[APPENDIX 29]

HYDROLOGY OF BOULDER CANYON RESERVOIR

WITH REFERENCE ESPECIALLY TO THE HEIGHT OF THE DAM TO BE CONSTRUCTED

By E. B. DEBLER

[OMITTING CHARTS AND APPENDIXES]

HYDROLOGY OF THE BOULDER CANYON RESERVOIR WITH REFERENCE ESPECIALLY TO THE HEIGHT OF DAM TO BE ADOPTED

INTRODUCTION

The Boulder Canyon project act (45 Stat. 1057), approved December 21, 1928, was largely predicated on data developed prior to 1924. The board of engineers appointed in pursuance of S. J. Res. 164, approved May 29, 1928 (45 Stat. 1011), in its report of December 3, 1928, considered some data which became available subsequently but was unable in the limited time available to give detailed consideration to these matters.

The Boulder Canyon act prescribed a minimum reservoir capacity of 20,000,000 acre-feet. The plans covered by the report of the board of engineers contemplated a dam to raise the water level 550 feet, with an initial storage capacity of 26,000,000 acre-feet. Marked reductions in the cost of producing power in southern California resulting from improvements in the art of steam power production make it necessary to achieve the lowest obtainable cost of production to insure the financial success of the project. Unexpectedly large power demands make it desirable to produce the maximum power consistent with engineering feasibility and cost.

Studies made in connection with the 1924 report indicated a declining cost for power with increasing reservoir capacities up to fully 34,000,000 acre-feet.

The present report is based on all data available to date and is directed primarily to the consideration of high level dams with especial attention to schemes of reservoir operation intended to produce a maximum power output consistent with adequate flood protection and an assured irrigation supply.

A number of important features have been given consideration to a degree of detail not properly presentable in this summary. Descriptions thereof will be found appended in a series of exhibits.

BOULDER CANYON STREAM FLOW

Discharge records.

Yuma gage height records are available from 1878 to date but discharge measurements date only from 1902. Gaging stations were established on the main tributaries in the upper basin at various times in and after 1895. Desultory measurements were made at Bullshead, 1902–03; Hardyville, 1905–1907; and Topock, 1917–1922. Dependable records have been obtained at Lees Ferry beginning with 1922, and at Bright Angel and Topock beginning with 1923. Methods in use at Yuma in earlier years, while in keeping with methods in common use at the time, were not adequate to obtain accurate records in periods of high water. Most of these imperfections would tend to indicate discharges higher than actual; some would tend to produce the opposite result. The Colorado River board reported an opinion that Yuma discharges should be reduced 10 per cent.

A careful study has been made of the reported discharges at Yuma in relation to reported discharges at gaging stations in the upper basin where the difficulties of measurement are far less, for the entire period of concurrent records. The results of the present study and the estimates by E. C. LaRue appearing in Water Supply Paper No. 556 compare as follows:

Mean annual discharge at Black Canyon in acre-feet

1897–1901, inclusive:	
Bureau's 1930 estimate	16, 200, 000
LaRue 1925 estimate	17, 700, 000
1902–1922, inclusive:	
Bureau's 1930 estimate from upstream records	17, 600, 000
Bureau's 1930 estimate from Yuma records	17, 300, 000
LaRue 1925 estimate	17, 800, 000

From this study it was concluded that the use of Yuma reported discharges as the basis of estimated flows at Boulder Canyon Dam is conservative. Nevertheless it is believed advisable to assume that Boulder Canyon water supply may be overrated and a general allowance for this purpose is hereinafter explained.

Boulder Canyon flow in relation to operated stations.

The limited records of stream flow on Colorado River make it advisable to use such records to the full extent available, consistent with confidence in the result. For the years 1897–1901, discharge estimates are based on upstream records, no measurements having been made downstream. For 1902–1922 the Yuma records have been used by deducting Gila River discharges and adding Yuma project diversions to obtain Colorado River flow; then applying a correction based on concurrent records of 1926 to 1929, inclusive, at Yuma and Topock, to obtain Topock discharges. The average annual loss from Topock to Yuma was found to be 750,000 acre-feet annually. The resulting estimated discharges at Topock for 1902–1922, together with the reported discharges there for 1923 to 1929 have then been corrected to obtain Boulder Canyon discharges, the correction factor adopted bearing the same relation to the recorded correction factor for Topock to Yuma, as the stream bed and valley floor areas. The loss from Boulder Canyon to Topock was thus found to be 250,000 acre-feet annually, and the loss from Boulder Canyon to Yuma, 1,000,000 acre-feet, or an average of 1,380 second-feet, under present conditions. The distribution of this loss through the year is based on the recorded distribution of loss from Topock to Yuma. While the annual loss is no doubt variable and bears some relation to heights and duration of floods, climatic conditions, etc., lack of sufficient records preclude a proper determination of such variation which is, in any event, comparatively small.

Correction for past and future depletion.

Past and 1928 irrigation development above Boulder Canyon, including transmountain diversions and of anticipated future development within the 50-year repayment period for the Boulder Canyon project have been reviewed, as has upstream power development. For the purposes of this report, Boulder Canyon Dam has been assumed completed in 1938 with development in the 10-year period of 1928–1938 at the average rate from 1928 to 1988. The results may be summarized as follows:

Development above Boulder Canyon

	1928	1938	1988
Irrigated area, acres	1, 717, 000	2, 040, 000	3, 368, 000
Capacity of irrigation reservoirs, acre-feet	662, 000		2, 933, 000
Capacity of power reservoirs, acre-feet	10, 000		8, 100, 000
Transmountain diversions, acre-feet annually	116, 000	180, 000	621, 000
Surface area of irrigation reservoirs, acres	27, 800	60, 000	86, 400
Surface area of power reservoirs, acres	2, 000		172, 000
Mean depletion for irrigation consumptive use, transmountain diversions and reservoir losses, acre-feet anually	2, 760, 000	3, 481, 000	6, 595, 000
Mean annual inflow to Boulder Canyon, acre-feet	15, 730, 000	15, 009, 000	11, 895, 000

Irrigation depletion has been taken at 1.5 acre-feet per acre annually for the first one million acres of development, with all additional areas to have a normal consumptive use of 1.5 acre-feet per acre. Normal reservoir losses are assumed at 4 feet per year over the mean exposed area. These normal losses have been fluctuated for run-off conditions with departure from the normal equal to one-half the departure in the case of run-off.

In estimating future stream flow, no allowance has been made for the hold-over effects of upstream storage estimated to total 11,000,000 acre-feet in capacity by 1988. Its effect would be to increase stream flow at Boulder Canyon during the critical period determining firm power capacity.

No consideration has been given to the ultimate stream flow available at Boulder Canyon since the matter of primary interest is the power output which will be available during the 50-year repayment period for amortization of construction advances. Even the repayment period is so long that the estimate of run-off conditions as far ahead as 1988 may be far astray.

FLOOD CONTROL

Maximum discharges at Boulder Canyon.

In view of the large increase in construction diversion capacity recommended by the Colorado River board, further studies have been made of the annual flood peaks that have passed Boulder Canyon. Expressed in terms of probability, the results are as follows:

Frequency with which discharge will be equaled or exceeded	Discharge in second-feet
Once in 5 years	130, 000
Once in 10 years	160, 000
Once in 20 years	190, 000
Once in 50 years	230, 000
Once in 100 years	260, 000
Once in 500 years	320, 000
Once in 1,000 years	360, 000
Once in 10,000 years	450, 000

During the period of discharge measurements at Yuma, 1902–1929, maximum discharges at Boulder Canyon have equaled or exceeded 100,000 second-feet on 17 separate occasions, 150,000 second-feet on 6 occasions, and 200,000 second-feet on 2 occasions, with a maximum of 210,000 second-feet. The flood of 1884 is estimated to have had a peak of 250,000 to 300,000 second-feet.

The storage capacity behind the construction diversion works is small but a break may nevertheless do some damage. The need for reassurance of downstream interests and the delay in construction and consequent loss in revenue that would result from a flooding of the dam excavation make it advisable to be conservative in provisions for flood diversion during construction. The recommendation of 200,000 second-feet by the Colorado River board, while very conservative, can hardly be considered overdrawn and appears advisable of adoption.

Flood control discharges from reservoir.

At present the floods annually recurring destroy a large part of the vegetal growth appearing on sand bars and in flood-water channels between periods of flood, thus maintaining a condition favorable to rapid erosion by rising floods.

Waters released from Boulder Canyon reservoir will, for all practical purposes, be clear and will issue at far more uniform rates than at present. The result on the river channel, for a long time to come, is extremely problematical. Eventually there will be a number of dams between Boulder Canyon and Laguna Dam with the river passing serenely through a number of slack-water ponds. Waste waters will then be relatively small in volume and their disposal to the Gulf will not be difficult. In the meantime a large part of the flow must be conducted to the Gulf.

Three possibilities at once present themselves. The stream may erode its bed actively until enough gravel is uncovered to produce a stable channel at materially lower elevations; it may degenerate into a shallow bank-eroding stream with a continual tendency to meander and to raise its bed; it may merely assume a highly meandering channel within its flood plain and flow therein in a clear and comparatively narrow, deep stream. The first possibility, if extended to the delta region, would solve the channel capacity problem but would introduce difficulty in maintaining diversion and bank protection works. The flood dangers in the second need not be described. The third possibility, while harmless at ordinary times, would be the most dangerous in time of flood. In view of uncertaintites connected with this situation, it is advisable to make liberal provisions for flood control, and maximum reservoir discharge of 75,000 second-feet with a near maximum flood, such as that of 1884, has been adopted.

Flood volumes.

In arriving at these volumes for the years of record since 1902, consideration has been given to the loss and temporary storage of water in the channels and by overflow between Boulder Canyon and Yuma. The 1884 flood is known to have been the largest flow, both in rate and seasonal volume, that has occurred in Colorado River since settlements were made along that stream. Estimates for the

1884 flood are based on a gage height at Grand Junction, gage heights at Yuma, detailed newspaper accounts of flood conditions in western Colorado, a flood observation at Lees Ferry, high-water marks in Black Canyon, and reports of conditions at Needles by the Atchison, Topeka & Santa Fe Railroad engineers.

Probability theories have been applied to the data with the following results, under conditions of no upstream irrigation:

Occurrence once in—	Run-off, in millions of acre-feet in excess of—				
	40,000 second-feet	50,000 second-feet	60,000 second-feet	75,000 second-feet	100,000 second-feet
10 years	9	7	6	4	2
50 years	13	10	8	6	4
100 years	14	12	9	7	4
500 years	17	14	10	8	5
1,000 years	18	15	11	8	5
1884 flood	22	20	18	15	12

From the above table it would appear that the 1884 flood was one of near maximum proportions. This conclusion is supported by accounts of stream-bed conditions found in the description of the Redrock Bridge in volume 25, Trans. A. S. C. E. In 1881 soundings were made for bedrock. In 1888, after the high flood of 1884, the so-called bedrock of 1881 was found to have been replaced by drift sand, gravel, and bowlders. Apparently the material taken for bedrock in 1881 had been in place for a period bordering on a geologic age permitting extensive compacting.

Flood control capacity and releases.

Studies of the relation of rainfall and run-off in the past 30 years indicates that run-off can be predicted to a considerable degree and reservoir operations conducted to take advantage thereof. Rainfall data for 1884 are meager as the Weather Bureau was not then in existence; nevertheless, there were strong indications toward the end of winter of heavy run-off. It has been concluded that operation can be so conducted as to result in a distributed reservoir outflow substantially as follows:

	Second-feet
April	55, 000
May	65, 000
June	75, 000
July	75, 000
August	50, 000

River losses and irrigation diversions, including the All-American Canal, would reduce these flows by 13,000 second-feet in their passage to Yuma.

With such outflow, the requisite flood control capacity is 9,500,000 acre-feet with upstream development as estimated for 1938 and 4,000,000 acre-feet with upstream development as of 1988. These reservations for flood control have been assumed in all computations for power output. For the period of run-off record, from 1902 to 1929, the largest releases at the reservoir, and corresponding flows at

Yuma, with the All-American Canal constructed and 1938 upstream development would have been as follows:

Mean out-flow in thousands of second-feet

Month	1907	1909	1917	1920	1921
January	21	21	21	21	30
February	21	21	28	20	29
March	35	22	26	21	21
April	25	36	26	22	21
May	21	39	28	25	21
June	20	40	28	24	20
July	48	19	37	29	38
August	36	19	22	19	29
September	21	35	19	19	19
October	23	35	19	19	19
November	32	32	20	20	29
December	30	31	28	28	32

NOTE.—Discharges through the delta below Yuma would be less by 13,000 second-feet in summer and 4,000 second-feet in winter.

IRRIGATION USES

The maximum diversion by the Imperial Canal up to 1928 has been 7,255 second-feet. Yuma discharges are 2,500 second-feet less than at Topock with a stable river at moderate discharges in midsummer and the loss from Boulder Canyon to Topock at such times is estimated at 300 second-feet. The maximum release required from Boulder Canyon under present conditions would then be 10,055 second-feet. By 1938 it is expected that the Los Angeles aqueduct would be in operation with a demand of 1,500 second-feet. The All-American Canal may also be constructed by 1938 with a capacity of 10,000 second-feet for irrigation purposes, but the maximum irrigation use from the canal will not exceed 8,000 second-feet for a long time, such use constituting an increase of fully 50 per cent over present California use. Mexico now uses about 2,000 second-feet and there is little reason to anticipate a greater demand even though a water allocation treaty be consummated. The maximum demand in 1938 is then estimated as follows:

	Second-feet
Present use and loss Boulder Canyon to Yuma	2, 800
Los Angeles Aqueduct	1, 500
All-American Canal	8, 000
Mexico	2, 000
Total	14, 300

Under 1938 conditions power releases equal or exceed this amount and irrigation demands need not be considered in reservoir operations.

Power demands in the lower Colorado River Basin and adjacent regions are expected to result in the construction of power dams on Colorado River below Boulder Canyon at a comparatively early date. Aside from this feature the development of the Parker and Parker-Gila Valley projects will necessitate a diversion dam at Parker, with favorable conditions for moderate storage capacity. Under these conditions it is to be expected that re-regulation of Boulder Canyon outflow to fit irrigation needs will be effected by dams below Boulder Canyon and that momentary irrigation demands need never be considered in Boulder Canyon operations. In the event irrigation plans should be perfected without provision for such re-regulating storage, it may in time become necessary to add the Bullshead Reservoir to the Boulder Canyon project. Increased power output will make such addition self-supporting.

The discharges necessitated by power requirements will assure an adequate annual irrigation supply at all times.

SILT

The Colorado River board adopted a figure of 137,000 acre-feet as the annual silt load of the Colorado River compared with a previous bureau estimate of 80,000 acre-feet. The estimates of upstream development contemplate reservoirs with a total capacity of 11,000,000 acre-feet, of which some 8,000,000 acre-feet would be in power reservoirs principally at the lower ends of the main tributaries. Construction of the Bridge Canyon Dam is included with an active storage capacity of 1,000,000 acre-feet.

The upper reservoirs will materially reduce silt flow while Bridge Canyon would almost completely stop silt flow into Boulder Canyon. The silt accumulation during the repayment period has been assumed at 3,000,000 acre-feet with a maximum deposit at a level slightly below the average storage level.

POWER OUTPUT

Plant efficiency.

The following efficiencies have been assumed in all operations:

	Per cent
Penstocks	97
Turbines	90
Generators	96
Transformers	99
Net over-all efficiency	83

Firm power.

Run-off records on Colorado River extend over a period of 37 years from 1895 to 1932. No other stream in this locality has longer records. Great Salt Lake obtains most of its inflow from the western slope of mountains, the eastern side of which drain to the Colorado River. Inflow to Great Salt Lake can be estimated for the past 78 years from known lake levels, known lake area, estimated evaporation rates, and allowances for increasing depletions for irrigation uses. From such estimates it appears that there have been three periods of low run-off in 78 years, each of which closely approximated that of 1900–1905, inclusive, in total run-off for the 6-year period, one of these having a total 6 per cent below and the other 4 per cent above the late period.

There are, furthermore, other periods with conditions only moderately better. Firm power should, therefore, be based on the output obtainable in the low run-off period immediately following 1900. It has been decided that a maximum monthly shortage of 10 per cent in firm power output will be permissible.

With declining storage, increasing outflow is necessary for full power output. When such depletion is carried too far, undesirable results obtain in that the maximum power shortage becomes unduly high, irrigation shortages are invited, and total power output during the critical period is depressed by the continuance of low heads. To meet this situation, an empirical rule has been adopted for a maximum permissible draft of 15,000 second-feet under 1938 conditions whenever the storage level is below 15,000,000 acre-feet; and of 14,000 second-feet under 1988 conditions whenever the storage level falls below 15,000,000 acre-feet.

The resulting firm power for various maximum high-water levels is as follows:

Maximum water level, feet	Raise in river (feet)	Firm power output under 1938 conditions (horsepower, continuous output)	Firm power output under 1988 conditions (horsepower, continuous output)
1, 204	557	608, 000	543, 000
1, 222	575	650, 000	582, 000
1, 229	582	663, 000	594, 000

Dump power output.

Except during the critical periods of low run-off, large amounts of power may be produced in addition to the firm power. This report assumes power installations such that the firm power, if generated at a uniform rate would constitute 65 per cent of the installation, in effect permitting a load factor as low as 65 per cent. Plant capacity at any time not needed for the production of firm power may be utilized to produce dump power provided a suitable market be found.

A detailed study of the relation of accumulated precipitation in winter and early spring to the run-off in the succeeding summer produced results permitting a rather extensive use of flood storage capacity for power production without encroaching upon the primary purpose of such storage for flood control and without endangering firm power output in case a protracted period of low run-off should develop. The details of these provisions are so complicated that they will not be reproduced here but may be consulted in Exhibit H.

Heights of dam considered.

The Colorado River Board report was based on consideration of a dam having a top elevation (exclusive of parapet) of 1,207 with ordinary high-water level fixed at elevation 1,197, a 550-foot raise of the low-water surface of the river. It has now been concluded that the 10-foot freeboard heretofore contemplated may safely be reduced to 3 feet, in view of the extremely rare occasions when the upper portion of the flood-control storage will be utilized. As the raise in water level has become the more commonly used term in designating the size of dam, that term will also here be used. The three levels considered are as follows:

Raise in water surface, feet	Top of dam, elevation	High water	Capacity at high water in 1938	Capacity at high water in 1988
			Acre-feet	*Acre-feet*
557	[1] 1, 207	1, 204	27, 000, 000	24, 000, 000
575	1, 225	1, 222	29, 500, 000	26, 500, 000
582	1, 232	1, 229	30, 500, 000	27, 500, 000

[1] Same as dam considered by Colorado River Board.

Summary of power output.

The results of the computations on the bases heretofore outlined are herein summarized.

Raise in water surface Elevation of top of dam High-water level	557 feet 1,207 feet 1,204 feet		575 feet 1,225 feet 1,222 feet		582 feet 1,232 feet 1,229 feet	
Upstream development as of	1938	1988	1938	1988	1938	1988
Reservoir capacity, acre-feet	27,000,000	24,000,000	29,500,000	26,500,000	30,500,000	27,500,000
OUTPUT IN HORSEPOWER						
Plant capacity	935,000	935,000	1,000,000	1,000,000	1,020,000	1,020,000
Continuous firm output	608,000	543,000	650,000	582,000	663,000	594,000
Average possible output, 1897–1929	837,000	722,000	887,000	754,000	901,000	765,000
Minimum output	547,000	489,000	585,000	524,000	597,000	535,000
ANNUAL OUTPUT IN MILLIONS OF KILOWATT-HOURS						
Firm power	3,970	3,540	4,240	3,800	4,330	3,880
Average total for 1897–1929	5,460	4,720	5,790	4,920	5,880	4,990

Reservoir operations and related data bearing on the reservoir with 575-foot raise in water surface are presented as Plates 1 and 2. [Omitted]

The power analysis indicates a large amount of dump power available over a major portion of time provided adequate equipment be installed for its generation. If contractors for firm power should so coordinate their sources of power as to be able to utilize Boulder Canyon power at a 100 per cent load factor, no dump power would be available except through the provision of additional power units. The price obtainable for dump power may not warrant such an undertaking. In view of these uncertainties it is inadvisable to take dump power into consideration in determining relative advantages for different heights of dam.

Determinations of firm power output have necessitated extensive estimates in base data. Due caution dictates that the results be scaled down at least until new and additional data obtainable only in the course of a number of years of observation, particularly of stream flow and rainfall, shall confirm or alter the estimates made. It is proposed that the comparison be based on firm power output 10 per cent less than that computed for conditions of 1938.

Firm power output under 1938 conditions:

Raise in water surface	Computed firm power output	Adopted firm power output	Adopted annual output of firm power
Feet	*Horsepower*	*Horsepower*	*Kilowatt-hours*
557	608,000	547,000	3,600,000,000
575	650,000	585,000	3,800,000,000
582	663,000	597,000	3,900,000,000

COST OF POWER OBTAINABLE BY RAISING DAM

The selling price of falling water has tentatively been announced at 1.63 mills per kilowatt-hour of firm power. Estimates have been made on the same basis, of the increase in construction and annual costs occasioned by raising the dam. These costs have been compared with the increase in output, in the following table:

	Increase in raise of water surface	
	From 557 to 575 feet	From 575 to 582 feet
Increase in construction cost	$3, 134, 000	$1, 258, 000
Increase in annual cost:		
Interest and amortization	145, 893	58, 545
Operation and maintenance		
Depreciation	1, 355	529
Total	147, 248	59, 074
Increase in annual power output, kilowatt-hours	269, 000, 000	79, 000, 000
Cost per kilowatt-hour for the increased output	0. 00055	0. 00076

The above table indicates a fast-mounting cost for the increased energy obtainable with a raise in height of dam, but with such costs still well below the cost with the 550-foot or 557-foot dam, even though the height be increased to 582 feet.

INTERFERENCE WITH BRIDGE CANYON SITE

At the head of the Boulder Canyon Reservoir lies the Bridge Canyon dam site, considered the most desirable of the sites on that section of the river. River level there is at elevation 1,207 feet, with 10,000 second-feet flowing.

The extent of interference by Boulder Canyon is presented in the following table:

	With 1938 development	With 1988 development
557-FOOT DAM AT BOULDER CANYON		
Maximum water level at Boulder [1]	1, 204	1, 204
575-FOOT DAM AT BOULDER CANYON		
Maximum water level at Boulder	1, 222	1, 222
Maximum encroachment ... feet	16	16
Greatest encroachment, 1897–1929 ... do	3	10
Time encroached, 1897–1929 ... per cent	0. 3	13
582-FOOT DAM AT BOULDER CANYON		
Maximum water level at Boulder	1, 229	1, 229
Maximum encroachment ... feet	23	23
Greatest encroachment, 1897–1929 ... do	8	15
Time encroached, 1897–1929 ... per cent	8	25

[1] Interference negligible, limited to backwater effect at high flood.

With a 557-foot dam there is negligible encroachment. With the 575-foot and 582-foot dams, the maximum encroachment is 16 feet and 23 feet, respectively, this result obtaining when a full reservoir at Boulder Canyon would be concurrent with a low discharge at Bridge Canyon.

Stream-flow conditions at Bridge Canyon resemble conditions at Bright Angel more nearly than at other stations and at that station there is a rise of 25 feet in water level for a discharge of 150,000 second-feet. The still-water level with a full reservoir for a 582-foot dam would then roughly equal the level obtaining at present with a flood of 150,000 second-feet.

With the 575-foot and 582-foot dams there would be a backwater effect whenever the reservoir would be full. With very high floods this effect might amount to as much as 3 feet for the 575-foot dam and as high as 8 feet for the 582-foot dam.

From the standpoint of power production at Bridge Canyon there would then be a material, though minor reduction in power output with a 575-foot dam at Boulder Canyon, increasing rapidly with higher dams. From the standpoint of design, to care for flood levels, the Bridge Canyon power site would not be greatly affected with heights of dam at Boulder Canyon up to 582 feet.

CONCLUSIONS

1. For adequate flood control a capacity of 9,500,000 acre-feet should be reserved under 1938 conditions of upstream development declining to 4,000,000 acre-feet in the 50-year repayment period to 1988.

2. Firm power output obtainable upon completion of Boulder Canyon Dam in 1938, with a 10 per cent reduction on account of uncertainties in available base data, would be as follows:

Raise in water level (feet)	Elevation of water surface	Elevation of top of dam (exclusive of parapet)	Continuous output	Annual output
			Horsepower	*Kilowatt-hours*
557	1, 204	[1] 1, 207	547, 000	3, 600, 000, 000
575	1, 222	1, 225	585, 000	3, 800, 000, 000
582	1, 229	1, 232	597, 000	3, 900, 000, 000

[1] Same dam as reported by Colorado River Board, with freeboard reduced 7 feet, raising water level accordingly.

It is estimated that these outputs can be maintained throughout the repayment period, particularly if other power dams are constructed along Colorado River.

3. Large amounts of dump power can be produced in seasons of high run-off without encroaching on flood control, irrigation, or the production of firm power. The cost and market for this power are so uncertain that no income should now be counted on from this source.

4. Raising the dam reduces the average cost of firm power output. There are indications, however, that this will not hold true for heights much beyond 582 feet.

5. For Boulder Canyon dams up to 575 feet, the power value of Bridge Canyon dam site would be affected but little and construction cost at Bridge Canyon would not be appreciably increased. For greater heights interference progresses steadily.

E. B. Debler.