this less than 25 000 acres can ever be irrigated.

In regard to Mr. Hill's computations on evaporation losses in Mohave Valley, it is difficult to determine with any certainty what conditions will be if the flow is regulated to a maximum of 40 000 cu. ft. per sec. The writer's estimate of present evaporation losses is based on the area overflowed by a river stage 10 ft. on the Topock gauge. This stage has been reached in the past few years with flows varying from 35 000 to 60 000 cu. ft. per sec. The writer believes there will be no material reduction in evaporation losses with the flow regulated to 40 000 cu. ft. per sec. Of course, if any of the overflowed area is reclaimed and put to beneficial use, it should be deducted from the area producing present evaporation losses. Under the most optimistic estimates not more than one-third of the overflowed area will warrant the cost of reclamation; the writer does not believe that any of it will.

In regard to flood protection, Mr. Hill's principal argument is that the writer disregards the opinion of those who have personally been combatting the floods of the Colorado. This is not the case—it was because the writer found considerable difference of opinion among those who have been combatting the floods that he deemed it advisable to make a careful study of the situation. That study is presented in the paper. The facts have been approved by the Reclamation Service engineers, to whose opinions Mr. Hill doubtless refers, and the writer has found no reason to change his conclusions.

The writer regrets that he did not specifically acknowledge the use of the data prepared by Mr. R. A. Hill. It was obtained from the Bureau of Reclamation, together with much other data, and so was acknowledged *en masse* as the work of that Bureau.

The writer agrees that it will be desirable eventually to equalize the flow of the river as far as practicable, but he also believes that the partial equalization set forth in his paper is sufficient to remove the flood menace and that until certain other matters are arranged, such as a treaty with Mexico and flood control on the Gila, no greater equalization is advisable.

The question has already been discussed as to whether the water supply from the Colorado is sufficient to meet all future irrigation needs, and the writer will do no more than reiterate his statement that in such a vast arid region, whatever present expectations may be, it is certainly prudent to avoid all unnecessary waste of water.

Mr. Lane raises the interesting question as to what results will follow the release of practically clear water into the silt-filled valley below the Canyon Section of the river. There are so many unknown factors in the problem that, as he points out, no one can predict results with certainty. It can hardly be doubted, however, that the river will pick up a new load of silt in a relatively short distance below the dam. Until it has acquired its new load, there will doubtless be an increase in the tendency to meander through the wider stretches of the valley, combined with a tendency to lower the bed of the stream, and these actions may affect the equilibrium of the stream all the way to its mouth.

H. T. Cory, M. Am. Soc. C. E., has discussed* the effect of Laguna Dam, which had a capacity for storing about 20 000 acre-ft. when it was first completed in 1909. Unfortunately, the effect of this silt storage was largely obscured by the effect of change in river conditions below. The river dropped out of its old channel into Bee River and Volcano Lake in 1909 and the lowering of the bed due thereto was probably greater than that due to the clearing of the water.

Mr. Debler's discussion is that of an advocate. He presents no new facts but puts forward arguments to prove that the large Boulder Canyon Dam should be built by the Federal Government. In some instances his statements are not sufficiently complete to give a true impression of the facts. For example, he quotes Messrs. Preston and Priest as saying that "overflow of the natural banks below Yuma begins at discharges of 30 000 to 50 000 sec-ft., depending on river conditions". This statement is correct, but needs qualification. As shown in the paper (page 317), overflow at these discharges does not occur above the lower end of the Yuma Project where the levees on the two sides begin to recede. The writer's original discussion of flood control and river conditions under different discharges was very carefully prepared and nothing in the discussions presented has indicated the need of a change therein.

* *Transactions*, Am. Soc. C. E., Vol. LXXVI (1913), p. 1204.

One of the chief reasons for considering a development at Mohave Valley is that it is possibly the cheapest place to obtain a strictly flood-control project which would not increase the usable water supply in Mexico.

The writer's presentation of possible power development at Mohave Valley (page 346), was intended to show that the project could be built to have a power value comparable to prospective Southern California projects; the comparison is believed to be essentially fair, but the writer does not advocate development of power at that site before a satisfactory treaty with Mexico has been arranged.

Mr. Debler's statement in regard to development on the Colorado by private capital under adequate Federal and State regulation, that "speedy development can be obtained in this way, along lines, however, as favorable as possible for power but with a minimum regard for irrigation and flood control", implies that power development is in the habit of over-riding irrigation. A review of the power developments that have been made in the arid States will show that this is not the case. Irrigation has not only been fully protected, but has generally been benefited and has rarely paid for the benefits it has received.

As Mr. Debler notes, the writer presents no definite plan of development as a substitute for the Boulder Canyon plan. The Bureau of Reclamation has conducted all investigations made by the Federal Government looking to development on the Colorado. Those investigations were concentrated on the Boulder Canyon Project and did not produce the data necessary to design that project, or any other, so as to conform to a full utilization of the waters of the Colorado. The writer has pointed out this fact and urged action to get the additional information without further delay. The additional information most essential is examination of at least four and preferably seven dam sites with sufficient borings to determine foundation conditions. Given that information, a specific plan can be prepared without much delay. Until that information is available no specific plan can be presented.

These conclusions may be summarized, as follows:

During the past four years as Chief Engineer of the Federal Power Commission, the writer's time has been largely devoted to examining applications for water-power projects to see that "the plans for same * * * shall be such as in the judgment of the Commission will be best adapted to a comprehensive scheme of improvement and utilization for the purposes of navigation, of water-power development, and of other beneficial public uses." As planned by its advocates, the Boulder Canyon Project, with its 605-ft. dam, does not, in his opinion, meet this requirement. Additional field investigations of dam sites immediately above and below Boulder Canyon are necessary to determine with certainty the extent to which the Boulder Canyon Project should be modified to make it fit into the best plan of development.

The re-election in 1924 of Governor Hunt, of Arizona, on a platform definitely opposing the Colorado River Compact indicates that early ratification of that Compact is unlikely. The most active proponents of the Boulder project are primarily interested in securing a large block of power. The project proposed has the physical capacity for appropriating and using more water than the Compact allots to the Lower Basin. Its advocates are not willing to curtail the capacity, and their proposals for legislative limitation have been rejected by the representatives of the upper States. Consequently, in the absence of the Compact the prospects of a compromise between advocates of the Boulder Canyon Project and the upper State interests do not look promising. It seems highly desirable to make the most of this probable delay by completing the field investigations needed and by negotiating a treaty with Mexico.

It is regrettable that the beginning of development on the Colorado should face such a delay, and the writer has given much thought to ways and means of avoiding it. It would seem that the upper States would have no logical ground for objection to any project that is designed and carried out on plans that would prevent the appropriation and use of more water than is allotted to the Lower Basin by the Compact. The Mohave Valley site was suggested as a flood-protection project on this basis. Perhaps the Dewey, combined with some other up-stream reservoir, would serve as well. To date, however, the interests needing flood protection have shown no disposition to look for any solution other than Boulder Canyon.

The Flaming Gorge and Diamond Creek projects are both desirable. Neither will conflict in any way with the terms of the proposed Compact. Although they will not, in themselves, greatly benefit the Lower Basin, they constitute a first step toward the ultimate complete development of the river. Both are authorized under preliminary permits issued by the Federal Power Commission; they will ask for licenses to begin construction in the near future. It is some time since the Federal Power Commission has given these projects consideration, and the writer cannot predict what action it will take, but all things considered, it appears that they offer perhaps the most favorable opportunity for a start on developing the Colorado.