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IRRIGATION AND RIVER CONTROL
IN THE
COLORADO RIVER DELTA.

BY

H. T. CORY, M. Am. Soc. C. E.

WITH DISCUSSION BY

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From almost every point of view, the Lower Colorado River, and particularly the Colorado Delta, is extremely interesting. Ever since its examination and description by members of Lieut. Williamson's exploration party in 1850, the various features, geological, geographical, anthropological, engineering, and otherwise, have been written about. In 1905 the diversion of the Colorado River into the Salton Sea and the events which followed it were so spectacular as to result in world-wide notoriety.

While engaged in re-diverting the river, the writer became impressed with the fact that the experience and information obtained should be made available to the Engineering Profession, and since then he has constantly been gathering data to that end. In February, 1907, a general paper on the subject† was contributed to this Society by C. E. Grunsky, M. Am. Soc. C. E., then Consulting Engineer to the Secretary of the Interior in United States Reclamation Service matters; so that, before giving detailed information, it seemed best to wait until time should have revealed the strong and weak points

* Presented at the meeting of January 8th, 1913.

† "The Lower Colorado River and the Salton Basin," *Transactions, Am. Soc. C. E.*, Vol. LIX, p. 1.

of construction and methods. Since then, experience with the control of the Lower Colorado River, and as local executive head of the immense irrigation project of the Imperial Valley, has brought the conclusion that the various possible vicissitudes of irrigation enterprises in the United States have been so well exemplified in the region as to justify setting forth such experience in considerable detail.

Ordinarily, more information is secured from failure than from success; consequently, no apology should be due for pointing out failures as well as successes in a paper, the functions of which are primarily to furnish useful engineering information.

THE COLORADO RIVER.

The United States Geological Survey has observed the discharge of the Colorado and its several tributaries since 1895, and the results are to be found in its Annual Reports and later in the Water Supply and Irrigation Papers, especially Nos. 249 and 269, on the Colorado River Basin. At various times 169 gauging stations have been maintained, and there are 76 at present.

General Discharge Characteristics.—From the data obtained at these stations, the discharge characteristics of the tributaries and main Colorado River are pretty well determined. The discharge records of the Green River, at Green River, Utah, the lowest gauging station above its mouth, and where the drainage area above it is 38 200 sq. miles, indicate a maximum flow of about 75 000 sec-ft., a minimum flow of about 700 sec-ft., and an average annual run-off of about 5 000 000 acre-ft. The greatest discharge is in June, averaging about 1 600 000 acre-ft.; the annual rise starts about April 1st, reaches its peak in the middle of June, and has passed by August 1st.

The data obtained on the Grand River indicate a proportionately great run-off and very much the same distribution throughout the year. The records, taken at Turley, N. Mex., on the San Juan River until December, 1908, and since then at Blanco, indicate an ordinary flood maximum of about 15 000 sec-ft., a minimum of 75 sec-ft., and an average annual discharge of 1 000 000 acre-ft., but with a much longer period of summer flood than in the Green and Grand.

The maximum flood discharge of the Little Colorado when it enters the Colorado River is not known, but is probably about 50 000 sec-ft. The floods are short and violent, and carry large quantities of silt in

suspension, in which regard the stream is similar to the Gila and Salt Rivers.

The Gila at Yuma is often dry, and has a maximum flashy flood discharge of probably 185 000 sec-ft. with a total average annual run-off of 2 750 000 acre-ft. Flashy floods have been known to occur in every month of the year except May, June, and July, at which times the Colorado has its maximum flow.

Power.—Excellent reservoir sites have been found on the headwaters and along the main channels of the various tributaries, by utilizing which a considerable portion of the flow could be stored for power and irrigation. Such storage would equalize the discharge, that for power having the greater relative influence. There are at present no water-power plants of any importance whatever in the whole drainage area of the Green River. A total of approximately 40 000 h.p. has been developed in the Grand, 7 000 in the San Juan, and 20 000 in the Gila Basin, in connection with irrigation construction. No data seem to be available as to the amount of energy which it is commercially practicable to develop under existing conditions on these various streams—it is obvious that there must be a vast difference between the figures for theoretically possible and for commercially feasible developments.

Irrigation.—The water of the streams making up the Colorado is already utilized for irrigation to a considerable extent. The oldest and largest development in the basin is perhaps that on the upper Green River, in Wyoming. Recently, large irrigation systems have been constructed in the Duchesne River Basin, and there is considerable irrigation around Vernal, and also Green River, Utah. Along the White and Yampa Rivers, in Colorado, meadow irrigation is extensively practiced, and projects are on foot for the irrigation of from 200 000 to 300 000 acres in this section.

Similarly, in the Grand Basin, there are extensive meadow lands in the upper part, and a half dozen small projects in contemplation for the Middle Basin which together would irrigate about 35 000 acres. In the Lower Basin is the Grand Valley Project, covering an irrigable area of 70 000 acres, and the Uncompahgre Valley Project, which, when completed, will irrigate about 150 000 acres, both by the United States Reclamation Service. Under other schemes, from 40 000 to 50 000 acres more will be irrigated.

Quite a little land along the San Juan, Animas, Pine, Florida, and La Plata Rivers, and the small tributaries of the San Juan, in Colorado, is now under cultivation, and also several thousand acres of valley land in New Mexico, but, as yet, irrigation has largely been confined to the bottom lands. The greatest probability of future irrigation development in this basin is in San Juan County, New Mexico, where it is said that probably 1 000 000 acres of fertile lands are excellently adapted for irrigation and for which the water supply is ample. The average annual run-off at Turley dam site is probably more than 1 000 000 acre-ft., the reservoir at that point having a capacity of 1 500 000 acre-ft., and the total stream flow at Shiprock, below the mouths of the Las Animas and La Plata Rivers, is more than 3 000 000 acre-ft.

In the Little Colorado River Basin there are scattered a few relatively unimportant patches of irrigated land, and the U. S. Reclamation Service has investigated and found feasible the irrigation of approximately 70 000 acres in the vicinity of Holbrook, by constructing storage reservoirs at St. John's and Woodruff, Ariz.

There are also irrigation possibilities in the Virgin River and Bill Williams Fork Basins, but their total area is relatively unimportant, as far as concerns their effect on floods, or the irrigation of lower lands.

There are excellent opportunities for irrigation in the Gila River Basin, chief of which are the projects examined by the U. S. Reclamation Service in the vicinity of Alma and Lordsburgh, N. Mex. At the latter point there are 250 000 acres of almost unbroken and very fertile land which could be irrigated by the stored water of the Gila River, although at considerable expense. Other good storage sites exist at San Carlos on the Gila, and at Roosevelt on the Salt, the latter having already been utilized by the U. S. Reclamation Service by building the famous Roosevelt Dam, behind which can be stored 1 100 000 acre-ft. of water. With this water, about 200 000 acres of land will be irrigated directly, and power will be generated for pumping water to nearly 60 000 acres more. In addition, there is an excellent reservoir site on the Verde River above McDowell, and large tracts of land on the Gila River in the vicinity of Solomonville and of Florence, Ariz., are now irrigated.

Along the Colorado River itself there are storage sites at Bull-head Point and at another point about 6 miles above the Laguna Dam

near Yuma, while there are irrigable lands between Mohave and Yuma aggregating some 400 000 acres.

Table 1 is a summary of the areas above Yuma which are now irrigated, in a technical sense, although much of this territory, no doubt, is watered in a very unsatisfactory manner.

TABLE 1.

District.	Acres.	Acres.
Colorado River direct.....	19 000	
Green River and tributaries.....	255 000	
Grand River and tributaries.....	305 000	
Fremont River.....	16 000	
San Juan River and tributaries.....	57 000	
Little Colorado River and tributaries.....	12 000	
Virgin River.....	16 000	
Gila River and tributaries.....	230 000	
Scattering (other tributaries).....	7 500	917 500

ADDITIONAL IRRIGABLE LANDS ABOVE THE YUMA VALLEY.

Above the Grand Cañon.....	450 000	
Colorado River Valley below Mohave.....	400 000	
The Gila Drainage Basin.....	400 000	1 250 000

IRRIGABLE LANDS IN THE DELTA.

Yuma Project.....	90 000	
Imperial Valley in the United States.....	600 000	
Imperial Valley in Mexico.....	800 000	
Other lands in Mexico—east of the Colorado.....	200 000	1 190 000
Grand total.....		3 357 500 acres.

TABLE 2.—APPROXIMATE STORAGE POSSIBILITIES OF THE BASIN.

	Acre-feet.
Green River, including the Brown Park Reservoir site.....	3 000 000
Grand River, including the Kremmling Reservoir site.....	3 000 000
Little Colorado.....	50 000
Bill Williams Fork.....	100 000
San Juan.....	1 500 000
Virgin River.....	2 500 000
Gila River.....	2 500 000
Colorado, below Mohave and above Yuma.....	
Total.....	10 150 000 +

It must be borne in mind that all the figures in Tables 1 and 2 are for developments which are theoretically possible, and they would

have to be more or less seriously reduced to be correct for commercially feasible developments, on account of the excessive cost and the formidable character of the silt problem.

Discharge at Yuma.—Observations of the gauge heights of the Colorado River have been made by the Southern Pacific Company on its bridge at Yuma since 1878. The U. S. Geological Survey has maintained a gauging station at this point since 1895, using rating curves for discharge reductions until 1902, since which time careful current-meter observations have been made every 3 or 4 days. Table 3 contains the data thus collected for the 18-year period, 1894 to 1911, reduced to averages.

TABLE 3.—ANNUAL DISCHARGE OF COLORADO RIVER, AT YUMA, ARIZONA, FROM 1894 TO 1911, INCLUSIVE.

Year.	Mean, in cubic feet per second.	Total acre-feet.
1894.....	7 400	5 390 000
1895.....	9 900	7 162 000
1896.....	9 000	6 515 000
1897.....	12 400	9 039 000
1898.....	9 100	6 581 000
1899.....	12 200	8 870 000
1900.....	9 400	6 798 000
1901.....	11 700	8 495 000
1902.....	8 400	6 127 000
1903.....	15 600	11 329 000
1904.....	13 900	10 119 000
1905.....	27 300	19 710 000
1906.....	26 800	19 475 000
1907.....	35 100	25 500 000
1908.....	18 900	13 700 000
1909.....	35 800	26 000 000
1910.....	19 700	14 335 000
1911.....	24 600	17 889 000
Mean.....	17 070	12 388 000

The minimum annual discharge was observed in 1894, and the maximum in 1909. The discharge has been strikingly greater since 1902 than for previous years, but too much dependence should not be placed on the data obtained prior to 1902, at which time very frequent current-meter observations were commenced. The lowest discharge was probably 2 400 sec.-ft. in January, 1894, the average for that month being only 2 510 sec.-ft.; the greatest was 149 500 sec.-ft. on June 24th, 1909. The smallest total discharge for one month was 154 100 acre-ft. in January, 1894, and the greatest was 6 250 000 acre-ft. in June, 1909.

TABLE 4.—MEAN MONTHLY DISCHARGE OF COLORADO RIVER,
1894 TO 1911, INCLUSIVE.

Month.	Cubic feet per second.	Total, mean monthly, in acre-feet.
January.....	7 340	450 400
February.....	8 370	466 000
March.....	12 830	767 800
April.....	16 380	973 200
May.....	34 280	2 104 200
June.....	50 500	3 000 000
July.....	29 630	1 819 200
August.....	13 500	892 700
September.....	9 880	586 300
October.....	8 400	519 000
November.....	6 600	395 000
December.....	7 060	483 200
Totals.....	17 080	12 369 400

The record for 1908 is given by months in Table 5 as typical of the monthly variation. The lesser disturbances caused by the floods from the Gila in the autumn are very well shown; in this case, the maximum discharge from this source occurs in December, instead of from the Colorado in June.

TABLE 5.—MONTHLY DISCHARGE OF COLORADO RIVER
AT YUMA, ARIZONA, FOR 1908.
(Drainage area, 260 000 sq. miles.)

Month.	DISCHARGE, IN SECOND-FEET.				RUN-OFF.	
	Maximum.	Minimum.	Mean.	Persquare mile.	Depth, in inches, on drainage area.	Total, in acre-feet.
January.....	7 400	5 600	6 320	0.028	0.03	389 000
February.....	45 000	6 300	14 200	0.063	0.07	817 000
March.....	33 000	10 100	16 100	0.072	0.08	990 000
April.....	35 000	12 900	17 800	0.079	0.09	1 060 000
May.....	33 000	23 000	27 200	0.121	0.14	1 670 000
June.....	61 700	30 000	42 900	0.191	0.21	2 550 000
July.....	53 800	18 900	32 600	0.145	0.17	2 000 000
August.....	36 100	18 800	24 300	0.107	0.12	1 490 000
September.....	19 300	7 000	11 400	0.051	0.06	678 000
October.....	20 600	6 600	9 510	0.042	0.05	585 000
November.....	10 200	6 000	8 000	0.036	0.04	481 000
December.....	72 500	6 000	15 900	0.071	0.08	978 000
The year.....	72 500	5 600	18 900	0.084	1.14	13 700 000

Necessity for Storage.—The figures for the discharge at Yuma show that, in an ordinary dry year, the Colorado, without regulation, will serve an area not greatly exceeding 500 000 acres. On the other hand, in

an ordinary dry year, with fairly complete regulation—that is, with 2 000 000 acre-ft. of water storage—this river will serve 1 500 000 acres, and any supply held over from wet to dry years would add to the reserve. It is conservative to assume at present that no reservoir site on the Colorado below the Grand Cañon can be utilized, on account of the apparent absence of rock foundations for dams in the river, and, even if other things were favorable, the tremendous quantity of silt in the water means a heavy reduction in the reservoir capacity which could be obtained. Indeed, it has been seriously suggested that by the construction of a series of such dams, the silting up would in time create large areas of excellent land, one above the other.

Above the Grand Cañon, the Kremmling Reservoir site, on the Grand River, and the Brown Park Reservoir site, on the Green River, would together store approximately 4 500 000 acre-ft., and thereby add much more than 1 000 000 acres to the irrigable lands of the Arid West. When it is considered that the present irrigated area of Southern California, exclusive of the Imperial Valley, is less than 300 000 acres, the potentiality of storage along the Colorado is startling.

Another very important feature of water storage along the river is the marked effect it would have in decreasing the difficulty of controlling the Lower Colorado River. Levee construction and bank protection must obviously be designed to guard against maximum floods, and it is these which the storage basins would affect to the greatest degree. The completion of the Roosevelt Dam, which will hold back 1 100 000 acre-ft. on the Salt River, will in future undoubtedly reduce to a considerable extent the dreaded floods from the Gila River.

Rise of the Bed at Yuma.—If the measured discharge of the river at various heights is used in making a rating curve, and this curve is extended back, by means of the gauge readings, to 1878, the results would indicate that the quantity of water formerly passing Yuma was materially less than at present. As a matter of fact, the average low-water plane has constantly risen, and a comparison of the gauge heights by 10-year periods beginning with 1878 shows the following average elevations:

1878 to 1889.....	114.5 ft.
1890 " 1899.....	116.6 "
1900 " 1909.....	117.4 "

The low-water plane at the end of 1909, however, was $3\frac{1}{2}$ ft. lower than during any of the six preceding years, which included the period of diversion into the Salton Sea. Indeed, it was lower, by more than $1\frac{1}{2}$ ft., than 20 years ago, and only 0.8 ft. higher than during 1878-79. The reasons for this interesting condition of affairs will be considered later.

Following conventional practice, the endcavor was made for a long time to establish a rating curve for the Yuma gauging station, but this was found to be impossible. The reason is that the bed is eroded during high water and silted up during lower stages, thus fundamentally changing the cross-section, not only for different gauge heights, but for the same gauge heights at the beginning and end of

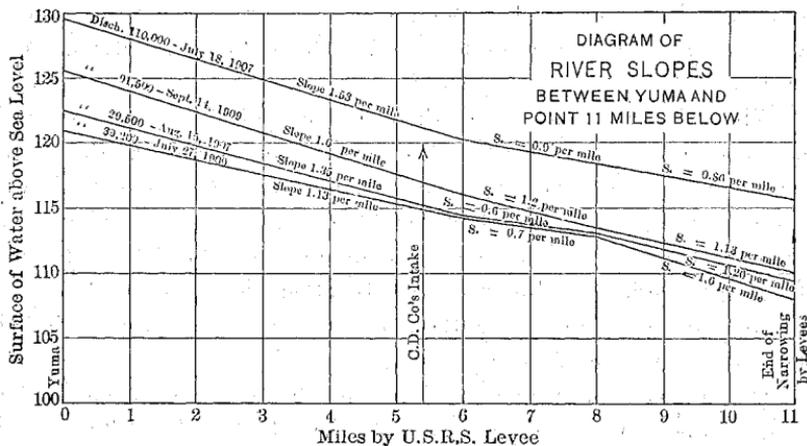


FIG. 2.

a high-water period. The reason for the exaggerated extent of such action is as follows: The Colorado at all times carries considerable silt, the quantity and character, of course, depending on the velocity of the water. Assuming a given discharge, and conditions of equilibrium, the bed of the river will have a given slope, the water will have a certain velocity, and will carry a certain quantity of sediment, none of which will exceed a definite size or specific gravity. If the volume of water increases, the water section and hydraulic radius will increase, and will result in greater velocity, which will give greater silt-carrying capacity. Conditions at the outfall or mouth are determined and temporarily unchangeable, therefore it follows that the grade of the river will automatically tend to flatten itself by

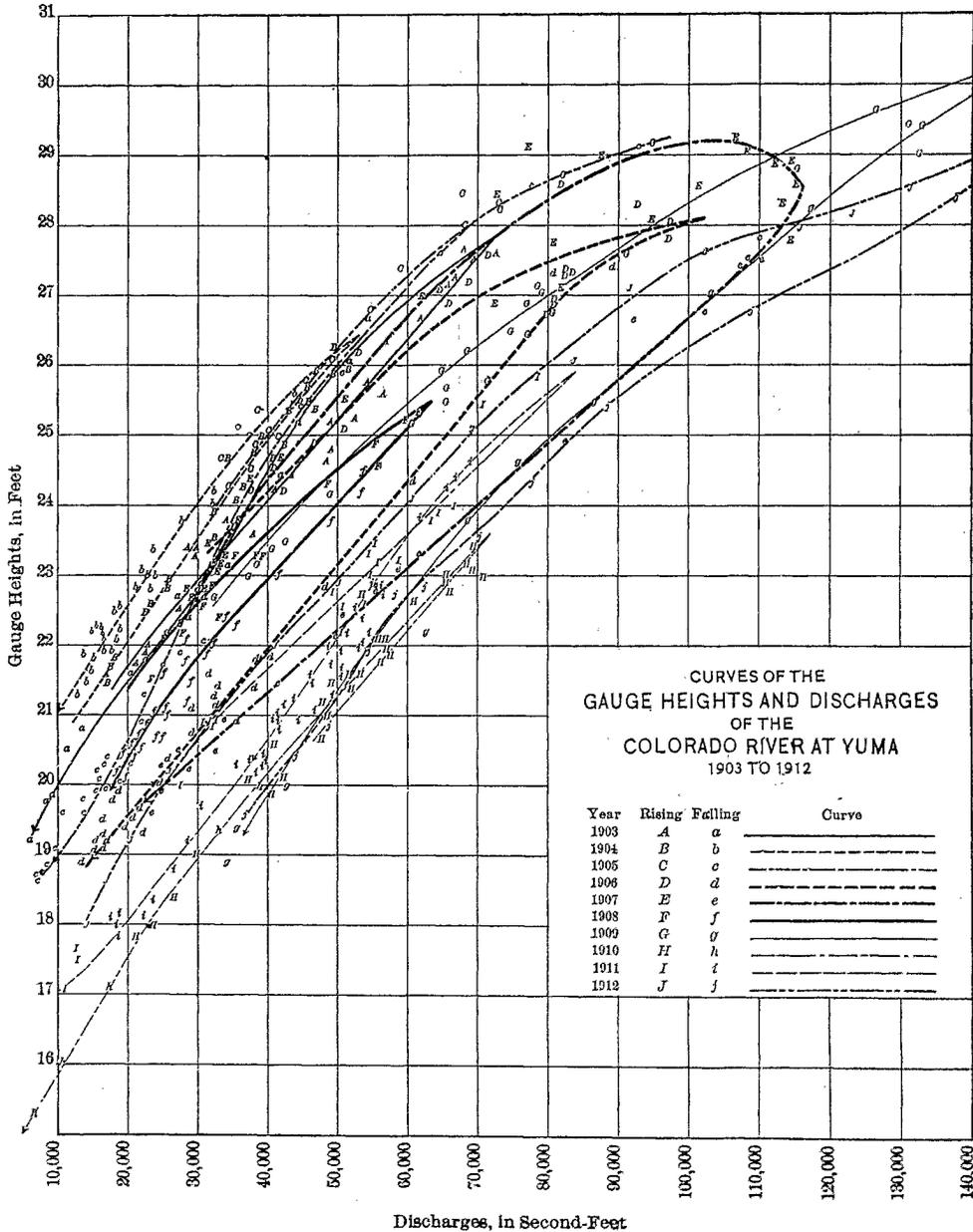
picking up additional quantities of silt and carrying them along. When the volume of water decreases, the velocity will slacken, resulting in carrying less silt, and the bottom will rise with increasing slope until equilibrium is again established. This condition of affairs results in surprisingly great changes at Yuma during long periods of high water. In 1907 and again in 1909 it was found that for an increase of 10 ft. in the gauge height there was a lowering of the bed of approximately 30 ft., making the total increase in depth of water almost 40 ft. In other words, the grade line drawn from the bottom of the channel at Yuma to the average water surface in the Gulf of California had 30 ft. more fall, from Yuma down, at the beginning of the summer floods of 1907 and 1909, than when the peaks had just been passed. A few weeks after the first of these floods had entirely passed, the bed of the river had been restored to its usual low-water position.

When flashy floods occur, there is not sufficient time for this action to take place to a marked degree, and therefore the flashy rise of November 28th, 1905, having an estimated discharge of only 115 000 sec.-ft., reached a gauge height of 31.3 ft., whereas the maximum discharge in the summer flood of 1909 was 149 500 sec.-ft. and the gauge height was only 29.2 ft. In other words, the flashy floods do not have time to render the river channel more efficient before the maximum demand is made on it.

The increase in the gauge height of the low-water plane is due to the same general action. As the river builds the delta farther and farther into the Gulf of California, the bed must rise all along the line, of course, taking averages of considerable periods of time. According to Capt. J. H. Mellon, of Yuma, Ariz., who for a great many years navigated the Lower Colorado, the delta fan has extended out into the Gulf more than 6 miles in the past 40 years. Assuming the fall of the river in the lower reaches at 1.2 ft. per mile, the rise in the bed should average 1.2 ft. in $6\frac{2}{3}$ years, or approximately 0.2 ft. per year. These figures are about what the hydrographs seem to show, namely, 2 ft. per 10-year period.

Effect of 1909 Flood.—The fact has been mentioned that the low-water plane at the end of 1909 was only 0.8 ft. higher than during 1879, and this becomes much more striking when the general elevations for the entire period are shown by a curve. There were two

PLATE XLII.
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 COLORADO RIVER DELTA.



factors which tended to produce such a result: first, the diversion of the river through the Abejas to the west during the summer flood of 1908, and the lowering of the river bed at that point; and second, the effect of the Laguna Weir basin, which existed as such for the first time that year.

It seems very probable that the Abejas diversion was the smaller influence, in spite of the fact that at the time it was generally considered to be the only factor of importance. Undoubtedly, the bed of the river, and consequently the surface of the water, lowered rapidly while the diversion was becoming an accomplished fact. The amount of such lowering could not have been more than a very few feet at most, although it probably seemed much greater to nervous and frightened observers.

Doubtless it was an important factor that the Laguna Weir had been completed just before the beginning of that year's summer flood, and created a reservoir having a capacity of perhaps 20 000 acre-ft. The waters of the Colorado, heavily laden with silt, were here stilled and their contents deposited. The large volume of water which passed over the dam—the greatest ever recorded on the river itself—contained little more silt than it would ordinarily during low-water stages. Consequently, it picked up and carried along the silt to an unprecedented extent. As the waters receded, the bed was built back to a very much less extent, because there was still an extraordinarily small quantity of silt in the water. Indeed, during this one season, the basin formed by the Laguna Weir was completely filled and some 20 000 acre-ft. of mud were deposited out of the Colorado at this point instead of being spread along the river bed thence to the Gulf.

Unfortunately, no sediment observations were made at Yuma during this flood period. Had this been done, the influence of the Laguna Basin on the low-water plane would doubtless have been approximately ascertainable. In any event, the gauge heights at Yuma, for discharges of 30 000 and 10 000 sec-ft., respectively, platted as ordinates, with the times as abscissas, as in Fig. 3,* for the period of 1902 to 1912, show very clearly that there has been no serious grade recession at Yuma due to the Abejas diversion.

* This method of plating seems to be the only one possible to show much relation, if any at all, between gauge height, discharge, and time at the Yuma gauging station.

GAUGE HEIGHTS OF COLORADO RIVER AT YUMA
FOR DISCHARGES OF 30000 AND 10000 CU. FT. PER SEC.
JANUARY, 1903, TO JUNE, 1912.

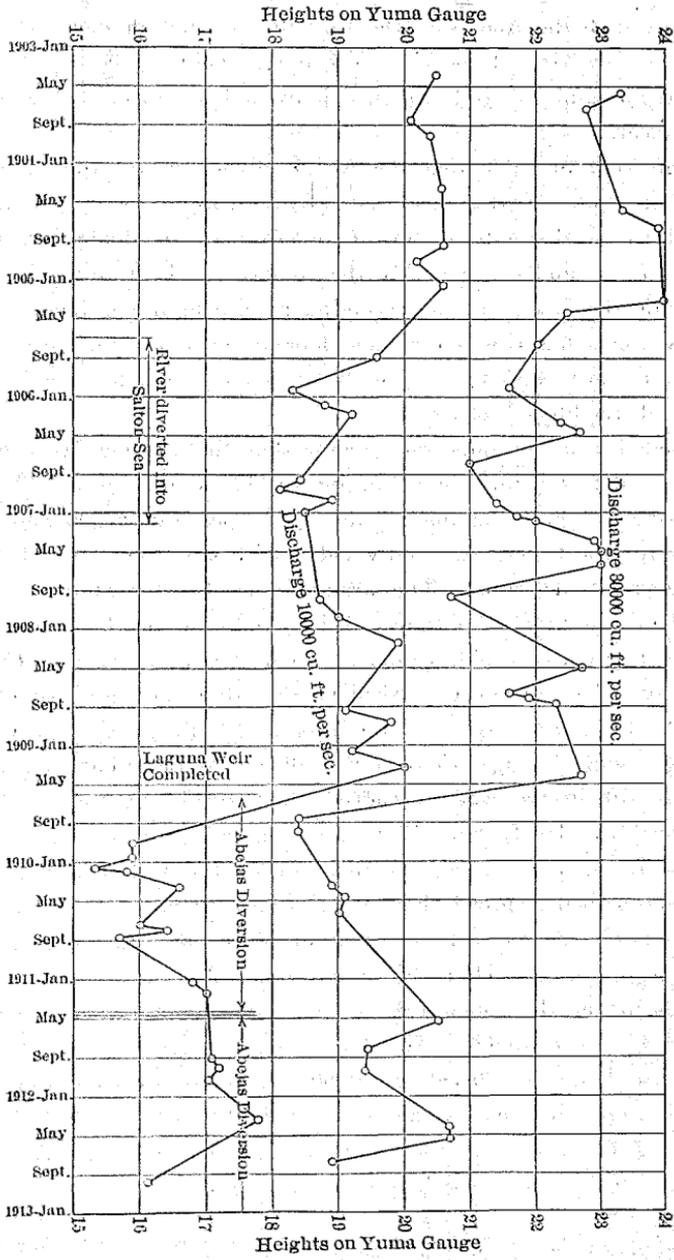


Fig. 3.

Silt.—Professor C. B. Collingwood, of the University of Arizona Agricultural Experiment Station, examined the silt contents of the Colorado River water at Yuma for a period of 7 months, beginning with August, 1892. One pint of water was taken each day and evaporated, and the sum of the daily residues for each month was then weighed and analyzed. The results varied from a minimum of 1 part of sediment to 613 parts of water in January, 1893, to a maximum of 1 to 97 in October, 1902, and an average of 1 to 388, the ratio of dry material to weight of water being 1 to 277. The corresponding ratio in the Mississippi is 1 to 1500; the Nile, 1 to 1900; the Danube, 1 to 3060. The average value of the fertilizing material was computed at \$3.22 per acre-ft.*

Later, January 1st to December 31st, 1904, Professor R. H. Forbes, now Director of the same Experiment Station, made a careful study of the quantity of silt,† and the relation of irrigating sediments to field crops.‡ It was found that the quantity of silt varied from 84 to 3263 parts per 100 000 by weight, and from 250 to 9800 parts per 100 000 by volume, or roughly $\frac{1}{1200}$ to $\frac{1}{30}$ part by weight, and that 1 acre-ft. of river water contained from a minimum of 1.14 tons to a maximum of 44.42 tons, and an average of 9.62 tons, of silt. Obviously, the total quantity of sedimental material cannot be obtained by multiplying the average sedimental contents by the total annual discharge, but the investigations were carried out in such detail that it was possible to compute the quantity of solid material from the discharge at the time, and in this way it was found that the total solid material carried past Yuma that year was 120 961 000 tons. The total discharge of the river during that year was 10 119 000 acre-ft., and the annual average for 1894 to 1911, inclusive, was 12 388 000 acre-ft. It would seem conservative to estimate that the average quantity of material would be as much larger than that delivered in 1904 as the discharge, on which basis the result would be $120\,961\,000 \div 10\,119\,000 \times 12\,388\,000 = 148\,084\,000$ tons. The specific gravity of the Colorado sediment is 2.65 and the weight of dry soil is 93 lb. per cu. ft., so that this quantity of material would make approximately 71 800 acre-ft. or 112 sq. mile-ft. of equivalent dry alluvial soil.

* These results are given in Bulletin No. 6 of the Arizona Agricultural Experiment Station.

† Bulletin No. 44.

‡ Bulletin No. 53.

Navigability.—In a technical sense, the Colorado River is navigable from its mouth up to Laguna Weir, and again from there to The Needles. This navigability was recognized when Mexico and the United States entered into the treaty of 1848 regarding the International Boundary Line. By the provisions of this treaty, neither country was to permit works which would interfere with navigation throughout that part of the river which is a common boundary. In a subsequent treaty (1853) this provision was abrogated, but the United States guaranteed in lieu thereof a free and uninterrupted passage of vessels and citizens as far as the river forms a common boundary. As a matter of fact, the swift, shoal waters and the shallow depth over bars in the river itself, together with a tidal bore at the mouth, where the range of tide exceeds 30 ft., has resulted in practically no commerce on the river below Yuma since the Southern Pacific Railroad completed its track in 1876. At various times the U. S. Army engineers have investigated the situation, but have always reported that the navigation interests were not sufficient to justify any expenditure for river improvement.

An Act approved April 21st, 1904, authorized the Secretary of the Interior to divert water from the Lower Colorado River for irrigation purposes and to construct a diverting weir across the river at The Potholes, or Laguna, in which no provision whatever is made for navigation.

DELTA OF THE COLORADO.

The Delta of the Colorado River of the West, at the head of the Gulf of California, lies approximately between the parallels of 32° and 33° N. and the meridians 114° 30' and 115° W. It is partly north of the International Boundary Line between the United States and Mexico, and in larger part south of that line. Its area, including the Pattie Basin and the Cocopah Mountains, is approximately 6 000 sq. miles. It extends practically from the mouth of the Gila River, at Yuma, westward to the rocky walls of the San Jacinto Mountains and south to tide water of the Gulf, while on the north it blends with the depressed area below the sea-level, from which the ocean has been cut off by the deposits of the stream. Its general deltoid form is shown on Fig. 4, together with the course of the main stream and principal branches, sloughs, and overflow channels.



FIG. 4

The Lower Colorado River.—The Lower Colorado River may be considered as that portion lying below the last narrows, at what is known as The Potholes—the location of the Laguna Weir, of the United States Reclamation Service. At this point the river debouches

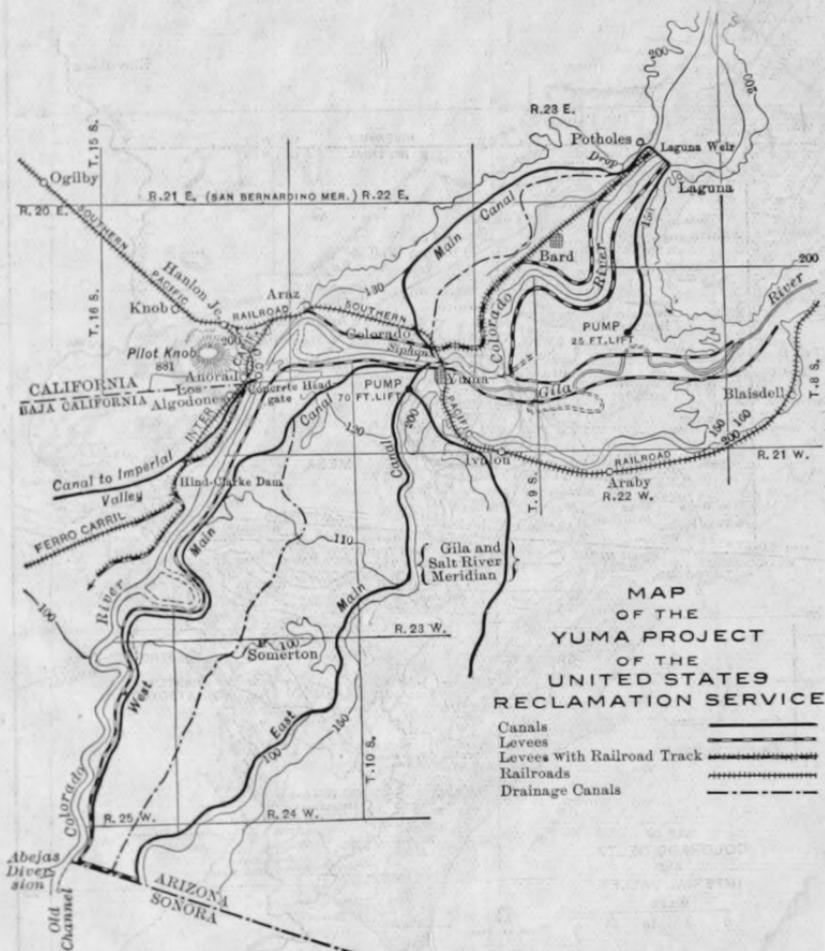


FIG. 5.

upon the plain, and the valley on each side is bounded by diverging mesas. About 13 miles below, and just above Yuma, the Gila River joins it. The present location of this portion of the river is shown on Fig. 5.

Alignment.—Below The Potholes there are two controlling points: one is a peculiar knob of indurated clay at Yuma through the center

of which the river channel has passed since the first advent of the whites; the other is the granite hill known as Pilot Knob. The small eminence at Yuma covers about 40 acres, and reaches a height of not more than 100 ft. above the general level of the delta plain. A similar though much smaller knob lies on the east bank of the river, about 1 000 yd. below and just to the south of the Southern Pacific Railroad Company's line and bridge, and is occupied by the reservoir and settling basins of that company. These peculiar topographical features control the river, with respect to its location at Yuma, and at Andrade, at the International Boundary Line, 8 miles farther down.

Grade.—The course of the river is quite winding, like every flashy, silt-bearing stream with a relatively steep grade. The elevation at The Potholes is approximately 140 ft. above sea level, and the distance by the river is about 100 miles to the head of tide-water and 114 miles to the mouth at the Gulf. Thus the general average fall is approximately 1.3 ft. per mile.

Remarkable Vegetation.—Attention must be called to the dense and varied vegetation throughout the region subject to the river's overflow. Arrow weed grows in nearly impenetrable jungles; mesquite and screw-bean trees occur in forests of varying density on older established soil, while freshly deposited mud flats and banks are almost immediately covered with seedling willows which quickly grow into heavy timber. For instance, Professor Forbes counted on an area 5 ft. square 1 500 willow sprouts up to 20 in. high, and in another older growth 90 young willow trees 20 ft. high.* Cottonwoods occur, but are not abundant. Along the river banks and sloughs there are dense thickets of common wild cane, which the Mexicans call *carrizo*, with a densely matted root stock which affords great resistance to erosion of the soil because the plant spreads both by means of these root stocks and by sending long slender stems or runners across the mud flats to distances of 20 or even 30 ft., and these strike root at every point, thus rapidly establishing the plant on newly made ground. In marshy locations are found great fields of a plant with an immense edible bulb used by the Cocopah Indians as a food, locally known as *tule*. In addition there is the *sesbania*, or so-called wild hemp, which is limited strictly to ground subject to overflow. It comes up from seed

* "The Lower Courses of the Colorado," R. H. Forbes, in *The Great Southwest*, Yuma, Ariz., Vol. 1, Oct., 1906, p. 2.

annually after the subsidence of the summer floods, stands in dense thickets from 5 to 20 ft. high, and is often square miles in area. This plant is also of interest because of its industrial possibilities. In general, the vegetation of the delta is remarkable for the manner in which plants of a kind mass together in areas, almost to the exclusion of other species, and for the remarkable density and immense areas occurring in continuous bodies, strips, and patches, particularly of willow, arrow weed, wild hemp, and *carrizo*.

Line Changes.—The entire Colorado River Delta has been said to consist of alluvial silt. When the river is low the water wanders in a devious way, along a very wide shallow bed in many places, and is everywhere confined by banks seldom exceeding 10 or 12 ft. high. During high stages these banks are overflowed at many points, and in the case of severe floods such overflow is practically general. The banks are thus wet and softened, and, when the river falls, caving and side-cutting proceed wherever the current is thrown at an angle against the confining banks, and often with startling rapidity. At the same time, the overflow water, being very heavily charged with silt, is checked by the dense, matted growth, and at once deposits its heavier particles, the smaller sizes being dropped a little farther down stream, and so on. Thus the country is built up most rapidly at the banks, and the land slopes away from the river at a constantly decreasing rate. Indeed, the theoretical cross-section of the land surface away from the stream is a hyperbola. Of course, these slopes are not identical at any two points along the river, but instrumental data at present available show the general average fall to be about $1\frac{1}{2}$ ft. in the first 100 ft.; 3 ft. in the first 300 ft., and from 5 to 8 ft. in the first 3 000 ft.

Although the coarser silt deposits are thus found immediately at the river bank, there are several reasons why this has little practical significance. The overflow water gathers in little channels which follow the line of greatest slope and in general approximately away from and down stream, the direction being the resultant of the general grade parallel to the river, and of the slope locally from the river's banks to the abeyment on either side. Such overflow channels build up their miniature beds and banks exactly like the main channel; they join to form overflow creeks, and these in turn form the overflow rivers.

As the level of the river rises higher and higher by such overbank deposition, it is obviously only a question of time until an unusual flood will produce sufficiently high velocities in some of these overflow channels to cause a recession of their grades extending through the river bank, thus diverting a portion of the water through the new route. Ordinarily, as the flood recedes, such breaks are clogged with drift and sediment, but sometimes the clogging action is not rapid enough to counteract the opposing forces successfully, and in this way radical and extensive changes of the river's course throughout the delta occur. Usually, these changes are in the nature of cutting off bends and thus shortening the channel.

At first thought it would seem that a diversion to the west would be a very probable occurrence during any great flood, because, with the constant extension of the delta southward, the gradient in that direction has become less, and to the west, more, until the fall toward the Gulf is much less than half as great per mile as that along former courses to the Salton Basin. As a matter of fact, however, though the overflow waters go down these channels with considerable rapidity, the cross-sections for many miles from the river are exceedingly inefficient, due to the dense vegetation, drift in the water, and occasionally, no doubt, to beaver dams.

In addition to the foregoing, there is another factor of importance: The bed of the main stream for quite a distance on each side of the International Boundary Line is excessively eroded during flood periods and filled up during lower water stages, as has been fully explained, so that, with a given flood discharge in the river, the water going over bank constantly decreases in quantity, in depth, and in velocity, and it is only the overbank flow which is important in connection with the overflow channels.

Character of Local Silt Deposits.—These various actions result in the formation of numerous little pockets throughout the inundated areas, in which water is left standing after the recession of each flood. Wherever this occurs the very finest of the silt settles out and, on becoming dry, cracks in large, somewhat hexagonal, irregular cakes. If the deposit is very thin, these cakes curl up when thoroughly dried and are broken up and carried away as dust by the wind; but when very thick the cracks are sometimes 6 in. and even more in width at the top and extend down 4 or 5 ft. Dust and vegetation accumulate in

such gaping cracks, and the next flood deposits another layer of sediment. Then, the heavier materials having settled first, the result is that the pockets are arched over, thus producing underground interstices which must be carefully guarded against in levee and other earth construction for holding back water.

The character of such deposits depends on the nature of the silt carried in the overflow water, and thus it happens that it is usually possible by examination to determine whether a deposit was made by a flood from the Colorado, or from the Gila proper, or from the Salt River.

The rate of such local deposition is sometimes startling. One instance the writer observed was due to the flood of 1905 which caused the diversion of the river into the Salton Sea. This filled in the ground on the left-hand side of the break about 3 000 ft. from the old river bank over quite an area to a depth of 6 ft., or almost to the roof of an Indian's *ramada*.

In this manner the Colorado River, from its exit from the Grand Cañon near The Needles, Cal., to about 3 miles south of Yuma, Ariz., has wandered about between its eastern and western abeyments, and, where these were any distance apart, has built up alluvial valley stretches which are practically level transversely.

The Principal Overflow Channels.—The overbank flow of the Colorado on the east side does not gather into channels of importance because the eastern abeyment is near by, except far down the stream, where there is what is known as the Santa Clara Slough. This, doubtless, at one time was the river's main channel, and during the severe summer flood of 1907 it carried so large a volume of water that for a time it seemed probable it would again become the main outlet of the river to the Gulf. This slough is about 40 miles long, and empties into the Gulf about 20 miles southeastward from the present mouth. This and the other smaller high-water channels on the east side are of no material importance in the engineering operations along the river.

By far the greater portion of the delta cone lies on the west side, where there are five inundation channels of considerable importance. These are shown on Fig. 4. In their order down stream from Andrade, they are known as the Alamo, New, Paredones, Abejas, and Pescadero Rivers. Without a thorough knowledge of them and their relation-



FIG. 6.—TYPICAL SURFACE OF CRACKED ADOBE SOIL.



FIG. 7.—TYPICAL SUBSURFACE OF CRACKED ADOBE MATERIAL. THE BOTTOM OF THE ROD IS 5.3 FEET BELOW THE SURFACE.

ship to the Colorado flood-waters, no satisfactory understanding of the problems of the Lower Colorado, and the endeavors to handle them, is possible.

The Alamo River, which was formerly often called the Salton or Carter's River, has its gathering ground in the northerly edge of the delta cone immediately south of Andrade. It follows somewhat closely the southern end of the sand hills, at times in a well-defined channel and again spreading out in broad swamp sections, known locally as

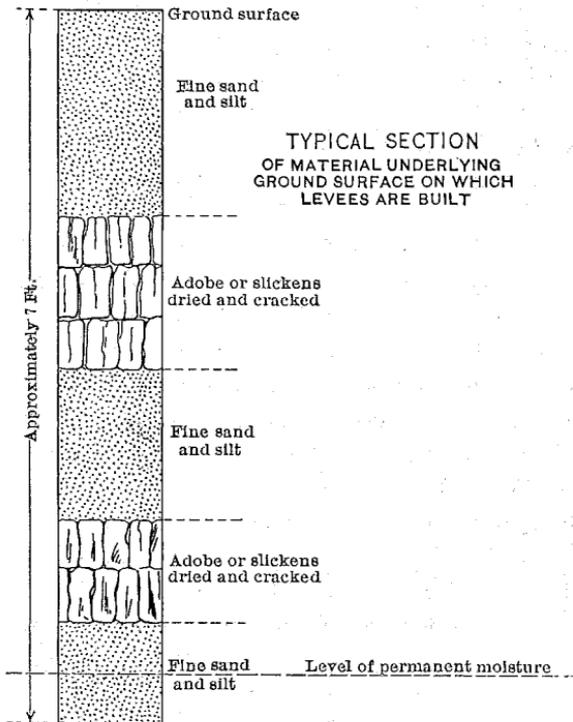


FIG. 8.

lagunas. About 40 miles west of the Colorado it crosses the International Boundary Line, and occasionally its waters were doubtless carried clear into the Salton Sink. The swamp areas, *Las Lagunas*, were also drained in part by the Quail River, which emptied into the Paredones. Farther down the Alamo there is a low area to the south and west through which the overflow waters from the great flood of February, 1891, broke over from the Alamo into the New River, the main point being at what is known as Beltran's Slough. The latter

runs into the low region between the Paredones and the Alamo, and this drains into New River through the Garza Slough. It seems probable that in 1891, for the first time in many years, the overflow waters reached the New River channel directly *via* the Alamo, rather than *via* Volcano Lake. During this flood from the Gila and the later annual summer flood of the Colorado, sufficient water reached the Salton Sea *via* the Alamo and the New Rivers to cover approximately 100 000 acres in the bottom of Salton Sink to a depth of about 6 ft., and it is estimated that the discharge of both these rivers aggregated 17 000 sec-ft. for a period of several weeks. Well-defined channels in the soft alluvial soil were cut out by both these streams, and since then the New River has carried some water every flood season, as it did occasionally before.* In July, 1903, it reached a maximum of only about 4 000 sec-ft., which was then the largest since 1891.

New River really heads in Volcano Lake, and probably is what remains of an overflow channel through which the ancient inland lake, Lake Cahuilla, emptied into the Gulf of California. At present its grade is to the north and into the Salton Basin, and from the lake's edge it follows for some miles the base of the Cocopah Mountains until it reaches about the + 10-ft. contour, where the mountains turn rather sharply to the west. The river continues in a general north-westerly direction and crosses the International Boundary Line at Calexico, where, until the recent tremendous erosion due to the diversion of the Colorado River into the Salton Sea, it followed a gentle depression down the lowest median line into the Salton Sink. At a few places in its course it spread out into broad channels, a few feet in depth, and formed occasional ponds or lakes, the most important of which were the Cameron Lake, near Calexico, Blue Lake, a few miles farther northwest, and Pelican Lake, a few miles farther on. It is now a great barranca, averaging from 40 to 80 ft. in depth and 1 000 ft. in width, from a point about 6 miles southeast of Calexico to the Salton Sea.

The Paredones is the first drainage channel on the southerly slope of the delta cone, and within quite recent years had direct connection

* Old settlers in the vicinity agree in saying that in 1840, 1849, 1852, 1859, 1862, and 1867 large quantities of water reached the Salton Sea. In 1862 that body of water attained unusual size, and the flow in New River that summer was so great that it stopped the mail stage-line service between Yuma and San Diego for several weeks, and a flatboat was built to ferry across it, near Calexico.

with the Colorado River. This connection was automatically reduced to the very small channel which existed in 1906, when the levee construction then done fundamentally changed overflow conditions. The Paredones gathers the overflow water from a large area, and a few miles from the river becomes a channel of considerable width and depth, following thence along down an element of the delta cone. During the extraordinary conditions existing in 1905-06, it carried a very large quantity of drift, which, with the assistance of some beaver dams, accumulated about 7 miles above Volcano Lake, and resulted in enlarging the branches leading toward the south. The overflow water of this river gathers to the south in the Pescadero, and to the north joins with the similar water from the Alamo and runs in part to Volcano Lake and in part through Garza Slough to New River.

The Abejas River drains the overflow from the region immediately south of the Paredones, and empties into the western side of Volcano Lake. Since the summer flood of 1908, this channel has been carrying the entire low-water flow of the Colorado and the greater portion of the flood flow, which is the condition to-day. The reasons for this diversion and the efforts to stop it will be considered at length later.

The Pescadero, another important overflow channel, drains the region immediately below that unwatered by the Abejas. It empties into a network of channels which conduct the water from that part of the delta cone and including Volcano Lake, finally gathering into Hardy's Colorado and emptying into the Gulf.

Volcano Lake may be another remnant of the waterway through which the ancient Salton Sea drained to the Gulf. It is a flat basin, the bottom of which is about 22 ft. above sea level, and its high-water stage is about 35 ft. At such a stage it extends about 10 miles northwest and southeast, and is about 6 miles wide. It is fed by the Paredones and Abejas Rivers, the latter since 1908 being the course of the Colorado proper, and by the system of sloughs which form the Pescadero network and also serve as an outlet. It is on the summit of the low, flat divide between the Salton Basin on the north and the Gulf on the south, and thus its discharge is both toward the north and the south. From the size of the outlet channels it is obvious that the greatest discharge has in recent times been southward. Since 1908 a line of levees has prevented any water from passing into the New River and thence into Salton Sea; the lake's waters, therefore, go to

the Gulf through Hardy's Colorado, which is an important channel, averaging perhaps 500 ft. wide and 20 ft. deep at maximum stages, with a fall varying with the stage in the lake from less than 15 to more than 30 ft. in a distance of from 45 to 50 miles.

The engineering operations which resulted in the irrigation of the Imperial Valley and its threatened destruction by inundation at various times since, have in very large measure been concerned with the overflow channels just described.

Diversion to the West.—Regardless of the tendencies for and against a fundamental diversion toward the west, the Colorado continued to flow in its regular bed to the Gulf until 1905. There can be no doubt that the operations of the California Development Company, and particularly in making an artificial cut from the Colorado River into the Alamo Channel and the utilization of that channel as a main canal, rendered the diversion to the west at that point, when it broke through in 1905, very much easier and more probable of immediate occurrence. Nevertheless, the behavior of the river since that time indicates pretty clearly that a diversion to the west somewhere within the first 25 miles below Pilot Knob was just about due, under natural forces alone. The conditions of equilibrium had become unstable to a degree, and this is the condition in which they are to-day.

Mesa and Delta.—The high mesa land which forms the eastern abeyment below Yuma extends therefrom almost south and into Mexico. The river turns, crossing the valley almost from east to west for about 5 miles, until it reaches the foot-hills forming the west abeyment; then it turns more than a right angle, hugging these hills, to the International Line; and thence it flows for 80 miles, in a remarkably direct general line, but little west of south, to the Gulf. On the west side of the valley the foot-hills end at Pilot Knob, a small mountain at the International Boundary Line, and the low mesa begins. The edge of the latter runs southwest for 4 miles; then it turns sharply directly west for 25 miles; then again it turns sharply to a little west of north for 50 miles—the latter edge forming the east side of the cut-off portion of the Gulf, Lake Cabuilla.

It is thus in a sense almost proper to say that the Colorado Delta begins practically at the International Boundary Line between California and Lower California, and that, for the first 14 miles below that line, the river is running on the very edge of the divide of the delta

cones, on one side sloping northwest to the Salton Sea and on the other to the Gulf. Furthermore, from that point the river (until 1908) was in a ridge of its own making, which it was raising constantly, and which is quite close to the eastern abeyment.

Pilot Knob.—Pilot Knob is a small, detached, and relatively abrupt mountain lying just above the International Boundary Line on the west bank of the river, and is one of the landmarks of the region. One of its rocky arms extends almost to the present west bank of the river. Fifty years ago the river had a pronounced bend, shown by the dotted line on the map, Fig. 13, and hugged this rocky point until passing it. The time when the shift of the river took place is not definitely known, but, very fortunately, at present the alignment here for several miles is almost straight.

It is quite significant that Pilot Knob is the lowest point along the river where a canal can be taken out for the diversion of water, with the diverting structure resting on solid rock. For this reason, it has been considered as a strategic factor in the irrigation of the Imperial Valley, but, in the writer's opinion, quite erroneously. The engineering fetish of a solid rock foundation for structures for irrigation and other purposes confining water, has resulted in needlessly spending amounts of money in the United States alone which must aggregate a tremendous sum. Perhaps no case is more spectacular than that of Pilot Knob and its relation to the irrigation system of Imperial Valley.

Early Suggestions Regarding Salton Sea.—Almost the very first explorers were interested in the Salton Basin and its various possibilities. The ability to create an inland sea by diverting into it the water of the Colorado attracted much attention, and it was very seriously suggested because of a supposed advantageous effect that it might have on the climate of the entire region. On the other hand, the possibilities of irrigating the Colorado Desert by the waters of the Colorado, which has since been accomplished, were not overlooked, work having been done on many more or less serious propositions at various times.

LATER IRRIGATION PROJECTS.

In 1891 and 1892, the Colorado River Irrigation Company was formed. Mr. C. R. Rockwood was placed in charge of the engineering work, and, under his direction, the entire problem of irrigating the Colorado River Delta was carefully examined and the important

features fully worked out. The financial stringency of 1893 put an end to the operations of this corporation, and in 1894 Mr. Rockwood was forced to sue the company for his unpaid salary. In partial satisfaction of the judgment which he obtained, the engineering records and data were taken over by Mr. Rockwood, and the Colorado River Irrigation Company ceased to exist. Nevertheless, it is interesting to consider the plans then evolved by that corporation, or, more properly speaking, by its engineer, Mr. Rockwood.

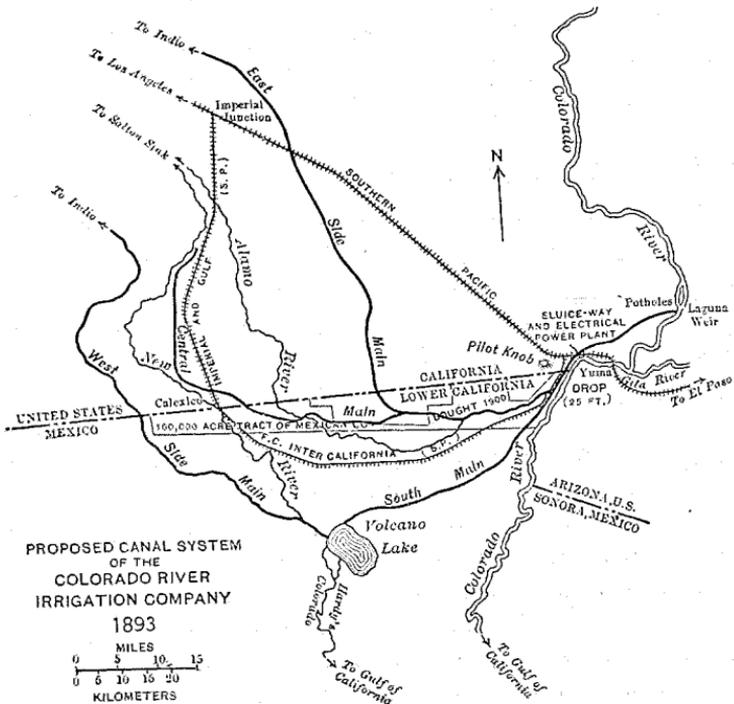


FIG. 9.

Plans of the Colorado River Irrigation Company.—These plans are outlined diagrammatically in Fig. 9, and show what is probably the ideal system of diversion and canals for watering all the land irrigable by gravity with the waters of the Lower Colorado. Events, however, shaped themselves so that the water for Imperial Valley has been, and is now being, diverted at Pilot Knob, and the U. S. Reclamation Service has built a diversion weir at The Potholes or Laguna to put water by gravity on all except the mesa lands in the so-called

Yuma Valley. Mr. Rockwood contemplated taking water out at The Potholes and installing in the main canal near Pilot Knob a sluice-way with which he intended to flush out the silt in the canal above which escaped being deposited in and removed by hydraulic dredges from a short enlarged section of the main canal immediately below the diversion point, where the velocity of the water would be reduced. The dredges were to be operated by electricity generated at the sluice-way. The maps showing the detailed surveys of these canals are now in the files of the California Development Company at its Calexico headquarters.

The California Development Company.—Mr. Rockwood, being thoroughly imbued with the practicability and advantages of the project to irrigate the Colorado Desert with the waters of the Colorado, undertook to carry it through, and finally did so by means of the California Development Company, under the engineering direction of, and with funds supplied by, Mr. George Chaffey, of Los Angeles, Cal. At the present time it is only important to say that, because of financial considerations, the engineering features were radically modified to diverting the water at Pilot Knob and utilizing a large part of the Alamo overflow channel as a main canal to carry the water around to the Imperial Valley, essentially as suggested by Lieut. Bergland in 1875-76. In this way the diversion work at The Potholes was eliminated, and a very cheap and quick method of getting water into the valley was arranged. By this decision the inclusion of the Yuma Valley as a part of the project was abandoned.

The Yuma Project, U. S. Reclamation Service.—As early as 1895 the Hydrographic Branch of the United States Geological Survey began stream gauging in California, starting with an allotment of \$5 000. More recently, the California Legislature has aided in the work on the basis of appropriating sums equal to those set apart by the United States. At the present time daily discharge observations are made on about fifty typical streams. Hydrographic investigations throughout the Western States, not only helped to prepare the way for national irrigation, but resulted in acquiring such hydrographic data that when the Reclamation Act was passed, in 1902, the best opportunities for national irrigation projects were pretty generally outlined. On account of legal and social complications elsewhere throughout California, the Yuma Project was finally selected as the first to be

commenced by the Reclamation Service in that State. On April 8th, 1904, a board of seven engineers recommended this project; on April 21st, Congress authorized the Reclamation Service to take water from the Colorado and divert it by a weir which would close it to navigation permanently above Yuma. On May 10th, 1904, the Secretary of the Interior gave his approval, and an allotment of \$3 000 000 was made.

There are approximately 75 000 acres of irrigable land under this project in Arizona, and 15 000 in California. Of this area, 98% is subject to the provisions of the Reclamation Act, the owners of private lands having signed the necessary agreements to limit their holdings to the size of the farm unit to be determined, and otherwise to conform to the regulations required by the Service. A Water Users' Association, consisting of the land owners of the project, handles the affairs of the district, from the farmers' point of view, and has contracted with the Secretary of the Interior to accept and use the water under the usual conditions fixed in such cases by the Government.

The Imperial Valley should logically have been included as a part of this project, particularly from an engineering point of view. However, water had been delivered into the Imperial Valley for almost 3 years when the Secretary of the Interior approved of the Yuma Project. In addition, there were complications—largely over-estimated and far more apparent than real—due to the fact that it is practically imperative to go through Mexican territory with canals to serve the American Imperial Valley. The project, therefore, was limited, for the present at least, to the irrigation of the Yuma Valley.

Fig. 5 is a map of the restricted Yuma Project. As it occupies a position on the river above that of the California Development Company's constructions, and for that reason in many ways has had a very important influence on the whole irrigation of the Colorado delta proper and related engineering problems, its essential features will be briefly described first. These are a diversion weir, and the levee, canal, and drainage systems. The diversion is by an overflow weir of the type developed by British engineers in their irrigation work in India, and improved and used later on the Nile. It is of loose rock, rests on a bed of river silt, is almost a mile long, very wide, quite low, and is in general an exceptionally interesting and expensive construction.

The next most unusual and interesting feature is the necessity for about 74 miles of levees to protect, from the overflow waters of the river, the greater part of the land to be irrigated. The canal system, with the exception of the siphon under the Colorado, is nothing out of the ordinary, and the same is true of the drainage system.

THE YUMA PROJECT, U. S. RECLAMATION SERVICE.

The project has proved very much more expensive than was originally contemplated, the estimated cost being \$3 000 000, whereas, the construction expenditures up to June 30th, 1910, were \$3 617 472.71,* exclusive of maintenance and operation charges and \$100 000 of the preliminary survey costs more properly chargeable to general investigations along the Colorado River than to the Yuma Project itself. Work on the project was reported as 80.8% complete, but this estimate was revised in April, 1911, and changed from 81.6 to 52.4%, making the proper percentage completed on June 30th, 1910, about 51.8. On this basis, the total cost will be \$6 964 233, or approximately \$77.25 per acre of irrigable land.

Laguna Weir.—The location and general design of this noted structure were determined by the character of the bluffs on each side of the last narrow point of the Colorado Valley, where they were almost a mile apart, and the fact that borings disclosed no bed-rock at reasonable depths in the river bed. Accordingly, it was decided to build a low, wide diversion weir of the so-called "Indian" type. The original design, as shown by Plate XLIII, was constructed with practically only one modification, namely, the interchange of the principal diversion from the Arizona to the California side.

Purpose.—The purpose of this structure, primarily, was to provide for silting out the heavier particles carried by the river, during flood periods especially, where such deposits could be sluiced out from time to time and in such a way that river floods would certainly carry them down stream.

Consideration will be given later to the silt problem, but it may be said that the only way of keeping the large, heavy, valueless particles of silt from getting into the distribution system, and clogging it, is to provide a settling basin where the water for a short time will either be practically still or the velocity reduced to not more than

* Ninth Annual Report, U. S. Reclamation Service, Washington, 1911, p. 81.

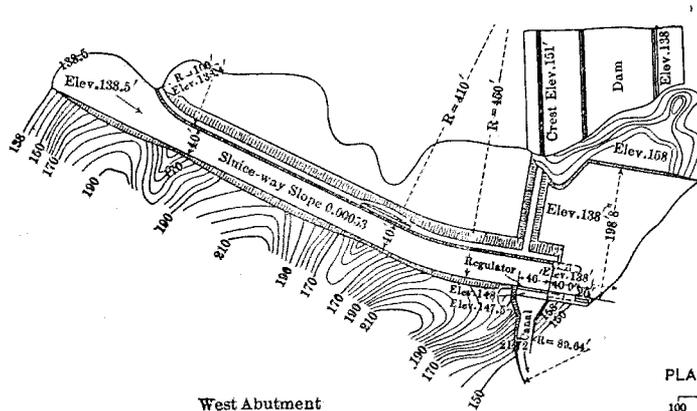
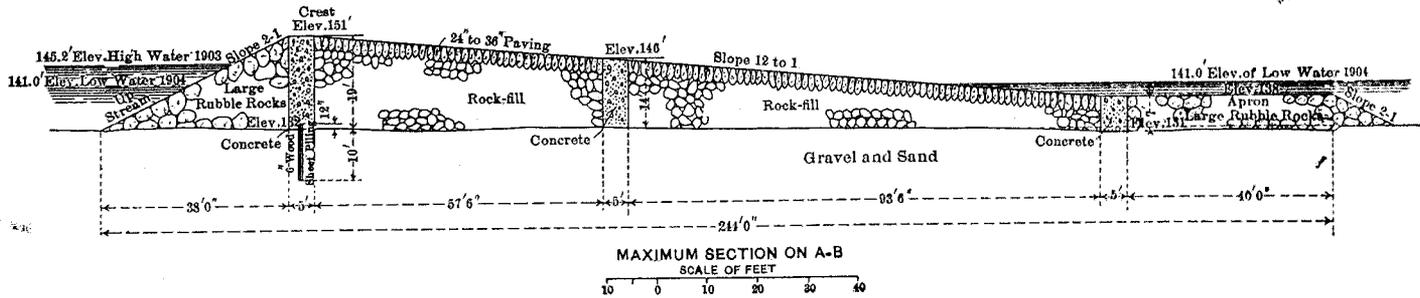
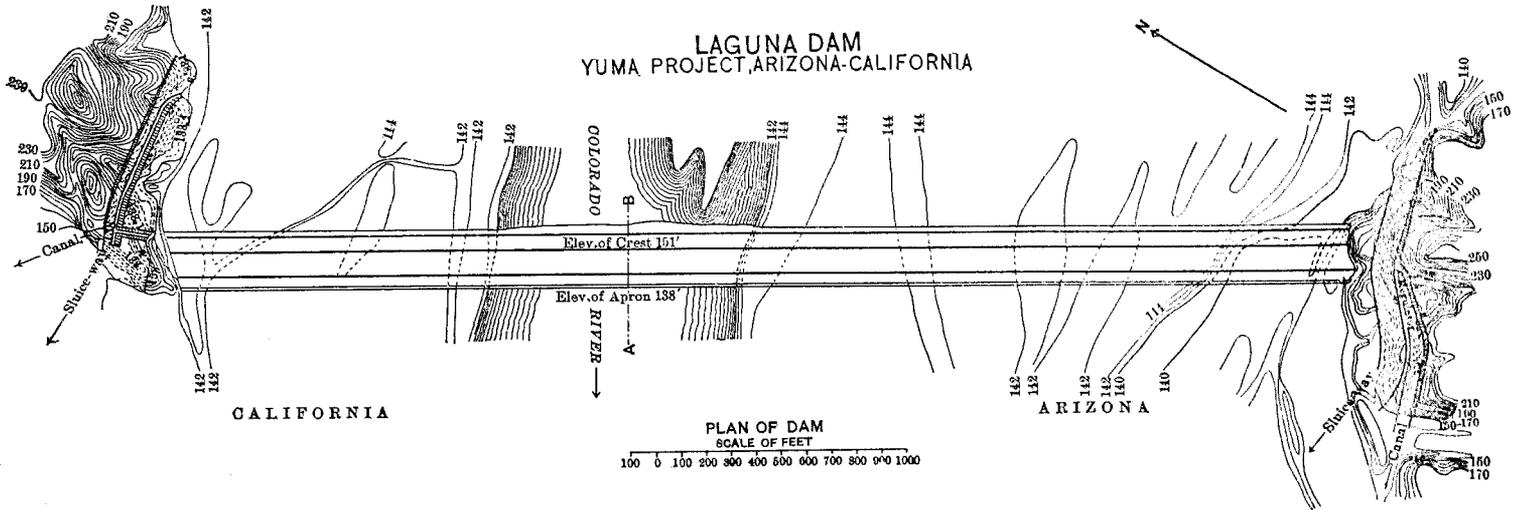
0.5 ft. per sec., with freedom from eddy currents. Such deposits may be removed either by sluicing out with large volumes of water at a high velocity, or by using pumps, dredges, or some other kind of machinery. It was estimated that in the main canal, originally designed to carry 1 600 sec-ft., the volume of wet silt to be removed therefrom daily was approximately 17 000 cu. yd. The sluice-way method of doing this means a higher initial cost and certainty of success, as compared with the very much lower cost, greater maintenance and operation charges, and somewhat less certainty of operation, for removal by machinery. The Laguna Dam (or rather weir) consists essentially of sluice-ways at each end of the structure, with a barrier between to hold up the water and afford a head for sluicing.

Sluice-ways.—The sluice-ways are controlled at their lower ends by large, vertical, steel-plate gates which are raised and lowered by electric machinery. The method of operation is to close the gates and cause the water in the sluice-ways above them to become practically still. The water thus held back quickly drops its heavier silt, while the canals are supplied through flash-board regulator gates in the outer sides of the sluice-ways, these gates being so long that a thin stream of water running over the tops suffices, and no water from near the bottom, where the sediment is greatest, is ever taken. From time to time, as may be necessary—and this varies greatly, depending on the stage of the river and the quantity of heavier silt particles carried—the gates are rapidly raised, and, with a fall of about 10 ft., the water rushes through the sluice-ways carrying away the silt deposits and dropping them a short distance below. During the annual and other floods, these deposits are taken up by the river and carried down stream. These sluice-ways are built through rock, their floor elevations being 13 ft. below the crest of the weir. They are lined and paved with concrete, and constitute a very massive and beautiful piece of work.

The Weir.—Between these sluice-ways the weir is built, the slope of the face being very flat, only 1 to 12, and capped with a concrete pavement, 18 in. thick, except a small portion which is paved with rough stones from 2 to 3 ft. thick. The crest was 10 ft. above the low-water mark at the dam when the structure was started,* and the top

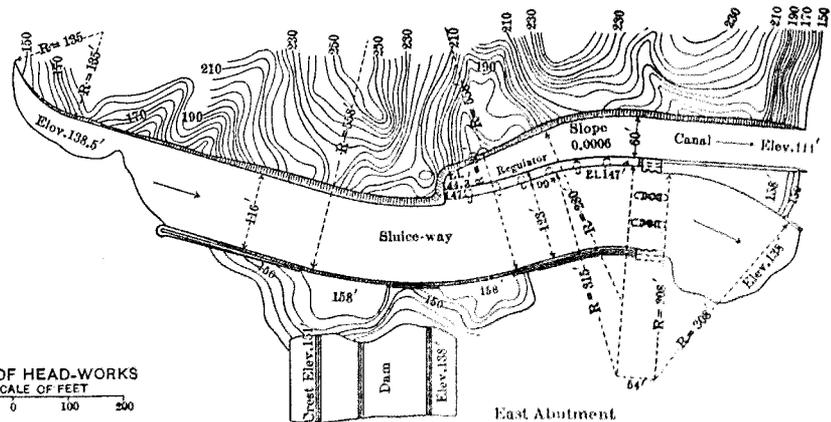
* See discussion of variation in elevation of river bed at different times and different seasons, and the consequent low-water mark.

LAGUNA DAM
 YUMA PROJECT, ARIZONA-CALIFORNIA



PLAN OF HEAD-WORKS
 SCALE OF FEET

100 0 100 200



of the down-stream wall is 3 ft. below; thus the total fall of the face is 13 ft.

The weir was constructed simultaneously from each end, and a gap of 800 ft. was left in the center of the river channel. The original plan for completing this gap was by building upper and lower coffer-dams with piling, brush, and sand bags, but this was changed and finally the barrier rock fill dam, developed by the operations of closing the first and second breaks described later, was utilized. Before the central section was filled in, the sluice-ways had been excavated and completed, the total capacity being more than enough to carry the low-water flow of the river. Rock was obtained in part from the excavation of the sluice-ways, and in part from the hills on each side; it was loaded on cars with derricks and steam shovels, and hauled by dinky locomotives to the various portions of the work. Cofferdams made of quarry spoil were extended out into the stream, and inside these large pumps were used to clear of water. As much excavation as possible was done with teams and scrapers, and the remainder was taken out by suction dredges and pumps. Sheet-piling and the parallel concrete walls were then built, and the rock filling between was put in, followed up by the concrete surfacing. The actual quantities used exceeded the original estimates considerably; they are given in Table 6.

TABLE 6.

Rock excavation.....	444 640 cu. yd., or about	146% of estimates.
Earth excavation.....	346 930 " " " "	123% " "
Rock in dam.....	375 018 " " " "	123% " "
Concrete*.....	76 069 " " " "	280% " "
Sheet-piling.....	82 779 lin. ft. " " " "	156% " "
Rock pavement.....	Insignificant—decrease.	100% " "

* In place of rock paving, the concrete surface was substituted.

On March 15th, 1905, bids for the construction of the Laguna Weir were opened, but those submitted were rejected and the work was re-advertised. Proposals were again opened on June 5th, and on July 6th, 1905, the contract was awarded at the following prices:

Rock excavation	\$1.30 per cu. yd.
Earth excavation	0.30 " " "
Rock in dam.....	0.35 " " "
Concrete	4.00 " " "
Sheet-piling	0.40 " lin. ft.
Laying pavement	1.00 " sq. yd.

The contract required the work to be finished within 2 years, which would mean just at the time of the peak of the summer flood of 1907. These prices, on the estimated quantities, made the bid amount to \$797 650. There were seven other bidders, whose figures ranged up to \$1 030 117.50. The Reclamation Service, under the specifications, supplied the cement to be used. On February 28th, 1906, the same firm was awarded the contract for furnishing and erecting the sluice-gates, regulator-gates, and operating machinery for the main sluice-ways and head-gates, the bid being \$65 900. The contractors began work on July 19th, 1905, and a year later had completed 26.4% of the work.

As the quality of the rock obtained was much poorer than had been anticipated, the Board of Engineers of the Reclamation Service modified some requirements in the specifications and contract which resulted in increasing the contract price by \$331 486, or to \$1 129 136, and extended the specified time for completing the structure from July 19th, 1907, to January 19th, 1908. On January 23d, 1907, when about 34% had been completed, the work was taken over by the Reclamation Service direct. On July 1st, 1907, 52% of the work had been finished, a year later 77% was done; and it was practically completed in March, 1909, just before the summer flood of that year began.

The Reclamation Service gives the following costs* of the Laguna Weir and the sluice and regulator works:

Laguna Weir.....	\$1 672 168.20
Sluice and regulator works.....	345 295.92

Other recent operations along the river have shown that a structure serving every purpose of the Laguna Weir could have been built by methods now well known at far less cost. The building of rock fill dams in the bed of such a stream as the Lower Colorado was considered impracticable until the work of re-diverting the river developed such method. However, it is now evident that it would have been far simpler, quicker, and cheaper to have developed rock quarries, thrown trestles across the bed of the stream, and dumped rock therefrom to form a wide rock fill dam, without any concrete walls whatever, and covered the top with concrete. There would be no difficulty in beginning the construction of such a dam in the center of the stream and causing the river itself to excavate its bed opposite the rock fill as the latter should be built forward. In this way the excavation

* Ninth Annual Report. United States Reclamation Service, Washington, 1911, p. 82.

would have been made to a little greater depth than the bottom of the concrete walls actually put in. The rock for such a purpose would by preference be graded, so that quarry spoil would in no way be objectionable, and rock material obtainable in the adjoining hills could be blasted out in large quantities, loaded with steam shovels, and consequently obtained and handled very cheaply. A structure having essentially the same top dimensions and surface covering, and extending deeper into the river bed than the existing one, would in this way have cost far less and be even more secure from failure. There would be practically no seepage through or under such a dam or weir, as the similar constructions, very much thinner and sustaining much greater heads, which closed the first and second breaks, seem to be absolutely water-tight.

To the cost figures should be added the proportional share of the total administrative and general expenses. Such administration figures are given as \$179 021.43, to which should properly be added at least \$75 000 of the item: "Preliminary surveys previous to selection of project—\$174 735.83," or a total of \$254 021.43. These are probably the approximate general expenses to be distributed over expenditures totaling \$3 717 472.71, or 6.89 per cent. On this basis, there should be added to the cost, for general expenses, \$114 243.24, or a total for the Laguna Weir proper of \$1 786 411.44, and to the sluice and regulator works \$23 583.71, making their total \$368 879.63, or a total of \$2 155 291.07, not including the loss of \$400 000 said to have been sustained by the contractor, which would raise the total to \$2 555 291.07.

The result is a magnificent and permanent head-works for taking water from the Colorado to irrigate by gravity about 75 000 acres of land in the Yuma Valley; and, at some future time, this structure may serve as well for diverting water to irrigate the entire Colorado Delta. Its very great cost, however, raises the question as to whether the silt problem could not have been solved in a more economical and equally satisfactory manner by pumping depositions thereof, in an enlarged section of the canal, back into the river, with suction dredges. This question cannot be determined until the maintenance costs of the sluice-ways and diversion weir are shown by experience, and the total costs and results of handling the silt with dredges, as is now being done at the California Development Company's head-works, have been ascertained for a considerable period.

Levee System of the Yuma Project.—Practically all the valley lands in the Yuma Project are subject to overflow, so that a general and comprehensive system of levee protection is necessary. Fig. 5 shows this system, practically all of which has been completed. In general, the designs were for dikes 4 000 ft. apart along the Colorado and 3 200 ft. apart along the Gila, with a height of from 4 to 5 ft. above the high-water marks; as constructed, however, there are long stretches along the Colorado where the levees are only from 1 600 to 1 800 ft. apart.

The first levee construction was in accordance with the usual Mississippi River practice. The ground was cleared, stumps and roots were grubbed out, the base was plowed, and the levee was built with earth taken from borrow-pits on the river side. These borrow-pits were about 400 ft. long in the direction of the levee, with cleared traverses between about 12 ft. wide; 40-ft. berms; allowable depths of pits, $2\frac{1}{2}$ ft. at the side nearest the levee and $3\frac{1}{2}$ ft. at the farther side; levee top width, 8 ft; side slopes, 3 to 1 on the river side and $2\frac{1}{2}$ to 1 on the land side. No muck-ditching was done.

The first stretch of levee constructed was 10 miles long, extending south from Yuma along the eastern bank of the river. In this section the current along the levee face was generally as little as would be expected anywhere on the project. Nevertheless, experience soon showed the desirability of an elaborate system of brush abatis work, a sample of what was put in here being shown by Fig. 10. At many points where any considerable quantity of water had come against the face of the levee the borrow-pits had cut together, the traverses having quickly been cut through and the breach widened more or less seriously. As it was expected that the river would fill up these borrow-pits with silt in the first few floods, such a result was disappointing.

It seems that no trouble was caused by the absence of muck-ditch protection under the levee. This must have been due to the fact that the ground where the levee was located was uniformly favorable. In the fall of 1906, however, the levee system of the project was extended some miles southward along the river, and the flood which occurred on December 7th, 1906—which got under the newly constructed dikes on the west side of the river in many places and resulted in the second break or crevasse to the west—caused several breaks in this new section, due to the lack of muck-ditches in unfavorable ground.



FIG. 10.—TYPICAL ABATIS WORK ON LEVEES OF YUMA PROJECT, U. S. RECLAMATION SERVICE.

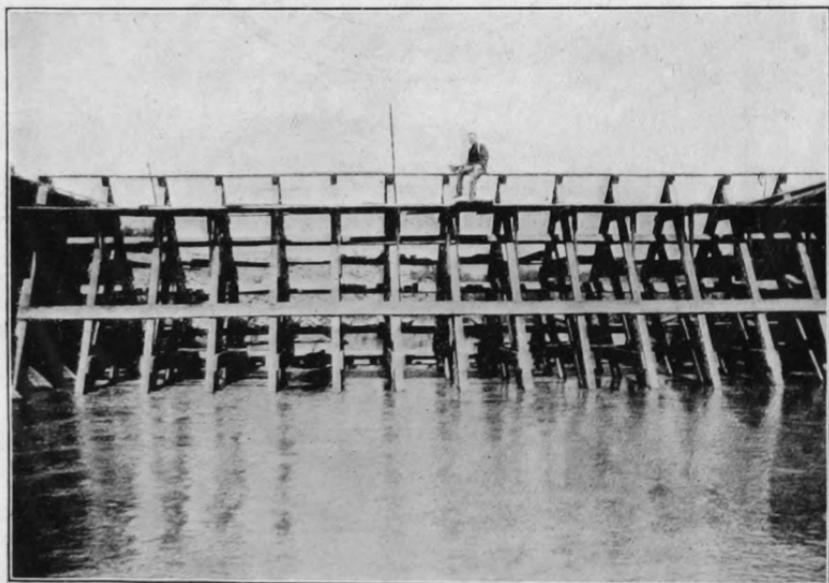


FIG. 11.—ORIGINAL INTAKE (CHAFFEY) GATE, IMPERIAL CANAL, COMPLETED IN 1901.

Experience with the levees, including the effect of this last-mentioned flood on the levee system of the project and on the levee work done on the other side of the river, caused a fundamental change in the design. In January, 1907, a Consulting Board of Engineers from the U. S. Reclamation Service was appointed to consider the matter of levee construction being done with money advanced by the Harriman interests on the west side of the river, and its recommendations are given later. Up to that date, 21 miles of levees had been constructed on the Yuma Project, extending from Yuma southward 15 miles and eastward along the south bank of the Gila 6 miles. All construction thereafter has been in accordance with the recommendations of this Consulting Board for the levees of the west side of the river, the essential features of which are "interrupted or checker-board borrow-pits" on the water side of the dikes, muck-ditches wherever test-pits show the necessity, and a large quantity of brush abatis work.

In 1907, a railroad track was laid in large part on the levee, from the Laguna Weir to Yuma on the California side of the river, chiefly for the purpose of hauling materials and supplies to and from the Laguna Weir. The Southern Pacific Company owns and operates this track as a branch line, thus serving an area which will be under intensive cultivation very soon, and greatly facilitating levee maintenance and repairs. Over this track a very large quantity of quarry spoil was hauled from the Laguna Weir construction work and used to blanket the river side of this levee to a point below where the swiftest water along its face is to be expected. None of the other levees of the project has any blanketing or any track on top.

Canal System of the Yuma Project.—Fig. 5 shows the general layout of the canal system of the Yuma Project as it is planned at present and in considerable measure constructed. The principal main canal is on the California side, and has a capacity of 1 700 sec-ft. The main canal on the Arizona side will irrigate only the land north of the Gila River. Water for irrigating the land lying east and south of the Colorado and below the Gila is to be carried under the river at Yuma in an inverted siphon, 1 000 ft. long, 14 ft. in diameter, about 50 ft. below the bed of that stream, and having an estimated capacity of 1 400 sec-ft. This siphon is now under construction. The original plan was to serve this territory with water taken from the

Arizona end of the dam and carried across the Gila River in four reinforced concrete tubes with a combined capacity of 1300 sec-ft. and laid 3 ft. below the river bed. This crossing was abandoned because the difficulty of holding the Gila River banks at the ends of the underground siphon was considered too great. There is practically no danger of this kind in crossing the Colorado with the siphon, because of the little eminences of quite hard material which control the location of the river at this point.

The design of this siphon, the investigations of the material in which it is located, the first methods of construction used, the difficulties encountered, the changes in plans and methods, with the reasons therefor, the methods of doing the work finally adopted, and the time and cost figures, are all interesting in the extreme, but will not be given here for several reasons, chief of which is that, on the completion of the Yuma Project, it is hoped the work will be described at length in a paper by the Project Engineer, F. L. Sellev, M. Am. Soc. C. E., or some other engineer of the Reclamation Service. Only such general description is here given as seems desirable to make quite clear the effect of the project itself directly and indirectly on the irrigation of the delta.

The total acreage which will ultimately be irrigated by the Yuma Project is given in the reports of the Reclamation Service as 90 160. This includes 17 000 acres of mesa lands which lie too high to be reached by gravity from the principal canal system. It is intended to develop 1 000 h.p. at the drop in the main canal, and with this to operate pumps to raise water for the higher distribution systems.

At present the main canal from the Laguna Weir on the California side down to the California shaft of the river crossing at Yuma is under construction, and quite a little main and some lateral canals lying between these points and behind the line of the levees on the west side of the river have been completed and are in use. Such canal construction, and particularly the checks, head-gates, etc., are models of their kind, being of concrete and of the latest and most approved type. Up to the end of 1907, there were no canals on the California side of the river; indeed, practically all the area was contained in the Yuma Indian Reservation, which has since then in part been apportioned to individual Indians and in part, 6 500 acres, on March 1st, 1910, opened to entry and quickly taken up

by white settlers. Two weeks later water was turned into the reservation canals, and rapid progress is being made in developing the region. On the east side of the river below Yuma about 8 000 acres are being irrigated through small canal systems which have been in operation for a long time and were taken over by the Reclamation Service since the creation of the project. The total acreage of the project to which water could have been supplied was about 16 000 acres; about 10 000 acres were actually irrigated during the season of 1911.

Drainage System of the Yuma Project.—As has been said, a large acreage of the Yuma Project is subject to annual overflow, and lies behind the levees. The water-table throughout practically the entire region rises and falls with surprising rapidity during all floods which are long in passing. Thus it is that during May, June, July, and August particularly, the water-table rises so near the surface as to result in rather high alkalinity in the soil. The river water which will be applied for irrigation also carries a considerable, though not serious, quantity of soluble salts. Evaporation takes place from land surfaces very rapidly in such a hot country, and when water is on the surface, or approaches so near it that capillarity makes connection between the water-table and the surface of the ground, the quantity evaporated is excessive, and the salts contained are left behind, largely in the top layers. Therefore, efficient drainage is very important. It is made even more necessary because the rainfall is really inappreciable, having been less than 3 in. per annum for the past 15 years, and causes very little leaching and washing away of alkaline deposits. In passing, it is important to say that, very fortunately, the alkali of the valley lands is peculiarly a surface accumulation, often being confined to the very upper layers, usually to the first 2 ft. in depth, and seldom being found at depths exceeding 6 ft.

The Yuma Project, therefore, includes plans for an elaborate and efficient system of drainage canals which will be doing the maximum amount of work during the annual summer floods of the Colorado. It is planned, where necessary, to pump such drainage water over the levees and back into the river. This drainage system has not been constructed, and indeed the detailed plans may not yet have been worked out, but it is desired to state here that arrangements have been made for drainage in the Yuma Project, and results along that line must be obtained in the Imperial Valley sooner or later.

IMPERIAL VALLEY IRRIGATION PROJECT.

In 1893, Mr. Rockwood found himself in possession of much engineering and other information regarding the irrigation of the Colorado Desert with the water of the Colorado River, in lieu of salary for a considerable time as Chief Engineer of the Colorado River Irrigation Company, and had a firm conviction of the project's possibilities. For more than 7 years he endeavored to finance the work, both in the United States and abroad. Many people suggested the irrigation of the Colorado Desert, as already mentioned, but Mr. Rockwood and associates actually brought it about. His very interesting story of the enterprise,* unfortunately, is accessible to relatively few people. In spite of his later mistakes, Mr. Rockwood is certainly entitled to much credit and reward for his efforts, which, practically speaking, were finally crowned with complete success.

Engineering Features.—The engineering features of irrigating the Imperial Valley from the Colorado River can now be much better understood than was possible in 1900. The experience of 10 years is always of value, and was particularly so in this case. The fall of the ground was known, and to divert the water and conduct it to the broad, ideally lying tracts of land to the west of the sand hills was obviously practicable. There were, however, two especially serious problems: the danger of diverting water from a wide, erratic stream flowing through a shifting channel along the top of a ridge of loose alluvial silt; and the difficulty of keeping open canals which carried water so heavily charged with silt.

Diversion.—The impossibility of properly financing the enterprise absolutely forced the abandonment of the idea of diversion at The Pot-holes, with its opportunities for settling basins and sluice-ways to care for the silt *en route*, and made the diversion at the rocky point of Pilot Knob practically unavoidable. It was always the idea to have a head-gate founded on solid rock. At the last, it was found impossible to obtain the money, even for this construction, but the diversion point was located there, with the intention of utilizing this rocky point of Pilot Knob for head-works, in the very near future, when the financial status of the company might permit.

* "Born of the Desert," by C. R. Rockwood, in the Second Annual Magazine Edition, *Calxico Chronicle*, Calxico, Cal., May, 1909.

Flood Protection.—It does not seem to have been realized, at the time, or indeed by any one until the diversion into the Salton Sea was actually an accomplished fact in 1905, that there was any really appreciable danger to the Imperial Valley by flood-waters from the Colorado. The writer hopes especially, that the discussion will bring out any contradiction of this statement which may be successfully maintained. Of course, it was known that large quantities of water had been carried through the New and Alamo Rivers into the Salton Sea in 1891, and also by the New River earlier, especially in 1862, but the channels had not eroded to any marked degree at the gathering ground along the Colorado River bank, but, on the contrary, had automatically closed. Instrumental data regarding that portion of the delta cone which is subject to overflow were entirely lacking, and indeed, little other reliable information about the region was available. It was planned to build levees along the river side of the canal with the material taken from the latter, but the purpose of these levees was to protect the canal itself from danger, and not to keep the flood-waters which might enter this waterway from enlarging it to a dangerous degree. Of course, any risk of the river being diverted into the Salton Sink, and soon inundating the entire Imperial Valley, involves the same risk to the irrigation project as such. Otherwise, such risk should obviously not affect an irrigation company in any way, unless its operations and constructions have an appreciable effect on such river diversion.

Silt.—With this means of diversion it was necessary to let the silt-laden river water enter the canals directly, and depend on keeping them open by dredging, erosion, etc. The chief difficulty obviously must occur in the first stretches of the waterway, due to the rapid deposition of the heavier or sandy particles of silt which the river water carries during flood stages of excessively high currents, and which drops down almost at once when the velocity decreases to, say, $3\frac{1}{2}$ ft. per sec. After such clarification, it is possible to design and operate canals in the Colorado Delta, as well as in India and elsewhere, so as to insure the carriage of the remaining finer silt into the smaller laterals and to the irrigated land. The first mile of the canal, therefore, was designed with a large cross-section so as to secure the deposition of this heavier silt there, where it could be removed by dredges.

Alkaline Lands.—From a farming point of view, a difficulty which was not given very serious consideration was the relatively high alkalinity in the upper layers of the soil throughout practically all the Imperial Valley. Wherever water came in contact with the ground, it was observed that vegetation at once sprang up like magic, and it was assumed, from this and from the obvious methods of its occurrence, that the soil must be exceedingly fertile and admirably adapted for general agricultural purposes. In one sense, a very serious mistake in this way was not made, for agriculture of almost unparalleled success has been followed for the past 10 years, with only at rare intervals a very slight thinning of crops indicating the need for proper drainage and the reduction of the excess of alkalinity.

In 1893 the Director of the Agricultural Experiment Station at the University of California was asked to investigate the agricultural possibilities of the land in the Imperial Valley. At that time it was proposed to provide an expedition properly equipped in order that the Director, Professor E. W. Hilgard, the great American authority on soils, might explore the region personally. The financial difficulties of the Company prevented carrying out the plan at the time, but a few samples of water from the lakes and of soil taken superficially, proved that the latter were very similar to that of the immediate bottom of the Colorado River, which previous analyses had shown to be of extraordinary intrinsic fertility.* In 1896 and 1897, some additional samples of soil and water were sent for examination. These corroborated the previous conclusions, but showed that a considerable quantity of alkali salts was present in the soils as well as in the waters, and thus indicated the desirability of a thorough examination of the region, from the soil standpoint. The subsequent soil investigations in the Imperial Valley and their effect on the fortunes of the region will be considered later.

Drainage.—Though the country as a whole lies ideally for irrigation and ordinary irrigation water drainage, the natural waterways are so far apart and so small and ill defined as to make the construction of an efficient, comprehensive drainage system almost as difficult and expensive as the irrigation canals. In the engineer's report to the Colorado River Irrigation Company, it was stated that the construction of a drainage system (though almost as expensive as the proposed

* Report, Agricultural Experiment Station, University of California, 1882.

irrigation system) was essential, but, some years later, when the work to be done was trimmed to the lowest practical minimum, it was decided that a general drainage system was not immediately necessary and possibly might never be required. This latter opinion was not as radical as might at first be assumed, because, even, to-day, there are probably not more than 5 miles of drainage ditches in the valley. It is being realized in a general way that at some time provision for drainage must be begun, and within the next few decades doubtless a fairly comprehensive plan will be developed. The diversion of the Colorado into the Salton Sea in 1905-06 resulted in eroding the beds of the Alamo and New Rivers into deep wide channels which will be the controlling features in the design of the ultimate drainage system for the valley, and thus produce a benefit which in the end must certainly exceed the total damages resulting from such diversion.

Climate.—The climate of the region, with its long, hot, dry summers, is peculiarly favorable to agricultural luxuriance. Thus it is that here the very earliest grapes, fruits, and vegetables are produced for the United States market, with the consequent advantage of commanding the highest prices. This is notably true of the Imperial Valley cantaloupe, now famous all over this country, and of the early grapes, asparagus, etc. On account of the very low humidity and gentle winds which blow much of the time in hot weather, the sensible temperature—which is indicated by the wet-bulb readings and gives the measure of heat felt by the human body—is much less than the actual temperature as measured by the dry bulb. It is conservative to say that a temperature of 110° in Imperial Valley is not more uncomfortable than 95° in Los Angeles or 85° in the more humid sections of the Eastern States. Furthermore, the nights are always cool, the low humidity resulting in rapid and large daily temperature variations.

At the same time, the heat in the Colorado Desert and at Yuma was proverbial, and one of the difficulties which the project had to encounter was the supposedly frightfully hot summers; indeed, the project would otherwise have been financed very much earlier. Since the control of the diversion canal was lost in 1905, the impression has become general that the project of irrigating this region was rejected by capitalists as involving too great engineering risks. As a matter of fact, the chief difficulty was the fear that the torrid climate would render colonization very difficult. It was for this reason only that Mr. George

Chaffey declined to consider Dr. Wozencraft's solicitations to undertake the enterprise as early as 1885, and it was Mr. Chaffey's subsequent experience in successfully establishing an irrigation enterprise in the interior of Australia, where a maximum temperature of 125° Fahr. was often reached, which led him to undertake the work here in 1900.

The International Boundary Line at the Sand Hills.—Perhaps, everything considered, the location of the International Boundary Line and the Sand Hills which lie to the west of Pilot Knob and overlap into Mexico for several miles, constitute the most important features of the irrigation, and protection from inundation, of the Imperial Valley. It is this which makes it impossible for the people of American Imperial Valley to organize to protect themselves under the laws of California. The menace is entirely on Mexican territory, and, apart from the difficulty of dealing with the problem as one of engineering and statecraft, is the worst feature of all, namely, the seeming injustice of compelling American citizens to protect their homes against a menace originating entirely on foreign soil.

Aside from the danger of the diversion of the Colorado to the west and into the Salton Basin, the important result of the present location of the International Boundary Line is that, practically speaking, water cannot be taken from the Colorado River and carried in canals lying wholly on American soil to the areas in American Imperial Valley susceptible of irrigation by gravity. It could be done, but it would require approximately 12 miles of a closed conduit running under the sand hills and costing at least \$10 000 000, a sum practically prohibitive.

Water Rights.—Due to the divided authority of the National and State Governments with respect to permission for taking water from the Colorado River as a navigable stream, water appropriation notices then, as now, had to be posted and filed, under the laws of the State of California, and arrangements had to be made with the United States War Department as well, if such diversion interfered with navigation. It appears that no attempt was made to obtain permission from the War Department for taking water from the river, because it was almost impossible to cause any "interference with navigation." This failure to secure permission from the War Department, however, had a very serious result later.

Ideal Plans.—The ideal way to carry such a project through is now quite obvious. All the engineering features should have been carefully worked out, elaborate soil surveys should have been made by well-recognized authorities, and experimental farms should have been established. The irrigation system should have been built in sections and colonized before additional areas were covered by canals. Water rights, entirely free from any possibility of attack, should have been obtained. In the light of experience, the writer believes that, by all means, these should have been obtained from the Mexican Government, and the diversion should have been made on Mexican soil, or the development should have been made under the Carey Act.

Dealings with Mexico would have meant the abandonment of the idea of diversion works founded on solid rock, but a structure with a wooden caisson foundation extending under the gates proper and the wing-walls would have been just as safe as the concrete head-gate actually put in later, and would have cost little more money, if indeed as much.

The ownership of all private interests in the Salton Sink ought to have been acquired, and such permission obtained from proper Government authorities that this naturally depressed basin would ever be available without question as a receptacle for the seepage, drainage, and waste water from the irrigated lands and canals. Data as to silt deposition and the cost of removing it from canals and intakes should have been obtained from experiments carried out on a commercial scale. Various details of the project, in short, should have been worked out very carefully and adhered to.

However, as in many irrigation and other projects in the West, the garment had to be cut according to the cloth. The sum total of events resulted in carrying out the project along lines which were far from ideal, but which later proved to be possible of execution with a remarkably small amount of money, everything considered.

THE CALIFORNIA DEVELOPMENT COMPANY.

The first practical step toward the actual irrigation of Imperial Valley was the incorporation of the California Development Company, under the laws of New Jersey, on April 26th, 1896. After two years of vain endeavor to obtain permission from the Mexican Government for the American corporation to hold land and acquire rights

of way for the main canals into American Imperial Valley, it was found necessary to form also a Mexican corporation. The California Development Company has a capital stock of \$1 250 000, divided into 12 500 shares of \$100 each; the Mexican Company—*La Sociedad de Riego y Terrenos de la Baja California, Sociedad Anonima*—has a capital stock of \$62 500, all of which is owned by the California Development Company. Hereafter in this paper the California Development Company will be referred to as the C. D. Co., and the subsidiary Mexican corporation as the Mexican Co.

The general practice throughout the West was, and still is, the sale of the "water right" to settlers at a definite price per acre—usually the right to buy water thereafter at specified prices. The arrangement adopted in this case was the formation of mutual water companies which would receive water wholesale and distribute it to their stockholders, the capital stock of such mutual companies constituting the water right.

Organization Under the Carey Act.—It would undoubtedly have been much better if the desert land in the United States had been segregated, and if the project, as far as American territory was concerned, had been carried out under the Carey Act. This Act, however, had not been passed when the original investigations were made, and, when financial arrangements were concluded, the California Legislature had adjourned and would not meet for nearly two years. Such delay was deemed too great.

Water Appropriations.—Water filings were made on April 25th, 1899, on the right bank of the Colorado River about 3 000 ft. above the International Boundary Line, by Mr. C. N. Perry, on behalf of the C. D. Co., appropriating 10 000 sec-ft., of the flow of the Colorado River to be used for the irrigation of American lands in the Imperial Valley. No serious attempt was made to obtain water rights in Mexico—in Mexican territory there was no chance to found diversion works on rock, and money for the first work of promotion would have been difficult to obtain with a projected intake in that country.

Rights of Way.—The C. D. Co. purchased 316 acres of patented land along the river just north of the International Boundary Line, and these included the rocky point of Pilot Knob; and the Mexican Co. acquired 10 000 acres in Mexico, belonging to Gen. Guillermo Andrade, and lying generally south of the Boundary Line, as shown

in Fig. 9, together with the bed of the Alamo River, which extended beyond the boundaries of this tract. In the American Imperial Valley (all the land belonging to the Government except Sections 16 and 36, belonging to the State of California, and known as "school sections") rights of way could not be purchased outright, but easements therefor were easily obtained as at present by application to the Secretary of the Interior, accompanied by maps and descriptions of the proposed constructions. All rights of way and property required for the construction of the project were thus arranged.

Contractual Relation of the C. D. Co. and the Mexican Co.—The two companies entered into a contract by the terms of which the C. D. Co. turned over to the Mexican Co. all the water to be diverted from the Colorado River by the former where the canal crosses the International Boundary Line at Algodones; the Mexican Co. agreed to deliver water to water users in Mexican territory as required and the remainder of the supply—the larger part by far—to the American water users at points on the International Boundary Line from 40 to 50 miles west of the river, and, from the water users of both countries, to collect for the water furnished, on a quantity basis; the C. D. Co. agreed to build, maintain, and operate all the Mexican Co.'s irrigation construction in Mexico; the Mexican Co., in consideration thereof, agreed to pay the C. D. Co. all sums received by the former for water rights, water stock, and water rentals from water users in the United States. These agreements were limited to water for lands which were irrigable by gravity from the system of canals beginning at the head-works constructed. It was stipulated, further, that no contract should be entered into with the Mexican Co. giving any person or corporation superior right over any other water user by reason of priority in date of contract or otherwise, and that the C. D. Co. should not be responsible for failure to deliver water to the Mexican Co. from any cause beyond its control, although admitting obligation to use due diligence in protecting canals and maintaining the flow of water therein.

By this arrangement, the Mexican Co. retains the money received from the water delivered to Mexican water users, and is put to no construction, maintenance, or operation expense whatever. This arrangement, however, is not as advantageous as at first appears, because the gross annual water rentals from Mexican water users did

not amount to \$10 000 gold per annum until the beginning of the ninth year, while the right of way contains at least 2 500 acres of land and includes 50 miles of the Alamo River channel, which is utilized as a main canal. It will be a number of years yet before the receipts of the Mexican Co. will be sufficiently large to make the contract an unusually profitable one.

Mutual Water Companies.—Next to the general plan of arranging to require the purchase by settlers of the water right usual in such cases, the fundamental idea was delivery of water to mutual water companies instead of individuals, the mutual companies to be operated by the holders of stock, namely, the farmers in their respective districts. The various mutual companies thus run their own local affairs and join together, through the C. D. Co. and the Mexican Co., in a community main canal leading from the river to the settlement west of the Sand Hills.

Triparty Contracts.—The mutual water companies required the construction of a distribution system, and ought or ought not to have paid a bonus for the contract to receive water at the International Boundary Line, depending entirely on the conditions under which the water should be delivered and the price to be paid for it. A triparty contract was entered into between the Mexican Co., the C. D. Co., and each of the mutual water companies, under the terms of which the Mexican Co. agreed to supply water to the mutual water companies "on demand" and at definite points on the International Boundary Line in the Imperial Valley for 50 cents per acre-ft., to be used only on lands within the respective districts; provided, however, that the aggregate quantity of water necessary to deliver under the contract should not exceed four times the number of acre-feet per annum that there were shares of capital stock in the mutual company; the mutual company agreed to order and pay for at least 1 acre-ft. of water each year for each share of its stock sold and located, regardless of its use by the mutual company or by its stockholders; the C. D. Co. agreed to build the distribution system of the mutual company and to maintain certain definite portions of the canal thereof perpetually, reserving the right to develop and use the water-power that might be obtained from the waters running through any of the canals, including those of the mutual company; a provision was made that at the end of 3 years the loss of water to the C. D. Co. in evaporation from

the canals of the mutual company should be determined, and such an extra allowance of water be supplied, as so determined, to the end that only the net quantity reaching each half section of land should be paid for; and the mutual water company turned over all its capital stock to the C. D. Co. and agreed to locate such stock on any lands within the exterior boundary lines of its district on order of the C. D. Co. The C. D. Co. sold the capital stock of these various mutual companies to the settlers, and with the proceeds built the main canals in the United States, the canal system in Mexico which belongs to the Mexican Co., and the distribution systems which became the properties of the various mutual water companies.

There were eight of these triparty contracts; they were essentially similar, though no two were exactly alike in every detail. The contract between the Mexican Co. and the C. D. Co., and the triparty contract as just outlined, together with the by-laws of the mutual companies, show the contractual relation of the water user to the organizations on which he depends for water. These by-laws, in general, provide that each share of stock shall represent the right to purchase water for the irrigation of 1 acre of land; that stock issued shall have written on its face a description of the land on which it is located; that no stock shall be located on any lands outside those described in the articles of incorporation; that one share and no more shall be located on each acre of land which can be served by the ditches of the company; that owners of stock issued but not located shall not be entitled to receive any water represented thereby, but shall, nevertheless, be liable for all assessments, the same as other outstanding stock of the company; that the shares may be transferred; and that acceptance by any stockholder of a certificate of stock shall be considered as a ratification by him of any and all contracts between the mutual company in question and the C. D. Co.

The inter-relations of the water users and the various corporations have been given in detail because of a general impression that the plan was devised for the purpose of taking advantage of the settlers. In its operations it has resulted in no unfairness of any importance to any of the parties concerned. Considering all the circumstances, the prices charged for water rights were very low—\$5.75 at the beginning, up to \$20 at present, and averaging \$12 per acre as the total cost to the settler, on easy terms—and the total annual water rental from the

TABLE 7.—COMPARATIVE STATEMENT OF EARNINGS AND EXPENSES
OF THE CALIFORNIA DEVELOPMENT COMPANY, FOR NOVEMBER, 1909.
(Property on a seriously deteriorating basis.)

	November, 1909.	5 months ending November 30th, 1909.
EARNINGS:		
Water sales.....	\$18 906.20	\$98 236.75
Water-power royalties.....	418.90	1 772.80
Rent, buildings and other property.....	82.05	488.51
Miscellaneous earnings.....	66.45	420.68
Gross earnings from operation.....	\$14 473.60	\$95 918.74
OPERATING EXPENSES:		
<i>Maintenance, canals and structures:</i>		
Superintendence.....	\$163.83	\$641.63
Maintenance and cleaning canals.....	10 588.76	47 130.74
Bridges.....	223.04	408.88
Canal structures.....	901.70	2 444.57
Buildings, fixtures and grounds.....	824.81	3 192.44
Total.....	\$12 702.14	\$53 818.26
<i>Maintenance of levees:</i>		
Superintendence.....		\$210.00
Patrolling.....	\$102.55	377.87
Roadway and track.....	126.12	1 034.01
Telephone and telegraph lines.....	84.87	217.04
Buildings, fixtures and grounds.....		44.87
Total.....	\$313.54	\$1 883.29
<i>Maintenance of equipment:</i>		
Vehicles.....	\$85.23	\$576.47
Grading implements.....		14.23
Corrals.....	29.01	525.56
Machinery.....		533.45
Shops.....	84.71	155.25
Automobile.....	135.96	1 115.04
Motor cars.....	83.94	154.46
Dredges.....	281.42	938.18
Total.....	\$649.07	\$4 012.64
<i>Distribution of water:</i>		
Superintendence.....	\$163.70	\$997.22
Zanjeros.....	760.00	3 853.63
Calibration and water measurement.....	21.52	365.00
Telephone and telegraph lines.....	163.40	815.53
Damages.....		50.00
Total.....	\$1 108.62	\$6 086.83
<i>General expense:</i>		
Salaries and expenses, general offices.....	\$2 981.66	\$15 444.09
Office expenses.....	332.37	1 515.04
Law expenses.....	618.28	3 399.92
Stationery and printing.....	132.36	684.86
Other expenses.....	107.40	459.67
Total.....	\$4 172.07	\$22 003.58
Total operating expenses.....	\$18 945.44	\$87 804.15
Net earnings.....	\$4 471.84	\$8 114.59
Taxes.....	\$197.76	\$1 134.88

water users in the valley will not suffice to pay maintenance, operation, and general expenses, properly figured, until such time as about 700 000 acre-ft. of water are sold annually. At the end of 9 years the sales have not yet reached that figure. Fig. 4 shows the boundaries of the lands of the various mutual water companies in the valley and under whose distribution systems lie all the lands which are as yet irrigated.

Operation of Triparty Contract.—For 3½ years the writer was General Manager for both the C. D. Co. and the Mexican Co., and handled all matters between these companies and the various mutual water companies. During the latter portion of that time, the protection of the Imperial Valley from inundation by the Colorado had become quite as important as its irrigation, and, for this protection, of course, no provision was contemplated in these contracts. Except for that, the arrangement proved to be very satisfactory, and produced a smooth and comfortable relationship unusual in irrigation enterprises. As a result of litigation, the Supreme Court of California has just declared the whole scheme practically legal. The Imperial Irrigation District was created several months ago, and the directors thereof have decided to take over only the functions which the C. D. Co. and the Mexican Co. now perform, and will not interfere in any way with the mutual water company plan of organization, or the water companies themselves.

TABLE 8.—STATEMENT OF EARNINGS AND EXPENSES
OF LA SOCIEDAD DE IRRIGACION Y TERRENOS DE LA BAJA CALIFORNIA.

	November 5th, 1909.	5 months, ending Novem- ber 30th, 1909.
GROSS EARNINGS.....	\$641.20	\$5 127.39
OPERATING EXPENSES:		
<i>Distribution of water</i>	0.00	0.00
<i>General expense:</i>		
Salaries and expenses, general officers and clerks...	421.54	2 073.85
Office expenses.....	64.07	341.32
Law expenses.....	223.99	696.64
Stationery and printing.....	39.55	101.21
Inspection fund (Mexican Government).....	150.00	750.00
Other expenses.....	291.25	563.47
Total.....	\$1 130.40	\$4 626.49
Total operating expenses.....	\$1 130.40	\$4 626.49
Net earnings.....	\$489.20	\$500.90

Imperial Land Company.—The parties who were induced to back the enterprise financially were afraid of the colonization end, and would have nothing whatever to do with it. Accordingly, it was necessary to form a colonization company—the Imperial Land Company—which was incorporated under the laws of California in March, 1900, and consisted in part of some of the promoters of the C. D. Co. and in part of other people. This corporation contracted to do all advertising and colonizing and sell all water stock in consideration of having the exclusive privilege of town sites and a commission of 25% on water stock sales. By using Government land scrip, this company obtained immediate ownership in fee simple of tracts of land in various parts of the valley and subdivided them into town sites. These town sites were covered with water stock in order to obtain water for domestic and municipal use through the assistance of the mutual companies, because no wells, except some very deep and unsatisfactory ones quite recently sunk on the east side of Imperial Valley, have ever been possible for domestic supply. The Imperial Land Company thus established the town sites of Mexicali, in Mexico, and Calexico, Heber, Imperial, and Brawley, in California. The other town sites—El Centro, the county seat, Holtville, Seeley, Dixieland, and several smaller places were platted and put on the market by other parties later.

TABLE 9.—OPERATING EXPENSES OF CALIFORNIA DEVELOPMENT CO.,
JANUARY 1ST, 1908, TO MARCH 31ST, 1909.

	1908, 12 months.	1909, January, February, and March.
Maintenance, canals and structures.....	\$71 419.94	\$18 177.32
Maintenance, levee.....	10 260.35	647.24
Maintenance, equipment.....	18 523.69	4 182.21
Distribution of water.....	15 613.42	4 559.10
General expense*.....	75 162.82	12 277.76
Construction of canals.....	73 765.12	27 359.47
Construction of levees.....	32 303.09	32 237.84
Totals.....	\$297 053.43	\$99 500.94

* Of this sum, \$30 665.28 was litigation expenses and costs.

During 1911 the total net deliveries of water to the mutual water companies in the United States were 597 176 acre-ft., or \$298 490.98.

This colonization company in general was successful, but not to the extent which would be expected, considering the unprecedentedly rapid settlement of the region, and the contract was certainly a fair one to

the C. D. Co., up to the time of its abrogation in 1906. Water stock was sold to the settlers for small cash payments and notes payable in five yearly settlements at 6% interest, such notes being secured by a pledge of the water stock purchased. Many of the settlers had scant means and only a filing right on the land, so that the water stock was not made appurtenant to the land, but left as personal property. The initial payment went to the Imperial Land Company, and was by it used for advertising and other essential purposes, the collateral notes secured by the water stock being taken by the C. D. Co.

TABLE 10.—AVERAGE DIVERSION AND DELIVERIES OF WATER BY THE CANAL SYSTEMS OF THE C. D. CO. AND THE MEXICAN CO. FOR THE WEEK ENDING JANUARY 19TH, 1912.

Gauge at Yuma.....	15.3 ft.
Gauge opposite intake.....	105.9 "
Elevation of bottom of diversion gate.....	98.0 "
Average flow of Colorado River at Yuma.....	4 000 sec.-ft.
Diversion from Colorado River at Andrade.....	1 559 " "
Used in Mexico.....	37 sec.-ft.
Used in United States.....	894.6 " "
*Wasted at Rositas waste-gate.....	821.3 " "
Total.....	1 252.0 sec.-ft.
Total loss, Andrade to Sharps.....	306.1 sec.-ft.

* 171.1 sec.-ft. of this passed through the plant of the Holton Power Company *en route* to this waste-gate for developing electrical energy.

This loss equals 19.6% in about 46 miles of main canal, chiefly the bed of the old Alamo River, or 0.43% per mile on the average—an extremely low figure.

Management of the C. D. Co.—Delta Investment Company.—

Until the water rentals became of importance, these collateral notes constituted the only receipts of the C. D. Co., and these assets were looked on with considerable suspicion by the financial institutions of Los Angeles. Nevertheless, they might have been taken as collateral at about 25 cents on the dollar had not the merit of the entire enterprise been rendered questionable in various ways, as explained later. When this occurred the Delta Investment Company was formed—in the fall of 1901—with assets consisting solely of C. D. Co. and Imperial Land Company stock contributed by the wealthier people of the enterprise. This company was given a contract to take over all the C. D. Co.'s bonds at 50 cents on the dollar, and all its collateral notes and mortgages at the same discount. By this arrangement, the Delta Investment Company practically controlled the C. D. Co., although the amount of the C. D. Co. stock held by it was much less than a majority.

TABLE 11.—ANNUAL EXPENDITURES
OF IMPERIAL WATER COMPANY No. 1 FOR 1911.

Capital stock = 100 000 shares, all of which have been sold, and are located on 100 000 acres of land. Total length of canals = 373.25 miles.

<i>Maintenance:</i>		
Superintendence.....	\$7 000.00	
Engineering.....	1 600.00	
Corral.....	3 805.11	
Automobile.....	500.00	
Shops.....	2 463.13	
Materials and supplies.....	22 046.11	
Labor, men and teams.....	75 887.41	
Damages.....	645.91	
Muskrats, bounty at \$1 each.....	492.00	
		\$114 439.67
<i>Operation:</i>		
Superintendence.....	\$9 815.74	
Engineering.....	168.81	
Zanjeros.....	22 609.02	
Corral.....	3 192.36	
Automobile.....	476.39	
Materials and supplies.....	1 892.93	
Telephone.....	260.16	
Water meters.....	260.47	
		82 675.93
<i>General Expense:</i>		
Salaries.....	\$6 410.02	
General expenses.....	2 971.18	
Printing and stationery.....	439.94	
Taxes and insurance.....	956.59	
Furniture and fixtures.....	520.45	
Legal expenses.....	10 889.88	
		22 187.51
Imperial Water Company No. 1, expense.....		\$169 303.11
Water Bought (from the C. D. Co.) 305 183 acre-ft., less 10% allowance for seepage and evaporation, at 50 cents per acre-ft., on net amounts.....		137 332.50
<i>Total expenditures*</i>		\$306 635.61

*The expenses of the company were almost exactly \$1.70 per acre, and the water rentals paid to the C. D. Co. \$1.37 per acre. The total cost to the farmers, therefore, averaged \$3.05 divided by 2.747, or \$1.11 per acre-ft.—a very low figure for water in California, where the "water right" averages \$12 per acre, or indeed much more.

It must be admitted that the Delta Investment Company took over such securities at a larger price than could have been obtained from any other source. Nevertheless, the securities were really good, everything considered, and quite a few large and apparently strange and dishonest transactions were made between the two corporations. Money was forthcoming for construction purposes, but was costing the C. D. Co. \$2 for every \$1 obtained. The result was that in a couple of months serious dissensions arose, and in February, 1902, an adjustment was made cancelling the contracts with the Delta Investment Company and Mr. Chaffey, who thereupon retired from the enterprise. March 1st, 1902, therefore, found the C. D. Co. a going concern, and Imperial Valley a reality, but the parent company, with all its bonds gone, its

WATER DELIVERED
 BY
 THE CALIFORNIA DEVELOPMENT CO.
 TO LANDS IN THE UNITED STATES
 DURING THE PERIOD, 1905 TO 1911.

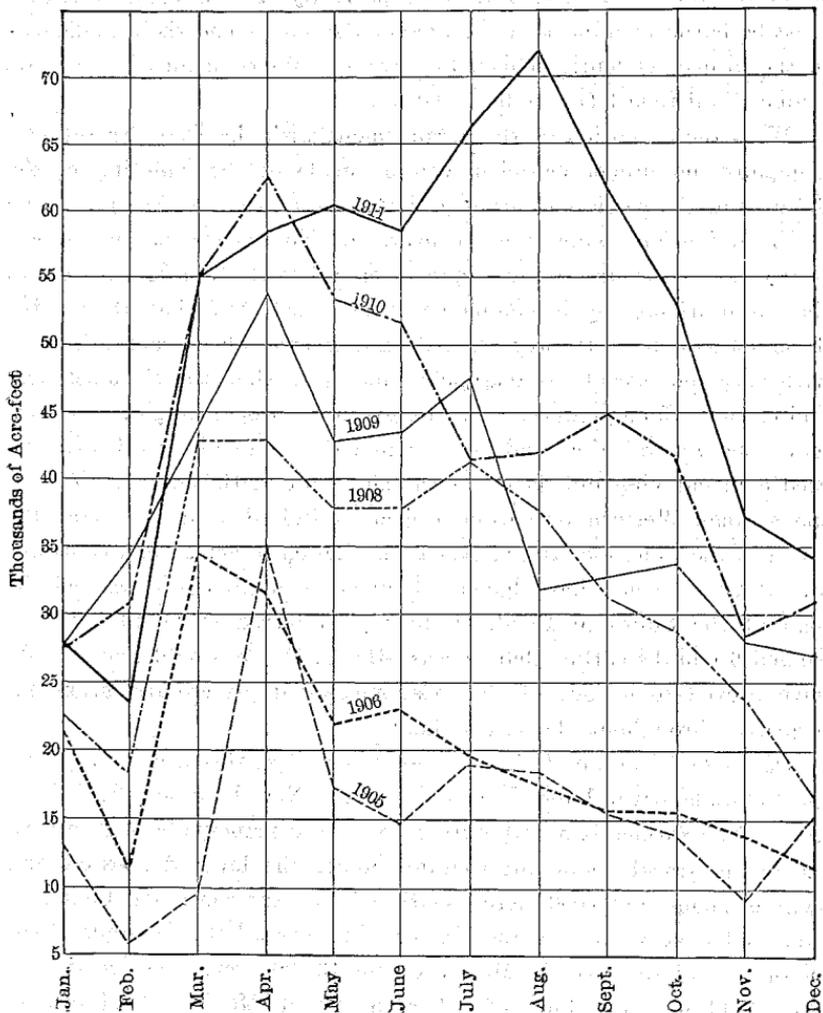


FIG. 12.

collateral notes and mortgages largely depleted, no money in the treasury, and deeply in debt. Shortly afterward actual results from farming under the project were so reassuring that the Company was able to borrow \$25 000 from the First National Bank of Los Angeles.

The contract with the Delta Investment Company was a serious thing for the C. D. Co., but, to be perfectly fair in presentation, it must be borne in mind that the financial interests had their confidence in the project violently shaken by advance rumors of an adverse Government soil report (to be discussed later).

With the exception of the arrangement with the Delta Investment Company, no proper criticism can be made of the handling of the finances of the whole irrigation project, as far as any of the promoters of the irrigation company are concerned. The writer has had opportunity and occasion to investigate thoroughly the relationship of all the corporations, and in common fairness must state that, though the deals back and forth were many and diverse, they were otherwise with very few exceptions reasonable and fair, when the circumstances and reasons which produced them are given the proper weight. Furthermore, the general aims and plans which the company practically succeeded in carrying out do not merit any more criticism than those of the average Western irrigation project, if indeed as much. Had the break in the Colorado River never been allowed to get beyond control—and it never would have happened, in spite of all obstacles, had the loan of the Southern Pacific Company (referred to later) been arranged 6 months earlier than it was—the C. D. Co. would undoubtedly have proved to be one of the most successful private irrigation enterprises throughout the entire land.

Colorado River Land Company.—It is well at this time to mention the Colorado River Land Company and the New Liverpool Salt Company. The former is a corporation consisting principally of Southern California stockholders, incorporated under the laws of Mexico, and owning about 1 000 000 acres south of the International Boundary Line and west of the Colorado River. It owns all the Colorado River Delta west of the river in Mexico except 162 000 acres, the location of these holdings and those of other important Mexican land owners being shown on Fig. 4. The existence and operation of this corporation have lately become important as being the agency through which the United States Government has handled the river control work

recently done by it. The company will hereafter be referred to as the C. M. Co., as it is locally called.

The New Liverpool Salt Company.—This corporation was organized many years ago for the purpose of obtaining salt from the deposits in the bottom of the Salton Sink, and began operations in 1884. In 1904 its plant was reasonably satisfactory in its details and had a capacity of 1 200 tons of salt per month. The actual value of the plant and the salt beds, taking into consideration the excellent quality of the salt,* the conditions under which the Company operated, and the competition it had to meet, is of course impossible to determine without access to the company's records. It appears, however, that negotiations at that time were pending for its sale, the figures being \$150 000 asked and \$100 000 offered. When the water began to come into the sink in large quantities, negotiations were dropped, and the entire plant was soon buried by the Salton Sea.

OPERATIONS OF THE CALIFORNIA DEVELOPMENT COMPANY.

When the C. D. Co. was ready to begin operations, there was on the lower river a dipper dredge with a 4-yd. bucket which had been built and equipped by the Hon. Eugene S. Ives, of Yuma, Ariz., and his associates, for digging irrigating canals near Yuma. This dredge was bought by the company in exchange for guaranteed bonds, floated down the river, and, in August, 1900, set to work excavating a canal along the lines marked "Original Intake" in Fig. 13 and then following the old Alamo overflow channel to a point 8 miles below. From that point the Alamo channel, with a little diking here and there, had sufficient capacity to carry for some time the water needed. From the beginning of actual construction until he left the enterprise (April, 1900, to February, 1902), Mr. George Chaffey was President and Chief Engineer of the Company.

About 500 ft. above the Boundary Line a temporary wooden head-gate, Fig. 11, known locally as the "Chaffey" gate, was put

*The published analyses of the deposit give the following average:

Sodium chloride.....	96.15
Sodium sulphate.....	0.70
Calcium sulphate.....	0.60
Magnesium sulphate.....	1.60
Insoluble.....	0.10
Water.....	0.85
	100.00

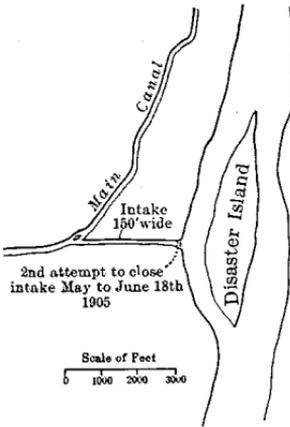
The California State Mineralogist reports the value as \$1 per ton.

in. This was a well-designed and well-built wooden, **A**-frame, flash-board gate, 70 ft. long, 15 ft. high, with a plank floor, and founded on piling. When it was built* nothing was known or even suspected with reference to the rapid and large variation in elevation of the river bed at varying flood stages and otherwise, and it is not surprising, therefore, that the floor was not put as low as it should have been, but, even so, it was not as deep as planned on account of an unnaturally early summer flood. The structure was made no larger, not because of cost, but because it seemed certain that when more water than the gate's capacity should be required, that fact would mean such revenues as to permit building the permanent concrete and steel diversion works at Pilot Knob, regardless of all other considerations. In passing, it may be said that the construction and design of this temporary head-gate was fully equal to that of any throughout the West, even to-day. The floor, however, was quite too high.

At what is known as Sharp's Heading, the Alamo channel was abandoned as the main canal, and the controlling works for the valley end were put in. These consisted of a wooden, **A**-frame, flash-board gate in the continuation of the Alamo, a similar gate at the head of the Encina or West Side Main canal, and a combined gate and drop, known as Sharp's Head-gate, from which leads off the Central Main, the chief canal in the valley.

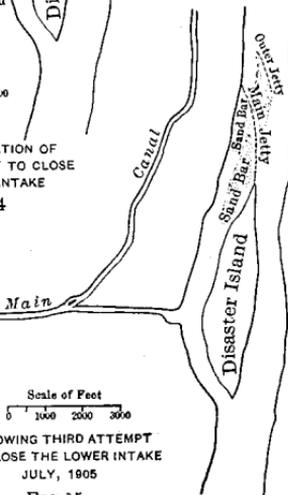
This last structure is well worth describing in some detail. In the first place, it is a most vital part of the system, because, being a combination of a drop and regulating gate, were it to fail, the water in the Alamo or Main Canal above it would immediately be lowered far too much to permit taking out any whatever for the East and West Side Mains. To realize the consequences of this, it must be remembered that irrigation water is needed every day in the year, and that no stock and domestic water for the entire region, except for the Town of Holtville, can be had, except from the irrigation system and by being brought in by the railroad in water cars. In the second place, for several months consecutively, in each year since 1905, it has been taxed beyond the capacity for which it was designed, without developing any serious weakness. Furthermore, at intervals of about 18 months, since it was put in service in 1903, the canal above it has

* Nothing really was known about the changes in elevation of the river bed until 1907



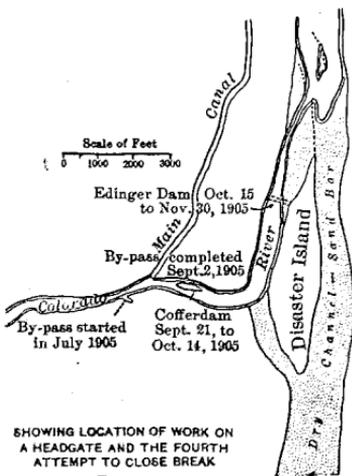
SHOWING LOCATION OF SECOND ATTEMPT TO CLOSE THE LOWER INTAKE

FIG.14



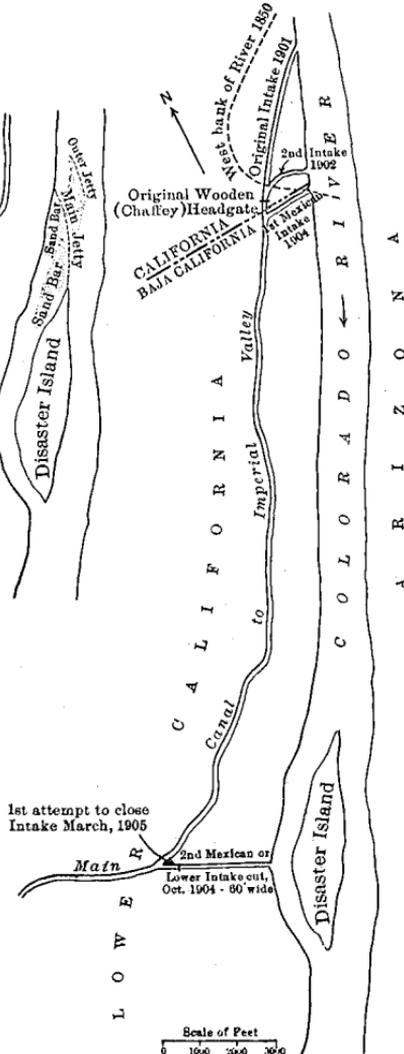
SHOWING THIRD ATTEMPT TO CLOSE THE LOWER INTAKE JULY, 1905

FIG.15



SHOWING LOCATION OF WORK ON A HEADGATE AND THE FOURTH ATTEMPT TO CLOSE BREAK

FIG.16



MAP SHOWING VARIOUS INTAKES OF THE CANAL TO IMPERIAL VALLEY AND LOCATION OF THE FIRST ATTEMPT TO CLOSE THE LOWER ONE

FIG.13

been emptied for periods of not more than 60 hours to permit of inspection and light repairs, but the very first overhauling or extensive repairs were begun on January 5th, 1912.

The writer confesses to a predilection for permanent structures of masonry, concrete, or steel, and this gate and the Alamo Waste-gate, built in 1905, were nightmares to him while in charge of the properties. It would seem that a large part of this was worry wasted, however.

Sharp's Head-gate was designed by, and built under the direction of, Mr. C. N. Perry, then Resident Engineer of both companies, the fundamental idea being to cut up the foundation into a number of water-tight compartments. Plates XLIV and XLV show this construction.

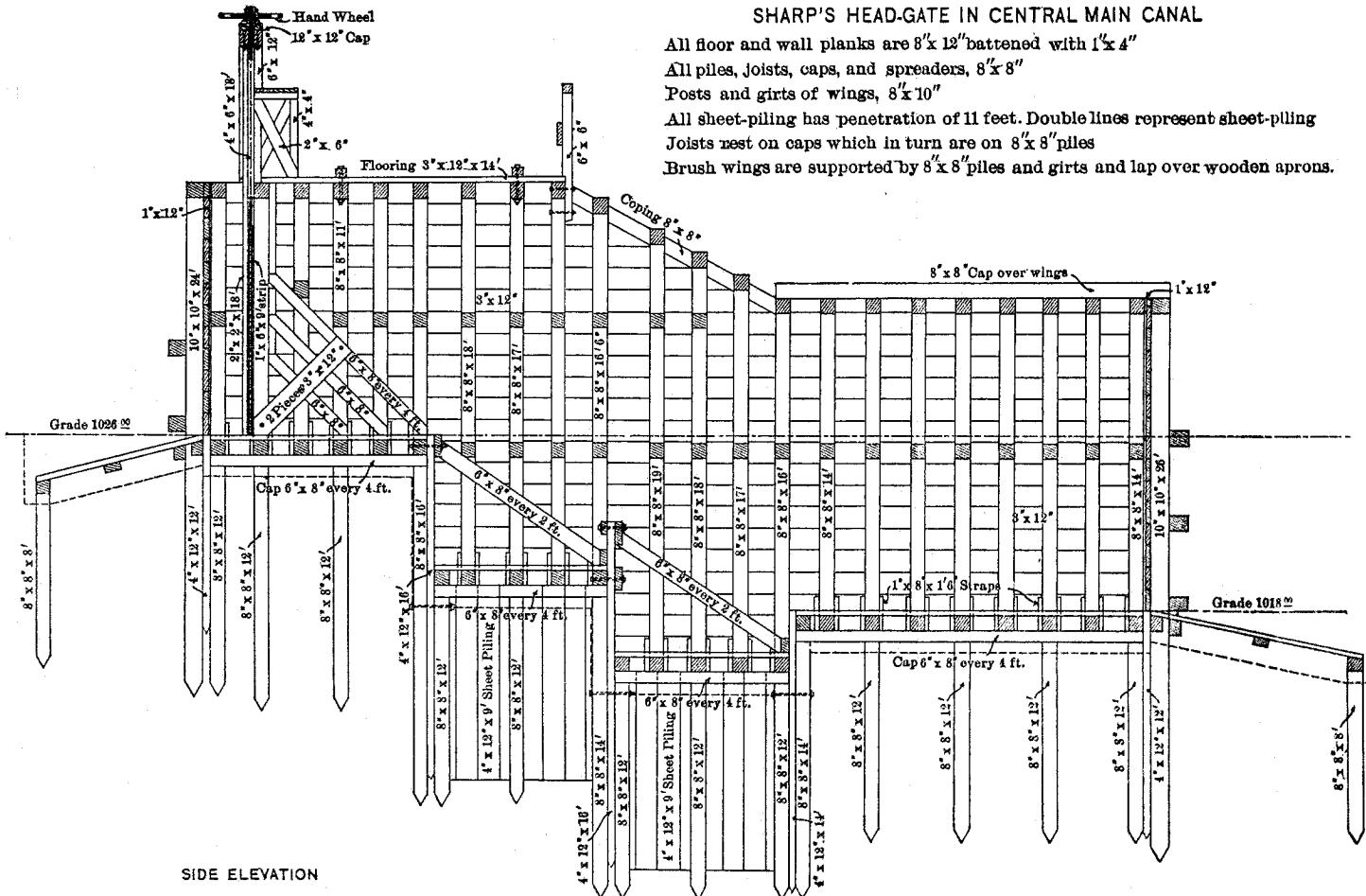
Where Beltran's Slough leaves the Alamo channel, a wooden, flash-board gate was built to waste water through Beltran's and Garza's Sloughs into the New River, but about 3 months after being put in service it failed, due to back currents below it.

The original plan for supplying the territory to the east of the Alamo was to utilize the Alamo channel from Sharp's Heading to Holtville, an earthen dam being used to bring the water to the surface of the land at that point. This dam soon failed, and the canal from there was connected with the Alamo at a point about $1\frac{1}{2}$ miles above Sharp's, such connection being made in record time, with a cross-section only large enough for the demand. The idea was that erosion would enlarge it, which in general has been the case, although some blasting was required to assist the action. Originally known as No. 5 Main, the canal is generally called the East Side Main. It, as well as the West Side Main, is occasionally broken in places by the severe rainstorms—almost cloudbursts—which occur at infrequent intervals in the region. To provide absolute protection against such damage would be very expensive, and neither No. 5, which owns the exposed portion of the East Side Main, nor the C. D. Co., which owns all the West Side Main, has done so. Otherwise, they, as well as the Central Main, are quite satisfactory.

Main canals were constructed from Sharp's to serve the territory between the New and Alamo Rivers (the Central Main); a second, the West Side Main, crossed New River to serve territory west of that waterway, and a third, the East Side Main, to serve the territory

SHARP'S HEAD-GATE IN CENTRAL MAIN CANAL

All floor and wall planks are 8" x 12" battened with 1" x 4"
 All piles, joists, caps, and spreaders, 8" x 8"
 Posts and girts of wings, 8" x 10"
 All sheet-piling has penetration of 11 feet. Double lines represent sheet-piling
 Joists nest on caps which in turn are on 8" x 8" piles
 Brush wings are supported by 8" x 8" piles and girts and lap over wooden aprons.



SIDE ELEVATION

east of the Alamo. In 11 months, or in June, 1901, delivery of water was begun through the Boundary Canal as far west as Calexico, and the Central Main was put into service in March, 1902, or in 19 months.

Imperial Water Companies Nos. 1, 4, 5, 6, 7, and 8 were formed, and triparty contracts were entered into with each. The C. D. Co. constructed the distributing systems for these districts, with the exception of that of Imperial Water Co. No. 7.* The total length of canals in all these distributing systems was approximately 700 miles on January 1st, 1905, and there were also about 80 miles of canal belonging to the C. D. Co. and the Mexican Co., making the total about 780 miles. During 1905 and 1906 relatively little canal building was done, because the river got beyond control; and, from 1907 to 1911, inclusive, the increase has been less than 20%, on account of excessive litigation following the vast expenditures for controlling the river, and because the canals existing on January 1st, 1905, covered 85% of the territory now under ditches.

With the exception of a permanent diversion gate at the river, two permanent structures replacing temporary ones in the valley, the building of the Alamo Waste-gate (Fig. 27), just above Sharp's Heading (June 25th to August 17th, 1905), and another in the Central Main at Station 134 (November 13th, 1904, to January 12th, 1905), that portion of the canal system completed on January 1st, 1905, has not been essentially changed or enlarged, and, with few exceptions, the original structures are still being used. There is a marked tendency on the part of the mutual water companies to replace wooden structures with permanent ones of reinforced concrete, but otherwise in general the canal systems are as satisfactory as any which could be devised.

The irrigation service afforded to farmers in Imperial Valley is the best of which the writer has ever heard. This has been the case with the exception of three short periods: the winter of 1904, 1 month (November) in 1906, and a total of 2 months in 1910, when there were shortages of water. Indeed, so accustomed are the water users

* The water rights for all the land south and east of the district of Imperial Water Co. No. 5 which could be irrigated by gravity from what was known as the Holt Heading—where the East Side Main heads—approximately 18 000 acres, were sold for \$50 000. The purchaser, Mr. W. F. Holt, formed Mutual Water Company No. 7, constructing the distribution system and selling for his own benefit all the capital stock of this company. The fact that this deal was made at the rate of \$3 per acre, including the consideration for the proportional cost of the controlling works in the valley and of the main canal thereto from the Colorado River, for one of the very richest sections of land, shows plainly the financial straits of the company at that time.

of this region to obtaining all the water they want whenever they want it, that a suggestion of delivery in rotation—which is done in almost all irrigation projects—would doubtless meet violent opposition.

A preliminary summary, issued on December 15th, 1911, by the U. S. Census Bureau, states that, in 1909, 2 664 104* acres of land were irrigated in California, of which 220 000 acres, or one-twelfth, were in Imperial Valley. The percentage irrigated of the whole number of farms was 44.6, or 39 352 acres. The area included in projects completed and under construction was 5 490 360 acres, or slightly more than double the present irrigated area. Probably there will soon be 450 000 acres under the Imperial Valley canals, or just about the same proportion of one-twelfth. Of the acreage irrigated in 1909, there were 400 acres (0.01%) under the canals of the U. S. Reclamation Service; 3 490 acres (0.1%) under the U. S. Indian Service canals; 173 793 acres (6.5%) under canals of irrigation districts; 779 020 acres (29.2%) co-operative enterprises; 746 265 acres (28%) commercial enterprises; and 961 136 acres (36.1%) individual or partnership enterprises. Of the irrigated acreage in 1909, 71% was watered by works controlled by the water users. Of the remaining 29%, almost one-third is under the canals of the C. D. Co. Aside from the very large area covered by the canals of this project, its relative importance is vastly increased by the vital necessity for continuous service every day in the year, which has no counterpart of which the writer knows, and the minimum daily demand in winter is one-fourth of the maximum.

OBSTACLES ENCOUNTERED BY THE C. D. Co.

The settlement of Imperial Valley† took place more rapidly than any of the men interested in the project had even hoped, and constituted the most marvelous achievement of irrigation in the West, up to that date at least, and probably to the present time. On January 1st, 1901, with the exception of a party of surveyors, not a single white

* Undoubtedly, the greater part of this total is irrigated only after a fashion, so that the relative importance of the irrigated area in Imperial Valley is much greater than the figures indicate.

† The Imperial Land Company decided to use the name "Imperial Valley," for the region to be covered by the irrigation canals, instead of "Colorado Desert" or "Salton Basin," partly to distinguish between the reclaimed and unreclaimed areas, but chiefly for the effect of the name on readers of the colonization literature put out by the company. The name, "Imperial Valley," is firmly established as referring to the cultivated portion of the Colorado Delta west of the river, whether north or south of the International Boundary Line.

man lived in the whole region; by January 1st, 1903, 2 000 people had come in; by January 1st, 1904, probably 7 000 people had made their homes in the new district, and by January 1st, 1905, the population was between 12 000 and 14 000. As early as 1904 there was a branch railroad through the district from the Southern Pacific main line at Old Beach, since called Imperial Junction, and, at the beginning of 1905, there were seven towns, with stores, banks, etc., 780 miles of canals, about 120 000 acres of land under actual cultivation, and 200 000 acres covered by water stock.

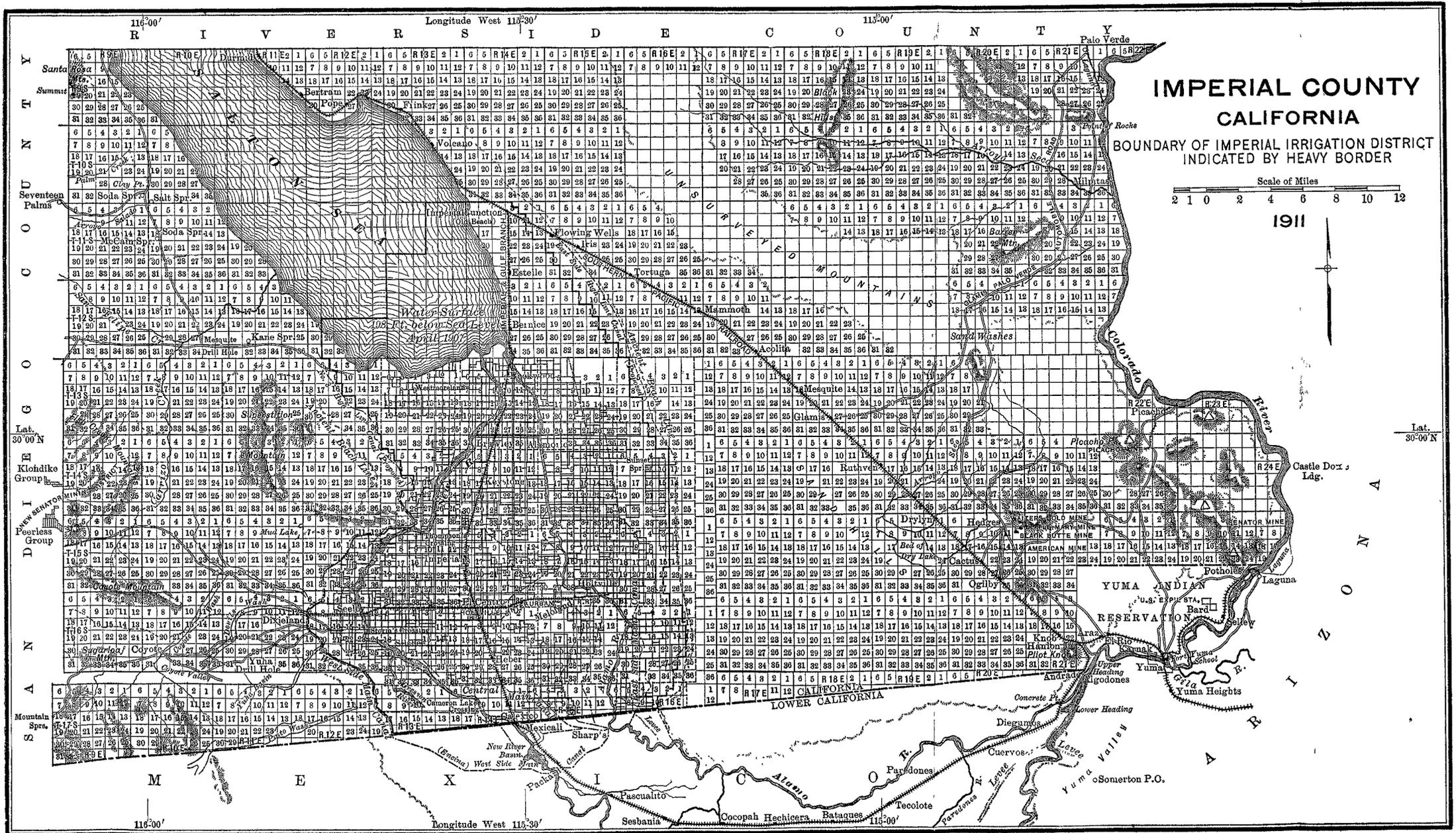
This unprecedented and unexpectedly rapid development overtaxed the resources of the C. D. Co., and, in addition, there were several untoward factors which accentuated the difficulty. These were serious complications in the United States Government Land Survey of the region, an extremely unfavorable soil report by the United States Agricultural Department, agitation for the United States Reclamation Service to supplant the irrigation system of the valley, a question as to the right to divert water from the Colorado River, and troubles at the intake by silt depositions.

United States Land Surveys in the Imperial Valley.—That portion of the Imperial Valley north of the 4th standard parallel was supposed to have been surveyed in 1854-56. The maps and notes for it were accepted, but there is at least some question whether the survey was ever actually made in the field. Later, in 1880, after the International Boundary Commission had surveyed the Boundary Line between the United States and Mexico and marked it continuously with permanent monuments, the area south of the 4th standard parallel was surveyed, this being locally known as the "Brunt" survey. The colonization company, in April, 1900, put out surveying parties under the direction of Mr. Perry, now County Surveyor of Imperial County, to re-run the Government lines and establish corners so that settlers might have proper descriptions for the tracts of land they wished to file on, and also that the distribution systems of the various mutual companies might be located along the Government subdivision lines, as the topography of the land is such that this ideal canal location is generally feasible. Mr. Perry found nearly all the corners of the Brunt survey, and used the notes showing certain connections made with the survey of 1856 along the 4th standard parallel. In this way

the lines to the north were retraced, but, some time later, when the survey had extended farther and the work of retracing the lines east of the Alamo River was commenced, it was discovered, by encountering natural features given by the notes of the 1856 survey, 2 miles or more out of correspondence, that there were serious errors. Exhaustive search was then made for the 1854-56 survey stakes, but in an area of thirty townships only five corners were discovered which seemed to be authentic. These were widely scattered, and showed great errors. Between the 3d and 4th parallels the actual distance was found to be $25\frac{1}{2}$ miles, or an error of $1\frac{1}{2}$ miles in a 24-mile north and south line. East and west the error was approximately 2 miles in 30.

Throughout the territory, Sections 16 and 36, the school sections, had been given to the State of California by the United States Government for the benefit of the State school fund, the remainder of the land belonged to the United States, and this dual ownership increased the difficulty of making any adjustment. In June, 1902, the president of the colonization company and the chief engineer of the C. D. Co. went to Washington, explained the situation, and, on the advice of the General Land Office, an Act was prepared and passed in July, 1902, authorizing a resurvey of twenty townships of the land in Imperial Valley. The outside lines of these townships were re-run in 1903 and are known locally as the "Henderson" survey. It was more than 6 years, however, before the interior lines in these townships were re-run and the work was completed and approved.

In the mean time, it was impossible for the Land Office to issue patents to the settlers, and thus men practically owning from 160 acres to two and three times that area of extraordinarily fertile land, with a selling value of from \$60 to \$100 per acre, could offer no security for a loan with which to make permanent improvements. The United States land laws are extremely strict and severe with reference to a settler borrowing money with which to make final proof. Under such circumstances, the interest rate was naturally from 10 to 12% per annum, while the interest on deferred payments for the water stock was only 6%, so that the C. D. Co. suffered severely. However, it was not until 1909, more than 3 years after the control of the company was taken over by the Southern Pacific interests, that any suits were entered to foreclose on the collateral notes and mortgages secured by the water stock.



Soil Surveys of the Imperial Valley.—In the fall of 1901 the Bureau of Soils, United States Department of Agriculture, made a soil survey of Imperial Valley. On January 10th, 1902, a preliminary report, "Circular No. 9," was issued covering the 169 sq. miles of territory which had been examined.* The report doubtless presented the only possible conclusions, according to the information at that time extant regarding alkaline soils of such depth as are found in the Imperial Valley. It was very unfavorable, however, and calculated to deter sensible people from settling in the region. For example, one statement was as follows:

"One hundred and twenty-five thousand acres of land have already been taken up by prospective settlers, many of whom talk of planting crops which it will be absolutely impossible to grow. They must early find that it is useless to attempt their growth. * * * No doubt the best thing to do is to raise crops such as the sugar beet, sorghum, and date palm (if the climate will permit), that are suited to such alkaline conditions, and abandon as worthless the land which contains too much alkali to grow those crops."

The warning was reiterated in a subsequent report.† It seems certain that, had the territory not been already settled in very large measure when these reports were sent out, Imperial Valley would yet be unreclaimed.

Agitation in Favor of a Reclamation Service Project.—When the United States Reclamation Service Act was passed, in June, 1902, the crops produced in the Imperial Valley were causing a return of confidence in the region, and the extraordinarily rapid development was being resumed. The irrigation possibilities on the Colorado River had already been examined by the United States Geological Survey, and in 1903 plans for the Yuma Project were outlined. The engineers of the Service were convinced that no diversion from the Colorado for irrigation could be permanently successful where provisions were not made for preventing the heavy silt from entering the canals—that it would take an impractically large amount of dredging to keep canals leading directly from the river open for reasonably satisfactory delivery of water. The cost of the Laguna Weir, borne by the land owners of Imperial Valley alone, constitutes a serious burden, but, if

* "Field Operations of the Bureau of Soils, U. S. Department of Agriculture, 1901, p. 587."

† "Soil Survey of the Imperial Area, California (Extending the Survey of 1901), Advance Sheet of Field Operations of the Bureau of Soils, 1903."

borne by all the irrigable land in both valleys, the cost per acre would be reduced to approximately one-fourth. Mr. William E. Smythe, of San Diego, who has been very prominent in the work of the National Irrigation Congress, and has written extensively on irrigation generally, urged the people of Imperial Valley to join with the Yuma Project; that the enterprise would then be backed by the Government with unlimited funds; that they would be required to pay to the Government only a small portion of the money they were obliged in one way and another to pay the C. D. Co., and that they would eventually attain the laudable desire of owning and operating their own system. The Imperial Water Users' Association was accordingly formed, with Mr. W. F. Holt, of Redlands, Cal., as its President, and negotiations were at once instituted with the C. D. Co. to acquire its canal system. Mr. A. H. Heber, President of the C. D. Co., who acted for it in the matter, knew that the estimates of the Reclamation Service for the canal line into Imperial Valley, lying entirely on American soil, were at least \$10 000 000, on account of the sand hills. He believed that the Alamo River for 40 miles was a very satisfactory main canal, and that by owning the 100 000-acre tract of the Mexican Co., building another waterway through Mexican territory would require the consent of the Mexican Co.; consequently, his idea regarding the values of the property were excessively high.

As a natural feature of these negotiations, and with a view to tempering such ideas as to price, the right of the C. D. Co. to take water from the Colorado was challenged. The navigability of that stream suddenly assumed serious commercial, national, and international importance. As usual in such cases, these questionings were carried to unfortunate extremes.

In the course of events, at a mass meeting held in Imperial on July 30th, 1904, Mr. Heber offered to have the price fixed by arbitration, one man to be appointed by him, one by the Imperial Water Users' Association, and a third to be selected by these two. This was not done, but the Engineers of the Reclamation Service made an appraisal of the C. D. Co.'s plant. The Imperial Water Users' Association appointed a committee headed by its president, Mr. Holt, to represent it in all negotiations, and it agreed with Mr. Heber on a price of \$3 000 000. Mr. C. D. Walcott, Director of the U. S. Geological Survey, and of the Reclamation Service, made a report to the Secretary of the

Interior in the matter on September 15th and again on October 1st, 1904, that

"from present knowledge of the conditions, a recommendation to pay three million dollars for the property and rights involved is not justified."

On being advised of this report, an endeavor was ostensibly made by the Committee and Mr. Heber to secure different action. It appears, however, that, without intimating to Mr. Heber that it had changed front, the Committee agreed with the Reclamation Service authorities against buying the property on the agreed basis. With such unpardonably bad faith on the part of the Committee, it is not surprising that the matter ended with relations between Mr. Heber and the Reclamation Service so strained that further negotiations were impossible.

In a further report made by Director Walcott on January 4th, 1905, to the Secretary of the Interior, it was advised that, even if there were no complications because of the unfavorable soil report by the Department of Agriculture and

"the present desperate situation of many of the inhabitants of the Imperial Valley, it was a matter of grave doubt whether it was wise to become involved in the situation.

"Much of the land filed on is unsuitable for cultivation owing to the large amount of alkali and other adverse conditions of the soil. The water supply is deficient, owing to poor construction and accidents to the canal system, and although during the fall months there has been ample water, it appears that the people will not utilize it, and from best information are not planting crops to any considerable extent. Difficulties of handling the silt are very great, and if the Government is to take up the project, it must make enormous expenditures at once to prevent the country lapsing into a desert condition."

Shortly after this, it was announced by the Secretary of the Interior that the Assistant Attorney General had concluded that no law existed whereby it could deal with the problem of carrying water through Mexico.

The effect of the entire incident was to render the people of the valley antagonistic to the company, and at the same time split them into several factions. More important, however, was the effect of the severe criticisms of the plant and water rights of the C. D. Co., which had been given wide publicity. The company's credit, which had slowly but steadily improved since 1902, was again destroyed in South-

ern California and in the larger financial markets of the United States. Consequently, early in 1905, when these negotiations ended, the company was almost on the rocks.

Water Rights Attacked.—Because of the attacks on the right to take water from the Colorado, then well under way, a bill was introduced into the House of Representatives in January, 1904, at the request of the C. D. Co., declaring:

“That the water of the Colorado River for the irrigation of the arid land that may be irrigated therefrom is hereby declared to be of greater public use and benefit than for navigation, and the diversion of the water from said river, heretofore made and that which may in future be made, for irrigation purposes, in accordance with the laws of the respective States and Territories in which such diversion has been or may be made, is hereby legalized and made lawful.

“Section 2. That any person, firm, or corporation be, and is hereby, authorized to divert, take, and appropriate water from the Colorado River for the purpose of irrigation, in such quantity, subject to and under the State appropriation of the State of California, as now in force under the laws of said State.” (H. R. 13 627, 58th Congress, 2d Session.)

The U. S. Reclamation Service had filed on some of the flood-waters of the Colorado in order to fill four large reservoirs between The Needles and Yuma, then under contemplation, and such filings were practically second only to those of the C. D. Co., so that the effect of this proposed legislation, other than on the C. D. Co., was null. The bill was bitterly opposed by Mr. Smythe, as representing the majority of the settlers in Imperial Valley. No attempt was made to amend the bill with a view of protecting all interests in a fair and equitable manner, but instead, under date of April 8th, 1904, the Acting Attorney General, Mr. Hoyt, in an opinion addressed to the Committee on Irrigation on Arid Lands, to which the bill had been referred, said:

“In view of these provisions [from the Treaty of Guadalupe-Hidalgo, February 2d, 1848; of the Gadsden Purchase, December 30th, 1853; and the Boundary Treaty of November 12th, 1884, between Mexico and the United States] and of the important irrigation projects now and hereafter to be carried on by the United States Government, I seriously doubt the wisdom of a surrender by Congress at this time of all control over the waters of the Colorado River.”

Accordingly, the Committee reported* requesting the Secretary of the Interior to investigate and report to Congress on the various questions involved in the use of the waters of the Lower Colorado River, with a view to determining their availability for irrigation, and recommend any legislation which might be necessary. Under this resolution, Director Walcott reported through the Secretary of the Interior, on December 24th, 1904, that governmental control of the waters of the Colorado River was absolutely necessary to obtain the best results; that, the river being navigable, water appropriations under the Arizona and California laws were not valid; suggesting that legislation be along the line guarding present navigation interests; confining diversions heretofore made to the extent of actual beneficial use of the waters diverted upon land capable of producing remunerative crops, and making the same appurtenant to specific tracts of land; and making the approval of the Secretary of the Interior necessary with respect to future appropriations.

Mexican Concession Secured.—Failing to secure an adjustment of water rights at the hands of Congress, Mr. Heber went at once to Mexico and quickly obtained a concession from President Diaz, which was ratified by the Mexican Congress on June 7th, 1904.

This concession authorized the Mexican Co. to carry, through its canal system in Mexico, 284 cu. m. per sec. (approximately 10 000 sec-ft.), to be diverted from the Colorado River in United States territory by the C. D. Co. and turned over to the Mexican Co. at the boundary line; to construct an intake on Mexican territory, and connecting with the said canal system, and divert through such intake 284 cu. m. per sec., to be used in the irrigation of lands in Mexico and in the United States, but with the proviso, "without injuring the rights of any third party nor the navigation as long as the river is destined for navigation"; that, of the water carried in the canal, enough should be used to irrigate the lands in Mexico susceptible of irrigation by gravity to an amount not exceeding one-half the total volume; that the Mexican Co. should begin surveys within 6 months, and within 12 months file, with the Secretary of Development, maps in duplicate of the proposed extensions and betterments, together with a descriptive report, and entirely complete the same within 7 years;

* House Joint Resolution Nos. 147, 133. State. 591.

that the company should pay into the Inspection Fund, as is customary in all concessions granted by the Mexican Government, a sum, in this case \$300 (Mexican money), per month, and should be subject to inspection by an engineer appointed by the Secretary of Development; granting the company the right of eminent domain over private property and defining the process by which condemnation could be carried out—incidentally with minimum possible difficulty—and permitting importation once for all, free of customs or duty, all equipment and apparatus necessary for the construction of the proposed extensions and betterments, together with freedom from all taxes, except stamp tax, for a period of 10 years; stipulating that under no circumstances should the company sell or mortgage the concession to any government or foreign state, nor admit it in partnership; that the company should be subject to the laws and rulings now in force, and which in future may be enacted, for the supervision and use of waters; particularly specifying that the company and its assigns shall always be considered as Mexican corporations, though all or any of its stockholders should be foreigners; that the corporation should be subject to the jurisdiction of the Courts of the Republic in all affairs emanating within Mexican territory, and that such stockholders should never be able to allege the rights of foreigners under any circumstances, but have the rights and the methods of establishing the same as the laws of the Republic grant to Mexican citizens, so that, in any matters, diplomatic or foreign agents should not have any interference.

CONDITION OF PLANT IN THE SUMMER OF 1904.

From the first, there was a great deal of trouble with the Chaffey Head-gate, chiefly because its floor was not down to the bottom grade line of the canal, as originally planned. As has been explained, this gate was a temporary structure, but well and substantially built. Just as it was being covered up by the operations of the dredge, *Alpha*, cutting the main canal into the permanent concrete head-gate from below, in 1906, the writer examined it carefully and found it in an excellent state of preservation. The floor was so high, however, that it was necessary, during the low-water seasons of 1902-03 and 1903-04, to cut a by-pass around the gate, and close it on the approach of the summer floods. When the Mexican concession was obtained, the first Mexican intake was cut from the river to the main canal, as shown in Fig. 13.

In the winter of 1902-03 there had been shortages of water in the valley, due to the fact that the main canal had not been completed to its final depth; and, with the apparatus and available funds on hand, it was impossible to keep the water supply up to the demands when the river fell exceedingly low. In the winter and early spring of 1904, another water shortage caused considerable damage in the valley, and claims amounting to \$500 000 were presented to the company. Every one of these was settled out of Court, however, in 1905 and the early part of 1906, with a payment of less than \$35 000, taken entirely in water and water stock, and the writer believes that every claim was fairly settled, at least as far as the settlers were concerned.

Below the intake the first 4 miles of the Main Canal caused much worry, due to the extent to which it silted up during floods, but, with this exception, the plant of the C. D. Co. was in quite satisfactory condition. The canals were generally well located and in fair condition, and the structures, though of redwood and not concrete, were substantially built according to good design, and were in excellent condition. The canals in the distribution systems of the mutual water companies were silting up constantly, on account of the muddy water. In part, this was unavoidable, but was largely due to uneconomical methods of water deliveries when dealing with muddy water, particularly in serving any settler on his demand, regardless of the very low velocity, if no one else wanted water from the lateral during the same time. The silt problem in the distribution systems of these companies, however, is as simple as it will ever be for any lands irrigated along the Lower Colorado. The financial status of the various mutual companies was quite good, and they had generally established a small but satisfactory credit with the local banks.

To avoid excessive silt depositions in the first 4 miles of the canal, in February and March, 1904, the Best Waste-gate, so-called, was put in 8 miles below the intake, where water could be wasted from the Alamo channel through the Quail River into the Paredones River and thence into Volcano Lake. This was a wooden A-frame, flash-board gate, 60 ft. long, but it was carried away in June, 1906, by the side-cutting of the banks while the Alamo channel was being enlarged by that year's summer flood. The idea was to divert a large quantity of water during the flood season of 1904, waste it through the Best Gate, and in this way scour out the upper portion of the canal. At

first the action was as expected, and some 2 ft. in the bottom were carried away. When the river reached its maximum height during the summer flood of 1904, however, and carried an excessive silt content, particularly of the heavier and sandy type, this scouring action was entirely overcome, and the bottom of this stretch was raised approximately 1 ft. higher than during the previous year.

The Silt Problem.—This action accentuated, and properly impressed on the engineers of the C. D. Co., the seriousness of the silt problem in diverting the Colorado River water. Generally speaking, during flood stages, the water carries all the silt it can transport, and the faster the current the larger the particles it picks up and carries along. It is certainly desirable, and probably essential, to provide settling basins at or immediately below the diversion point, in which water can be practically stilled and thus insure the deposition of the heavier silt having very slight fertilizing value, and the admission of only such partly clarified water into the canals. Unless some provision is made, as at the Laguna Weir, the diversion canal immediately below the head-gate must act as a settling basin, which is just what happened from the very beginning in the canals of the C. D. Co.

The results of such excessive silting were obviated in various ways, largely by the construction of new intakes, until the diversion of the entire river occurred, and the permanent head-gate was put in service in 1907. The clam-shell dredge, *Delta*, was utilized intermittently to remove the deposits until 1910; then a submerged weir was built across the river, to raise the water at the intake; and lastly large suction dredges were operated just below and just above the regulating gates.

Rather carefully kept records indicated that the bed of the canal at the Lower Heading was raised a little more than 5 ft. between March 1st, 1907, and March 1st, 1910, most of this taking place in the first 6 months. The bed of the Alamo near Sharp's Heading was raised approximately 2 ft. in the same time, and there is constant deterioration all along between these points on the Alamo channel. The reduction of capacity in the larger canals has been noteworthy, but the maximum effect is shown in the smaller laterals constituting the distribution systems of the various mutual water companies.

Mr. Robert G. Kennedy states* that on the Bari Doab Canal from the Punjab River, the canals in Sind from the Indus and Shwebo,

*"The Prevention of Silting in Irrigation Canals," *Minutes of Proceedings, Inst. C. E.*, Vol. CXIX, 1896, pp. 281-290.

and the Mandalay canals in Burmah, it appears that in a non-silting and non-scouring channel the mean velocity is independent of the width, but increases with the depth of the channel, according to the equation:

$$V_0 = 0.84 d^{0.64},$$

in which V_0 = the mean velocity of a non-eroding, non-depositing current; and d = the depth for fine sand-silt, the constants varying slightly with the kind of silt.

He also points out the exceedingly important deduction that during flood stages in the river, the diversion of large quantities of water in an effort to scour away silt depositions in the upper reaches of canals will have the opposite result, because of the excessive silt contents of the water diverted.

The same rule probably applies fully in the case of canals carrying Colorado River water when they are free of vegetation. In point of fact, however, rank growths of tules and willows spring up, on the banks and berms and along the edges out into the water, with such rapidity as to increase tremendously the deterioration of carrying capacity, particularly in the smaller canals. Furthermore, the rate of deterioration in these laterals increases with the decrease in channel efficiency. The maintenance of the district distribution systems, therefore, consists, in large part, in keeping down and removing the brush and tules.

The various distribution systems were ordinarily designed and built on the basis of a capacity of 1 sec-ft. per 120 acres of land thereunder, although in some cases the ratio was decreased to 1 sec-ft. per 93 acres (8 in. vertical depth of water in a month). It would have been just as well, indeed considerably better, and of course cheaper, to have made the canals much smaller, for they were put into service when only a small percentage of the land was in cultivation, and, as they carried only a fraction of their capacity, they very soon silted up badly. Removing the silt deposition and the accompanying tule growths is fully as expensive as the excavation of the original section.

This needlessly large excavation was required by the contract provisions under which the C. D. Co. built the distribution systems of the various mutual water companies, and such provisions at the time were necessary to assure colonists that the water supply would be ample. In the construction of the first lateral canals built, however,

the leaving of inside berms was a defect which should have been avoided. These flat stretches, usually kept damp and seldom deeply submerged, afford ideal conditions for tule growths, and should be studiously avoided in this region.

Canal Maintenance.—In general, the best method of clearing away the brush, tules, and deposited silt in the smallest canals has been found to be by Mexican or Indian hand labor. The presence of checks and other canal structures at relatively close intervals makes the use of machinery of questionable economy. For the large canals, "V's", dragged by horses or traction engines, portable floating dipper-dredges, Lidgerwood cross-draggs, portable clam-shell dredges, and a number of devices designed by local inventive geniuses have been tried with varying success. The results in all cases depend so greatly on the efficiency with which they are handled and the local conditions under which they work that it will not be profitable to attempt to give any cost figures—indeed, with the exception of Imperial Water Company No. 1, no cost-keeping worthy of the name has been attempted.

Perhaps the most satisfactory appliance for cleaning canals too small for floating dredges is a clam-shell bucket arranged on wheels so that it may follow along the bank. (Fig. 17.) The C. D. Co. has two of these machines, manufactured by the Stockton Iron Works, Stockton, Cal., which cost \$5 000 each, f. o. b. factory. These consist of a clam-shell bucket having a capacity of 15 cu. ft., with a 40-ft. steel boom carried on an all-steel frame. The maximum width is 14 ft. The power is supplied by a 15-h.p. Atlas gasoline engine, manufactured in San Francisco, and the machine is self-propelling, with two speeds forward and one reverse. No definite figures, including deterioration and cost of moving from one job to another, are available, but it is understood that the cost of handling material with these machines is about 13 cents per cu. yd.

For handling silt in the upper reaches of the Main Canal along the river, the large 4-yd. dipper dredge, *Alpha*, used in the original construction, was perhaps the most efficient of all agencies for the first few years until the waste banks along the canal became too high to permit of its further use; it handled material for about 6 cents per cu. yd. A suction dredge, the *Beta*, equipped with a 12-in. Kroh centrifugal pump—manufactured in San Francisco—was tried very soon after the canals were put into service, but too much difficulty was

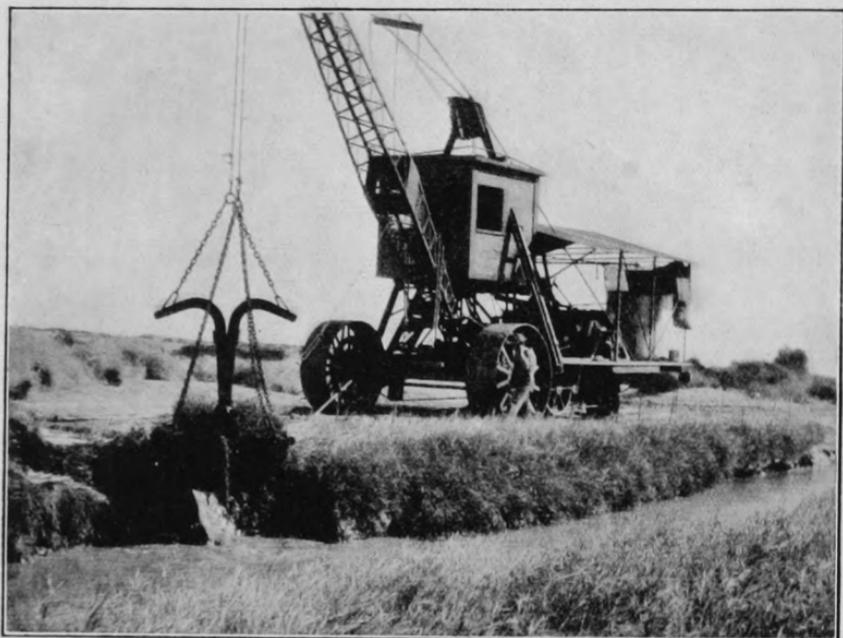


FIG. 17.—STOCKTON CLAM-SHELL DREDGE CLEANING CANALS IN IMPERIAL VALLEY.

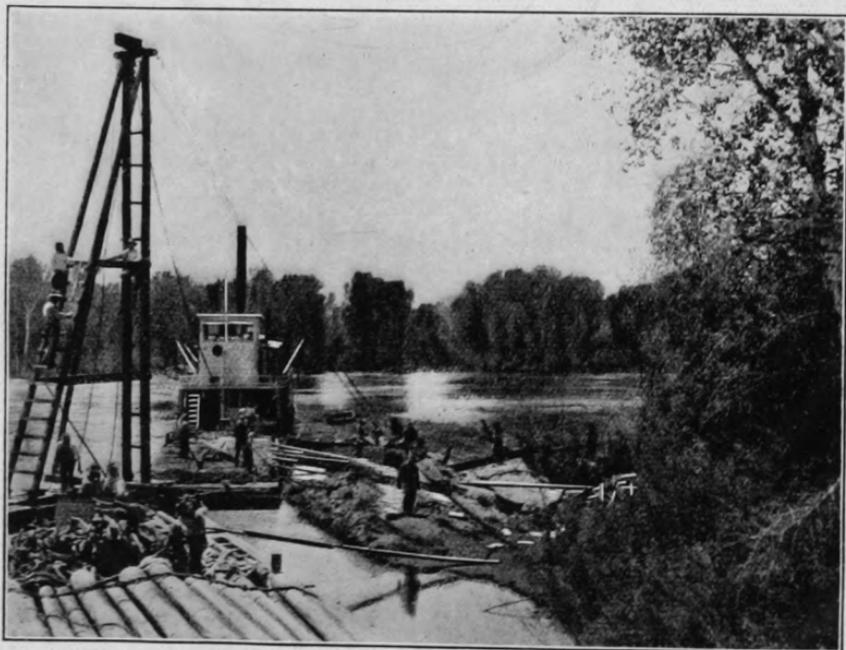


FIG. 18.—THIRD ATTEMPT TO CLOSE BREAK AT LOWER MEXICAN INTAKE, JUNE 1ST, 1905.

caused by roots clogging the pipes and machinery. Mr. H. W. Blaisdell, of Los Angeles, one of the principal stockholders of the C. D. Co., devised a rotary cutter for use at the end of the suction pipe, but it was not successful. This dredge was used at the Lower Heading, in the construction of the Rockwood Gate, and in the subsequent diversion work until June, 1907, when it was dismantled.

In the central main in the valley, and also in the Alamo channel just above Sharp's Heading, a 2-cu. yd. dipper dredge, the *Gamma*, has been used almost continuously since it was put in operation in 1904, removing material at about 5 cents per cu. yd.

The clam-shell dredge, *Delta*, described in some detail later, has done excellent service in silt removal and incidental levee building, as well as in channel straightening, since its arrival on the work in November, 1906. It is now engaged in building cut-offs and making general channel improvements, rather than removing the silt deposits direct.

In the summer of 1910 an arrangement was entered into between the various mutual water companies combined and the Receiver of the C. D. Co. whereby the former were to furnish the money and build a suction dredge and rent it to the latter for 10% annually on its first cost. This dredge was built just below the concrete head-gate, and its operation is confined to the American side of the line, the contract being entered into with the North American Dredging Company, of Los Angeles, on December 10th, 1910, for the construction and equipment of an exact duplicate of one of the latter company's dredges in San Pedro Harbor, for \$57 300. After being put into service it was found necessary to remodel the upper deck, in order to make the quarters of the crew suitable for the climatic conditions, at a cost of \$950, and a bonus of \$2 200 was paid for completion 11 days ahead of the contract time—4 months—making the total cost \$60 450, exclusive of engineering, inspection, and legal expenses, which brought the grand total cost up to approximately \$63 600. This dredge, the *Imperial*, has a hull 105 ft. long, 55 ft. wide, and 8 ft. deep, and is equipped with a 15 by 60-in. Kroh centrifugal pump driven by a vertical compound engine, steam being supplied by a 250-h.p. marine-type boiler. This dredge handles the silt deposits in the enlarged section of the canal below the head-gate at the rate of about 200 cu. yd. per hour lifted to an average height of 35 ft., at a cost of from 5 to 7

cents per cu. yd., exclusive of interest, taxes, and depreciation, using crude oil fuel at \$1.40 per bbl., equivalent to coal at \$5.60 per ton.

The *Imperial* was equipped with a cutter for stirring up the material, but this was found to be unnecessary for handling the silt deposits just below the head-gate, and the cutter engine, of vertical compound type, with 8 by 15 by 10-in. cylinder, was installed on the barge, *Silas J. Lewis*, mentioned later, in the canal above the head-gate to run the 10-in. Kroh pump formerly on the *Beta*, the resulting dredge being known as the *El Centro*. Under like conditions, the cost of handling material with the *El Centro* is approximately the same as with the *Imperial*.

With these two suction dredges, it is claimed that the bed of the Main Canal has been lowered approximately 5 ft. above and at the head-gate and for a distance of $3\frac{1}{2}$ miles below, diminishing gradually to nothing throughout the next $2\frac{1}{2}$ miles. If future experience confirms such results, it would seem that the periodic dredging of silt depositions from a settling basin near the intake, at a cost of from \$30 000 to \$40 000 per annum, will solve the silt problem in the Imperial Valley canal system, except for the very fine silt which cannot be gotten rid of except by allowing the water to be quiescent for some time.

The following general cost figures on maintaining the 373.25 miles of canals of the distribution system of Imperial Water Company No. 1 during 1911 are taken from the annual report of the Superintendent, R. S. Carberry, Assoc. M. Am. Soc. C. E.

Cleaning 465 miles of canal cost \$60.64 per mile. The figures in 1910 are 562 miles at \$43.81 per mile, and the average cost for the last 6 months of 1909 was \$73.16. Clearing on 194 miles of canal cost \$35.39 per mile. Cutting brush on 392 miles cost \$20.71 per mile. The figures in 1910 were 346 miles at \$43.47 per mile, and \$60.65 per mile for the last 6 months of 1909.

In this report it is stated that canal "V'ing" is the best method for cleaning canals, generally speaking, and the company owns three "V's", each costing about \$600, and three caterpillar traction engines to operate them, each costing \$4 200. During the year, 363.8 miles of canal were "V'd" at \$58.81 per mile, as compared with 362 miles in 1910 at \$60.74 per mile, the details being as follows:

"V'ing"	\$16.76
Repairs to engines	16.29
Repairs to "V's"	5.00
Fuel and oil	5.96
Mexican labor following "V's".....	14.80
	<hr/>
Total average cost per mile.....	\$58.81

During the year, 1 415 miles of canal were worked on, so that the whole system was covered in various ways nearly four times during the year. A small portion of the system was not worked on at all, so that this statement gives some idea of the difficulty in maintaining the system.

The cost of building 117 new structures was \$6 278.75, and the cost of repairing old structures was \$4 145.05, making the total cost of structure maintenance and renewal \$10 423.80. The average number of men employed per day (300 working days per year) was 162, or 0.43 man per mile of canal per day, in addition to teams and machinery. The bottom width of the canals constituting this system varies from 20 to 5 ft.

Canal Operation.—The mutual water companies have never considered delivering water to stockholders in rotation, but instead, without exception, supply any water user on demand, even though he may be at the very end of a long lateral and the only person desiring water from that lateral at the time. Thus, naturally, exceedingly small quantities of water are carried occasionally in every canal except the very largest laterals, and the result is low velocities and heavy silt deposition and canal deterioration. The feeling seems to be general that the additional cost of maintaining the various distribution systems is more than offset by the advantages or convenience of the water users in obtaining irrigation water at all times on 24 hours' notice. The amount which the maintenance cost of canals could be cut by adopting a rotation system of delivery is problematical, but must be between 35 and 65 per cent. This fact should be borne in mind in making comparisons with the cost data just given.

THE FOURTH OR LOWER INTAKE.

This is such a very important matter that the reasons for digging the lower Mexican intake and the method of handling it when

completed are given by quoting from Mr. Rockwood,* the man who did it.

"As soon as the summer flood (1904) dropped and I discovered that instead of the bottom being lower it was approximately 1 ft. above that of the year previous, we adopted the only means at our command to attempt to deepen the channel.

"Knowing the character of the material to be removed, we knew that with the dredging tools which we had (4-yd. dipper dredge *Alpha* and 12-in. suction dredge *Beta*), it would be impossible to dredge out this 4 miles of canal in sufficient time for the uses of the valley, providing the water in the river should drop as low as it had the previous year. The dredges were brought back, however, and put at work, but the result proved, as I had anticipated, that it would take practically all winter to dredge the canals; that is, it would take all winter to provide new machinery, even if we had the money; and in hopes, then, that it might possibly prove effective, I employed the steamer *Cochan*, and, placing a heavy drag behind it, ran it up and down the canal in hopes that by stirring up the bottom there would be sufficient velocity in the canal itself to move the silt deposits on below the 4-mile stretch to a point where I knew the water had sufficient velocity to keep the silt moving. A month's work, however, with the steamer proved that the work being done by it was inadequate.

"*The Great Problem.*—We were confronted then with the proposition of doing one of two things, either cutting a new heading from the canal to the river below the silted 4-mile section of the canal, or else allowing the valley to pass through another winter with an insufficient water supply. The latter proposition we could not face for the reason that the people of the Imperial Valley had an absolute right to demand that water should be furnished them, and it was questionable in our minds as to whether we would be able to keep out of bankruptcy if we were to be confronted by another period of shortage in this coming season of 1904-1905.

"The cutting of the lower intake, after mature deliberation, and upon the insistence of several of the leading men of the valley, was decided upon. We hesitated about making this cut, not so much because we believed we were incurring danger of the river's breaking through as from the fact that we had been unable to obtain the consent of the Government of Mexico to make it, and we believed that we were jeopardizing our Mexican rights should the cut be made without the consent of the Government. On a telegraphic communication, however, from our attorney in the City of Mexico, to go ahead and make the cut, we did so under the presumption that he had obtained the necessary

* "Born of the Desert—Imperial Valley in Its Making Not A Dream—A Brief History of the California Development Company." By C. R. Rockwood. Second Annual Magazine Edition. *Calexico Chronicle*, Calexico, Cal., May, 1909.

permit from the Mexican authorities. It was some time after this, in fact after the cut was made to the river, before we discovered that he had been unable to obtain the formal permit, but had simply obtained the promise of certain officials that we would not be interfered with, providing that plans were at once submitted for the necessary controlling structures to be placed in this heading.

Reasons Why.—This lower intake was constructed, not, as is generally supposed, because there was a greater grade from the river through to the Main Canal at this point. The grade through the cut and the grade of the Main Canal above the cut were approximately the same, but the cut was made at this point for the reason that the Main Canal below the point where the lower intake joined it, was approximately 4 ft. deeper than the Main Canal through the 4 miles above this junction to the Chaffey gate, consequently giving us greater water capacity. In cutting from the Main Canal to the river at this point, we had to dredge a distance of 3 300 ft. only, through easy material to remove, while an attempt to dredge out the Main Canal above would have meant the dredging of 4 miles of very difficult material. We began the cut the latter end of September and completed it in about 3 weeks.

“As soon as the cut was decided upon, elaborate plans for a controlling gate were immediately started and, when completed early in November, were immediately forwarded to the City of Mexico for the approval of the engineers of the Mexican Government, without whose approval we had no authority or right to construct the gate. Notwithstanding the insistence of our attorney in the City of Mexico and various telegraphic communications insisting upon this approval being hurried, we were unable to obtain it until 12 months afterward, namely, the month of December, 1905.

Unprecedented River Conditions.—In the meantime serious trouble had begun. We have since been accused of gross negligence and criminal carelessness in making this cut, but I doubt as to whether any one should be accused of negligence or carelessness in failing to foresee that which had never happened before. We had before us, at the time, the history of the river as shown by the daily rod readings kept at Yuma for a period of twenty-seven years. In the twenty-seven years there had been but three winter floods. In no year of the twenty-seven had there been two winter floods. It was not probable, then, in the winter of 1905, that there would be any winter flood to enlarge the cut made by us, and without doubt, as it seemed to us, we would be able to close the cut before the approach of the summer flood by the same means that we had used in closing the cut for three successive years around the Chaffey gate at the head of the canal.

“During this year of 1905, however, we had more than one winter flood. The first heavy flood came, I believe, about the first of February,

but did not enlarge the lower intake. On the contrary, it caused such a silt deposit in the lower intake that I found it necessary, after the flood had passed, to put the dredge through in order to deepen the channel sufficiently to allow enough water to come into the valley for the use of the people.

"This was followed shortly by another heavy flood that did not erode the banks of the intake, but, on the contrary, the same as the first, caused a deposit of silt and a necessary dredging. We were not alarmed by these floods, as it was still very early in the season. No damage had been done by them, and we still believed that there would be no difficulty whatever in closing the intake before the approach of the summer flood, which was the only one we feared. However, the first two floods were followed by a third, coming some time in March, and this was sufficient notice to us that we were up against a very unusual season, something unknown in the history of the river as far back as we were able to reach; and, as it was now approaching the season of the year when we might reasonably expect the river surface to remain at an elevation that would allow sufficient water for the uses of the valley to be gotten through the upper intake, we decided to close the lower.

"Five Floods in One Season.—Work was immediately begun upon a dam similar to the ones heretofore successfully used in closing the cut around the Chaffey gate. The dam was very nearly completed, when a fourth flood coming down the river swept it out. Work was immediately begun on another dam which was swept away by the fifth flood coming down during this winter season."

These closings of the by-passes or cuts around the Chaffey Gate were effected by throwing a barrier of brush across the cut and dragging earth over it with Fresno scrapers, pushing it into the water on the up-stream side, thus gradually rendering the barrier impermeable and then building it up as an earthen dam. In attempting to make the closure here mentioned, in March, a small pile-driver was rigged up on the end of the *Alpha*, and one line of 8 by 8-in. pine timbers, 3 ft. apart, was driven across the opening about 3 000 ft. west of the river bank, and an 8 by 8-in. waling was bolted to each pile above the water surface. Brush fascines were then made up, and all the sand bags available—about 10 000—were filled in readiness. Simultaneously from each side, brush fascines with the brush ends up stream, were piled above the piling and weighted down with sand bags, making alternate layers of fascines and bags, until the water was confined to a 30-ft. channel in the center. This barrier was about 20 ft. thick up and down stream. The opening was then spanned with long cottonwood timbers and a similar brush-sand-bag construction

was built upon them. The supporting timbers were then shattered with dynamite, letting the mass drop into the opening. At the same time a large quantity of brush was thrown in above and allowed to float into the opening to help close it. In this way the barrier across the opening was built above water and teams passed over it dragging in dirt from both sides, the flow being reduced so greatly that the dredge below it nearly went aground. With a few thousand more sacks of earth to place along the upper toe of the barrier, the work would have been successful. As it was, the structure was undermined, settled down, and eventually failed entirely.

In this attempt 10 000 sacks were used, 8 days' time with the dredge at \$100 per day, and 225 men-days time of Indian labor at \$1.50 per day. This makes the total cost of closing about \$1 800.

Instructions were then given to move the dredge up close to the river bank, where the soil was thought to be better, and make another attempt. The current through the break, however, was too swift, and instructions were given to go up the old Main Canal to the upper Mexican intake to stop it, which was done, using the method which had failed below.

A similar method was used to throw the water through the Alamo Waste-gate on its completion in June, 1905, 3 months later, 30 000 sacks of earth being filled in readiness and every one used. This barrier dam was thrown across the channel carrying 2 500 sec-ft. of water and with a total or final head of 10 ft. This has always seemed to the writer to have been a most remarkable achievement, the only equipment at hand being a skid pile-driver and Fresno scraper teams.

To resume Mr. Rockwood's narrative:

"About this time, I left for the East and at the earnest solicitation of the Imperial Water Company No. 1, which agreed to advance \$5 000 for the effort, a third* attempt to close the break was made under the direction of Mr. C. N. Perry and the superintendent of Imperial Water Company No. 1, Mr. Thomas Beach. On my return from the East, on the 17th of June, I found them heroically attempting to stop the break, with the waters so high in the Colorado that all of the banks and surrounding lands were flooded, and I immediately stopped the work as we realized fully that nothing could be done until after the summer flood had passed.

"The Colorado on a Rampage.—At this time, the lower intake had been enlarged from a width of about 60 ft., as originally cut with the

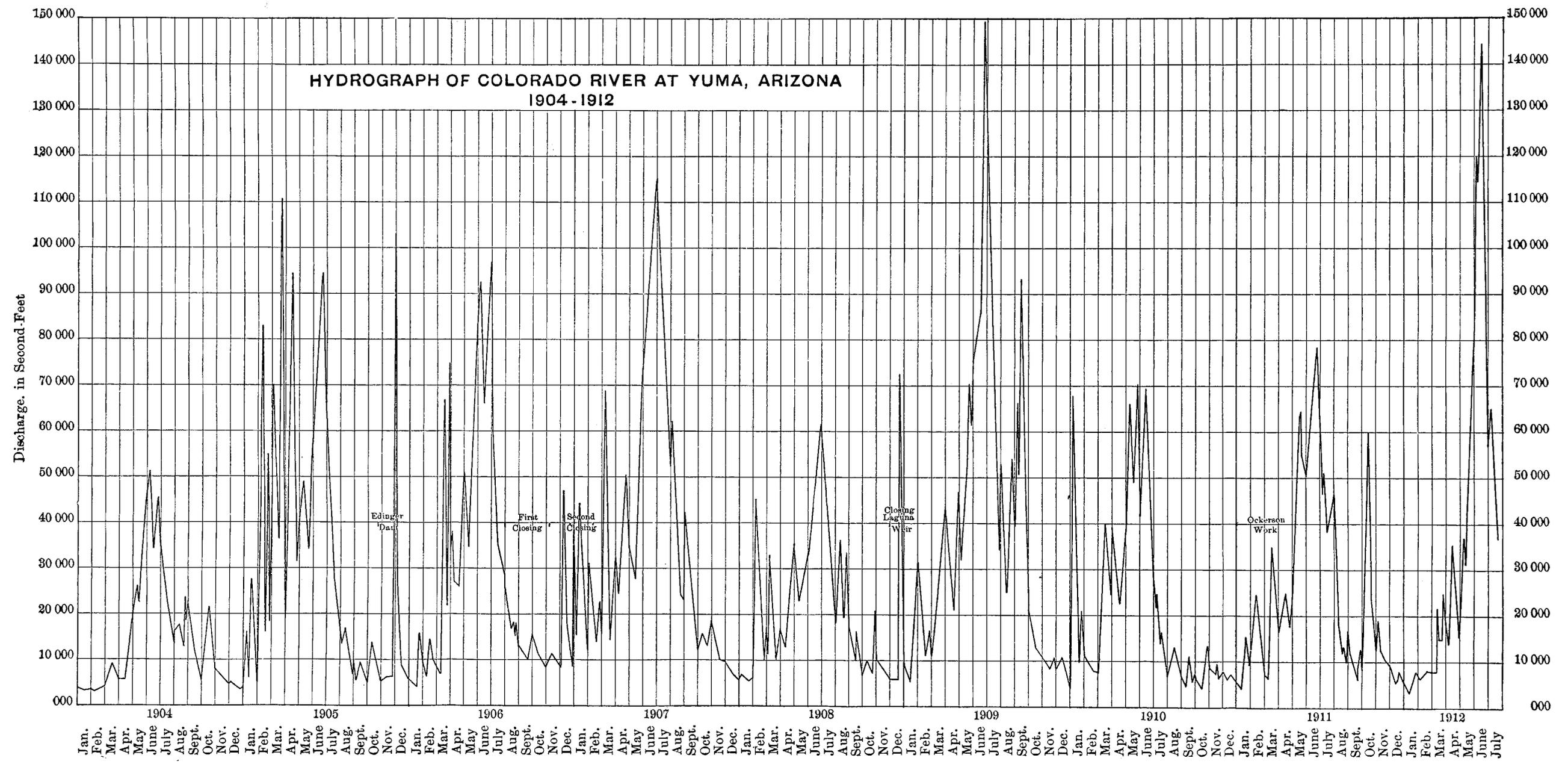
* Really, the second serious attempt, Fig. 14.

dredger, to a width of possibly 150 ft., and it did not then seem probable that the Colorado River would turn its entire flow through the cut, but as the waters of the river began to fall, the banks of the intake began to cave and run into the canal, the banks of the canal below the intake fell in and, as known by most of the residents of the valley, the entire river began running through the canal and into the Salton Sea in the month of August of this year of 1905."

Plate XLVII shows the discharge at Yuma to have been an unprecedented sequence of floods from the Gila water-shed. Indeed, the precipitation throughout all that region traversed by the Southern Pacific line from Yuma to very near El Paso during this period was quite without precedent. Track ballasted with local material, which had always proved satisfactory, was during this year the despair of the entire Maintenance of Way Department, and for months trains were allowed to go over it only at half speed and with lurchings of the coaches and Pullman sleepers like ships at sea.

Mr. Rockwood's statement gives a very fair presentation of the matter as he viewed it. The writer is perhaps as well aware as any one that the river was diverted through this cut into the Salton Sea, and when he first inspected the situation in August, 1905, he felt, like practically all other engineers who gave the matter cursory consideration, that making this cut was a blunder so serious as to be "practically criminal." After 4 years of more or less bitter experience with the region, he is perfectly convinced that, matters having gotten into such condition, making the cut was absolutely imperative and by all means should have been done. The difficulty had not been any tendency whatever to divert the entire river, but—very much to the contrary—to induce enough water to go that way. Up to that time, a head-gate to prevent too great a quantity of water from entering the canals was of far less importance than some means of maintaining their carrying capacity. That a head-gate should have been provided is, of course, self-evident. It would have been utter folly, however, to have put a flash-board gate of any type directly in the diverting channel, because of the drift which would have accumulated against it. Nothing less than a structure containing immense openings could have been used without insuring that the cut would be choked up. This type of construction was practically unused in western irrigation works at the time, and would have cost a great deal of money, therefore, considering the financial condition of the C. D. Co., it is plain that the only

HYDROGRAPH OF COLORADO RIVER AT YUMA, ARIZONA
1904 - 1912



practical thing would have been a gate, not in the cut itself, but in a by-pass, and built with the idea of closing the by-pass on the approach of the summer floods and using this gate as much as possible. It was not alone the straitened financial condition of the C. D. Co. and the situation generally in which it found itself which resulted in there being no permanent diversion works put in; two other important factors entered. The first was the practical change of management, from a construction point of view especially, to the Chaffeyes in the summer of 1900; back to Mr. Rockwood in February, 1902, and internal difficulties in the C. D. Co. late in 1904. The second—indirectly connected with the first—was the hesitancy of the management to provide permanent head-works before the technical men in the corporation had agreed as to what the situation demanded. The real mistake was not in "putting all the eggs in one basket," but in not "then watching that basket." Obviously, no one could be responsible for doing such a thing without realizing the need for watching it most carefully and being fully prepared to take most aggressive action should occasion arise.

SOUTHERN PACIFIC LOAN.

Early in January, 1905, it occurred to the management of the C. D. Co. that the phenomenal development of traffic furnished to the Southern Pacific Railroad by the Imperial Valley warranted the hope of financial assistance from that corporation. Mr. Julius Kruttschnitt, Director of Maintenance and Operation of the Harriman Lines, declined to consider the proposition, but Mr. Harriman, on being approached, was at once interested and ordered an investigation and report. As a final result, the Southern Pacific Company agreed to loan \$200 000 on condition that 6 300 shares of the capital stock be placed in the hands of a trustee to be named by the Southern Pacific Company until the loan should be repaid, and taking over the management of the property until that time. Accepting a loan under such conditions was seriously objected to by a large part of the company's stockholders, but at the annual meeting in Jersey City, in May, a board was elected pledged to the arrangement. On June 20th, 1905, the Southern Pacific Company took over the management of the property, with Mr. Epes Randolph, President of the Associated Harriman Lines in Arizona and Mexico, as President, and

Mr. W. J. Doran, of Los Angeles, as the trustee mentioned in the contract. Both these gentlemen are still acting in these respective capacities. When the loan was arranged, and even when it was finally consummated, the railroad officials in San Francisco and the East did not consider the conditions along the river worthy of serious concern.

Mr. Rockwood was retained temporarily as Assistant General Manager and Chief Engineer, as members of the Southern Pacific management were entirely unfamiliar with the affairs of the C. D. Co.

THIRD ATTEMPT TO CLOSE THE BREAK.

As soon as the summer flood of 1905 began to recede, work was started. Immediately opposite the lower intake was an island, later dubbed Disaster Island, about $\frac{3}{4}$ mile long and $\frac{1}{4}$ mile wide, consisting really of a sand bar on which quite a growth of cottonwood and arrow weed had accumulated. A line of piling, 12 ft. from center to center, was driven from the upper end of this island to the Mexican shore, as shown in Fig. 15, and between this piling was woven barbed wire and brush. The theory behind this work was that, by spreading over a great width the water passing down the west channel and into the lower intake, a sand bar would be created, thus choking off the flow and gradually forcing all the water into the east channel. On July 15th about one-third of the river flow was going down the old channel and two-thirds toward the Salton Sea, and the result of this endeavor was still problematical. By August 1st a bar, approximately 2 800 ft. long, had been formed, but there was an opening, approximately 125 ft. long, through which the rush of water was too great to be controlled with the means at hand, and the work was abandoned. Up to this date, about \$30 000 had been expended on the foregoing endeavors to close the break.

VARIOUS SUGGESTIONS FOR HANDLING THE SITUATION.

At this time it was evident to all that the low-water flow of the Colorado would be entirely diverted into the old Alamo overflow channel and thence to the Salton Sea. The elevation of the water surface at the head of Disaster Island, with a flow in the river of 10 000 sec-ft., was approximately 100 ft., while the bottom of the Salton Sea is approximately — 287 ft., making the total fall in that direction 387 ft. The distance was about 95 miles by the watercourses, so that the average fall was 4.01 ft. per mile. Toward the Gulf the fall was 100 ft., and the distance to

tide-water was approximately 80 miles, or a fall of 1.25 ft. per mile. The continually diminishing quantity of silty water going down the old channel as the summer flood receded was constantly raising the bed along that direction, the action being rapid enough to be noticeable almost daily. In all probability there were about 6 months ahead during which the flow of the water would be low, and before this period should elapse the river must be re-diverted or the consequences would be most serious.

The plant and the salt deposits of the New Liverpool Salt Company in the bed of the Salton Sea were already entirely submerged, the water covering about 100 000 acres, with a maximum depth of about 16 ft. Except for the increase of depth and the consequent increase in the length of time this property would be shut down, no additional damage was really being done at this point. Indeed, 14 years earlier, this property was covered to a depth of 6 ft. by the great flood of February, 1891, and the summer flood following, and in all probability a similar and greater inundation would have resulted from the excessive floods during the spring and summer of 1905 had the C. D. Co. never constructed any works along the river. The rising waters of the Salton Sea were threatening the tracks of the Southern Pacific Railroad along the east side of the sink, and the officials of the Los Angeles Division were clamoring for aggressive action. The higher officials of the company, however, were not yet very much perturbed. On the other hand, the Alamo channel was being enlarged and deepened, to the very great benefit of the C. D. Co., and the irrigation system of Imperial Valley, because the insufficient carrying capacity of this channel and the heavy silt deposits therein constituted a serious menace to the entire project.

To close the lower intake entirely meant obtaining all the water required for the irrigation of Imperial Valley through the 4 miles of badly silted Main Canal lying between it and the upper intakes, and this was out of the question. Even with large sums of money, which might be obtainable from the Southern Pacific interests, machinery could not have been bought, assembled, and put into operation in time to have permitted the delivery of more than enough water to supply the inhabitants and live stock of the valley with drinking water if the river flow should be reduced to 6 000 or 7 000 sec-ft. Imperial Valley at that time consisted of at least 125 000 acres under cultivation, five

towns with an aggregate population of 2 500 people, and a rural population of approximately three times that number. There were, perhaps, 100 000 head of hogs, 50 000 head of cattle, and other live stock in proportion.

Many plans were suggested, from this time, August 1st, 1905, until the break was finally closed in 1907. Many of these, of course, were thoroughly absurd, and came from cranks and people who had not the faintest conception of the conditions. Indeed, almost the only people who appeared to be able to see that the problem was not merely one of shutting off the lower intake were the engineers of the C. D. Co. and a few of the well-informed men in Imperial Valley. Representatives of the New Liverpool Salt Company, the Southern Pacific Company, various departments of the United States and Mexican Governments, and the general public, all joined in demanding aggressive action to stop the menace of a new Salton Sea.

Such suggestions were addressed to Mr. Harriman and to nearly every other official of the Southern Pacific interests, and to Mr. Randolph and other authorities of the C. D. Co. Ultimately, most of these found their way to the writer; they constitute a most interesting collection. It is not profitable to mention more than four of these suggestions, which may be designated the Laguna Weir Plan, the Concrete Head-gate Plan, the Rockwood Head-gate Plan, and the Barrier Dam Plan. Edwin Duryea, Jr., M. Am. Soc. C. E., also offered to close the break according to a plan, which, however, he declined to outline.

The Laguna Weir Plan.—The Laguna Weir Plan consisted in abandoning operations for the time being at the scene of the break; concentrating all efforts on the completion, at the earliest possible date, of the Laguna Weir, which was being built by the U. S. Reclamation Service; building a canal thence passing Pilot Knob and intersecting the break from $\frac{1}{2}$ to $\frac{3}{4}$ mile west of the Colorado River, this canal to have a capacity equal to the low-water flow of the river; then diverting all the river water through this canal; finally, to build a dam across the intake between the canal junction and the river bank in still water. The Laguna Weir was actually completed in the early spring of 1909, just before the annual record flood of that year. It is not clear just how its completion could have been essentially hurried. Had this plan been followed, the Colorado would have emptied into the Salton

Sea for 3 years longer than it actually did, and during this time 55 000 000 acre-ft. of water went by Yuma, only a very small portion of which would have gone down the old channel to the Gulf. This would have raised the water in the Salton Sea to the 180-ft. contour, with the effect of drowning out a large area of cultivated land in the Coachella Valley and forcing the abandonment of 60 miles of main line track by the Southern Pacific Railroad.

These effects, however, would have been of relatively minor importance. The irrigation system of Imperial Valley would have been strained far beyond the breaking point in several places, while the cutting back in New River would unquestionably have reached the Alamo channel and lowered the water therein far beyond the point where any could have been gotten into the Imperial Valley by gravity. This, of course, would have meant the depopulation of that region, an appalling result, without parallel in history.

The Laguna Weir Plan is thus seen to have been impracticable, and no one actually connected with the work gave it serious consideration. Nevertheless, Director Walcott, of the U. S. Geological Survey, who was a close personal friend of Mr. Harriman, strongly advised it, and Mr. Harriman almost insisted upon it for quite a time.

Concrete Head-gate Plan.—The Concrete Head-gate Plan was put forward by the late James D. Schuyler, M. Am. Soc. C. E., who acted as Consulting Engineer of the C. D. Co. from July, 1905, to June, 1906. It consisted essentially of building a reinforced concrete and steel head-gate on the Pilot Knob site, where solid rock foundation could be secured, such gate to be able to carry the low-water flow of the river; and then, from this head-gate down to its junction with the crevasse, to enlarge the canal to a similar capacity. This, it was considered, would permit the diversion of all the water through the head-gate and canal, leaving the river below, and consequently the break itself, dry. The underlying idea was somewhat similar to that of the Laguna Weir Plan, except that it contemplated only 4 miles of canal enlargement and a diversion structure which could be completed in 3 or 4 months, instead of 3 years.

This plan involved the construction of permanent head-gates on rock foundation at Pilot Knob, so long contemplated; and the construction and equipment of a dredge with which the requisite 4 miles of canal could be dug economically and quickly. The idea was adopted

in a tentative way in September, 1905, approximately 90 days after the Southern Pacific Company undertook the management of the C. D. Co., and Mr. Schuyler was instructed to proceed with the preparation of plans for the head-gate, while Mr. F. S. Edinger, under whose direction the Edinger Dam was built, arranged for the dredge. At the suggestion of the Golden State and Miners Iron Works, of San Francisco, the clam-shell type, with 150-ft. boom and 5-cu. yd. bucket, was selected. Work was begun on the concrete head-gate on December 15th, 1905, and contracts for the clam-shell dredge were arranged a few weeks later.

One of the chief recommendations of this plan was that the constructions, in large measure, would be permanent. It was assumed that, while perhaps the maximum quantity of water which would have to be diverted for the irrigation of Imperial Valley would never exceed 5 000 sec.-ft., a gate twice as large would not have any particular disadvantages in its maintenance or operation. It was urged, further, that this arrangement of diverting structure and large canal would be available in case of future breaks, should any ever occur.

The difficulty about the plan was that, regardless of the size of the gate, enlarging the 4 miles of canal to carry 10 000 sec.-ft. within sufficient time to afford reasonable relief was a very serious problem, while the capacity of this canal would be reduced so quickly by silt deposition that its use in case of future breaks would be out of the question. Furthermore, to insure the diversion of all the water in the river, required a canal cut considerably below the water-table in the ground through which it would have to pass, and large patches of quicksand occur so frequently in this region that it would be folly to hope to miss all of them. Such patches would cause the inflow of material from the sides and the bottom to a serious extent.

Mr. Rockwood's Plan.—Mr. Rockwood urged the necessity of a rapid re-diversion, not so much because of the effect on the Southern Pacific tracks along the Salton Basin as because he understood the critical condition at a number of points in the irrigation system of Imperial Valley, and that the severe strain could not be withstood successfully for very many months. His suggestion, made in August, 1905, was to put in, immediately beside the break, a wooden **A**-frame, flash-board head-gate, capable of passing the low-water flow of the river; with dredges to dig channels from the break to the gate both above

and below; divert the water through this by-pass and gate with a piling-brush-sandbag barrier dam; complete the dam as an earth fill across the break, and build levees both up and down stream as far as might be necessary; then close the gate to such an extent as would admit only enough water to supply the irrigation needs. This plan was approved, and work was started on September 20th. It was abandoned completely 3 weeks later; was again approved on December 15th, 1905; and was carried out until the gate construction failed, in October, 1906. It was daring only in its size and the foundation of so important a structure on alluvial soil, and it would have resulted in permanent diversion works on Mexican soil—where, by all means, they should have been, originally, and as contemplated in the Mexican concession, granted in 1904.

The Barrier Dam Plan.—The Barrier Dam Plan consisted in throwing a barrier dam of some sort across the crevasse and raising the water surface above it sufficiently high to throw all the discharge of the river down the old channel to the Gulf. The usual type of dam suggested was of piling and brush mattresses of fascines weighted down by sandbags. This method seemed to its proponents to afford opportunity for decreasing the quantity of water diverted in the minimum time, and neglected that side of the problem which required the furnishing of water for the Imperial Valley. The best plan for a structure of this type was that put forward by Mr. Edinger, and worked on under his direction from early in October until its destruction by the great flood of November 29th, 1905.

FOURTH ATTEMPT TO CLOSE THE CREVASSE.

Mr. Rockwood presented his plan to Mr. Randolph and Mr. Schuyler, and they, as well as several engineers of the Southern Pacific Company, approved of its trial. Plans were hurriedly worked out for a wooden A-frame, flash-board gate, 120 ft. long, with a concrete floor, and founded on piles. Rush orders for materials were placed, and the first shipments left Los Angeles on August 7th. It was fully expected to have the structure completed by November 15th.

The original intention was to construct the gate in a by-pass to be excavated by the dredge *Alpha* on the south side of the intake, but examination showed an unfavorable foundation, as the ground slid into the cut so rapidly that the dredge was almost caught and held by it. The plans, therefore, were changed, and it was decided to construct

a by-pass on the other side of the break; force all the water through this by-pass; and then build the structure where the intake had been, thus saving both time and money in the excavation. The break at this point was about 300 ft. wide—just about the length of excavation required for rapid and successful construction. The dredge was put to work on this by-pass, and no difficulty whatever was found in making the 700-ft. cut required. The plan worked very well, and a large part of the water began to go that way at once. Work was begun on the up-stream side of the coffer-dam, the idea being that, when all the water was diverted through the by-pass, another earthen dike would be thrown in, about 250 ft. below the first, and thus make the coffer-dam for the gate construction. In this way, the second dam would be built in still water and in very short order with the dredge.

At this time—about September 15th—it became evident to Mr. Rockwood that he could not attend to the business affairs of the company properly and remain in personal charge of the work along the river. It seemed easier to find some one capable of completing the gate in accordance with the plans outlined than to find any one qualified to handle the corporation's affairs. Mr. F. S. Edinger was selected, as he, until June, 1905, had been for many years Superintendent of Bridges of the Southern Pacific System, and had had very large experience in coffer-dam work. About 3 months previously he had left the Southern Pacific Company and entered the contracting firm of Shattuck and Desmond, of Los Angeles and San Francisco. About September 20th, Mr. Edinger and Mr. Rockwood went over the ground and the plans together, and Mr. Edinger commenced the work.

The records show that, about October 1st, the river usually rises 2 or 3 ft., principally due to rains on the water-shed of the Gila River and Bill Williams Fork. This year was no exception, and the slight rise about October 1st shook Mr. Edinger's confidence in the plan. He quickly outlined a barrier dam plan to Mr. Randolph, who approved of it, and work was shifted to it at once. This plan consisted of constructing a piling and brush dam across the west channel between the head of Disaster Island and the Mexican shore, a distance of about 600 ft., and it was expected that the river would all be turned down the east channel before a gate could even be put in. All material was at once removed from the gate site, and work was rushed on the construction of what is locally known as the Edinger Dam.

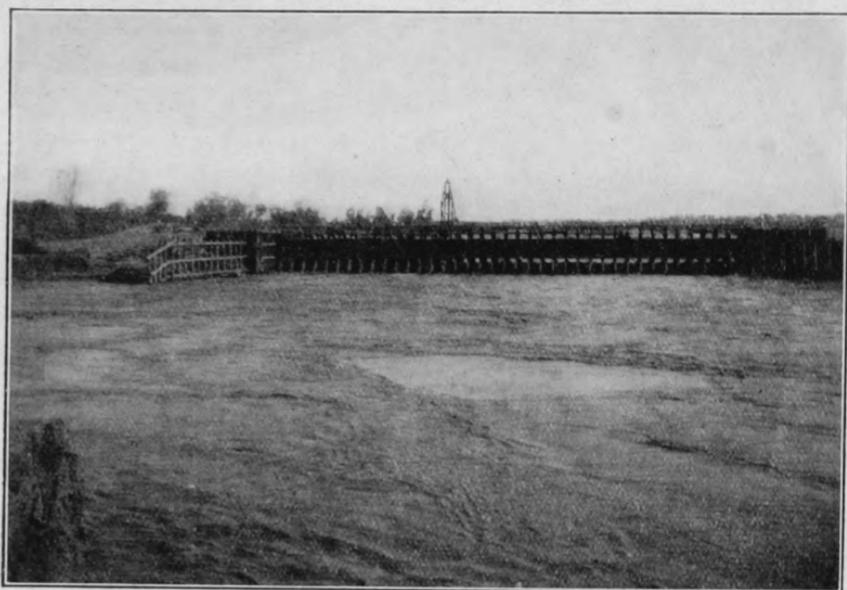


FIG. 19.—ROCKWOOD HEAD-GATE, OCTOBER 6TH, 1906, PASSING
12 000 SECOND-FEET.



FIG. 20.—EDINGER DAM, NOVEMBER 8TH, 1905. BRUSH AND WIRE MAT IN
FOREGROUND, READY TO BE PLACED.

This plan of handling the situation, in addition to shutting off all water flowing into the Imperial Valley through the lower intake, was seriously defective in that even a short flood sufficiently great to send any water overbank in the immediate vicinity of the dam—and that would require much less water than usual on account of the silted-up condition of the whole river bed below the break—would in a few hours result in cutting a channel around the end of the structure and entirely shunting it. Indeed, such a re-diversion was exactly what took place a little more than a year later, when the waters broke under the levee, $\frac{1}{2}$ mile south of the Hind Dam, in December, 1906. Had the Edinger Dam been entirely successful and completed on November 15th, such re-diversion would have been caused by the terrific flood of November 28th, and so on; the hydrograph, Plate XLVII, shows a number of floods sufficiently great to have done this. Indeed, at this time, no one seems to have realized that a large, deep, and efficient channel had been created from the Lower Heading westward for many miles, and that future safety demanded, not only closing the intake, but an elaborate system of levees reaching miles both up and down stream.

The plan of the Edinger Dam consisted in driving rows of piling and filling the interstices with brush mattresses and fascines. The idea behind it was essentially similar to that of the work abandoned about August 1st. To have been successful, the construction would have had to withstand a head of from 8 to 10 ft. However, on November 29th, when a head of 35 in. had been obtained, a terrific flood came down from the Gila, reaching a gauge height of 31.3 ft. at Yuma and a discharge of 115 000 sec-ft. Large quantities of drift were carried by the floodwaters. This drift collected against the Edinger Dam in great quantities, and a large volume of water went down the east side of the island and the old channel. Before the flood had reached its peak, the dam started to give way, and in an incredibly short time was practically destroyed. When the river had again fallen, the old channel was silted up higher than before, the new channel was scoured still deeper, and when the flow of the river had decreased to 17 500 sec-ft. all the water was again going toward the Salton Sea.

The flood not only wrecked the dam, but carried away practically all the material on the ground, and, after it receded, side-cutting along the west side of Disaster Island began to take it away rapidly. It was soon obvious that it would be folly to resume work at that location,

and it was decided that the piling-brush-sandbag barrier dam method was not to be given further consideration.

So much water went through the break to the valley, at the failure of this dam, that the *Alpha* was sent to the Quail River and put to work cutting a channel southward in the hope of diverting a large part of the flow into the Paredones and thence *via* Volcano Lake into the Gulf. It was an endeavor to divert a large part of the water from an old overflow channel on the north side of the delta cone into an overflow channel on the south side thereof. It had little result, however, and the Quail River cut soon closed itself.

On October 15th there were 20 white men and 25 Indians at work on the Edinger Dam; on November 1st, 42 white men and 50 Indians; on November 10th, 106 white men and 65 Indians, and on November 29th, 250 white men and 80 Indians. Two steamboats with barges attached, and the relatively large barge, *Silas J. Lewis*, with their crews, were also at work.

On the books of the company, the cost of the Edinger Dam is not thoroughly segregated from the expense incurred in the head-gate work up to the time of its abandonment for the barrier dam plan. The expenditures on it, however, were about \$60 000, and the grand total to December 1st, 1905, was about \$100 000.

FIFTH ATTEMPT TO CLOSE THE CREVASSE.

It was decided to work simultaneously on the Concrete Head-gate plan and the Rockwood plan, which was done.

Concrete Head-gate.—The location of this interesting structure is shown on Fig. 22, where the granite point of Pilot Knob is near the right bank of the river. The general design was outlined by Mr. Schuyler, and the principles used, dimensions, elevations of flow, etc., were submitted to Messrs. Rockwood and Randolph, and approved by them. George S. Binckley, M. Am. Soc. C. E., then worked out the details and prepared the working drawings. Contracts for the structural steel and ironwork were let to the Llewellyn Iron Works, of Los Angeles, and for the construction work to Mr. Carl Leonardt, also of Los Angeles, on November 25th, 1905. Time was made the essence of the contract, and Mr. Leonardt hurried the necessary equipment to the ground and began actual work 2 weeks later. Although it was expected to complete the gate ready for use within 90 days, the entire job was not finished until June 28th, 1906.

Type and Size.—The intake gate is doubtless the largest and most expensive irrigation canal head-gate in America. The design is a modification of the Taintor or radial-gate type, which has been used for many years for irrigation constructions in the Western States. This style of structure was adopted in order to obtain openings of maximum area easily and quickly opened or closed by one man. It had probably not been used in California, although a large wooden radial-gate had been built some years before at the head of the so-called Peoria Canal from the Gila River, near Gila Bend, Ariz. It was about 25 ft. high and 30 ft. wide, which is nearing the extreme for construction of that class. This wooden gate, however, was never used, as the dam across the Gila River was destroyed by flood soon after its completion. The maximum height of radial-gates and canal head-works in Idaho at the time was about 11 ft., and the water was not expected to rise to the top of the gates, the river level being controlled by other means.

Here, however, the extreme flood level is 19 ft. higher than the low-water level, so that gates at high flood time are subjected to great pressure. Sufficiently large vertical lifting gates would have required very heavy and massive piers, and the gate would have been very large and disproportionately high as compared with the width. These considerations caused the adoption of culvert openings between the piers for supporting a cellular structure of reinforced concrete, and thus admitting of loading the construction with gravel filling in the cells in order to get the required stability and weight at minimum cost. The gates were thus required to close culvert openings of minimum size, being in fact no larger than with the head at a uniform low-water height, although, of course, much heavier and stronger on account of the increased pressure at flood stages. There are eleven such culverts, each 10 ft. high and 12 ft. wide. In addition, there is a "navigation pass," the purpose of which was to permit passing a small gasoline launch through the gate. This navigation pass is practically useless because the mill race through it, when the difference in water level above and below the gate exceeds 1 ft., precludes the idea of dragging a boat through it; indeed, no attempt has ever been made to use it. The floor of the gate is 98 ft. above sea level, according to the C. D. Co. datum, and 100.9 ft. according to the U. S. Reclamation Service datum. At the time, and until after the summer flood of 1909, the average low-water surface in the river was about 108 ft. The elevation

of the flow line at the gate, therefore, was fixed so that the culverts would run full at low-water stage. The present low-water surface is about 105 ft.

The area of the eleven culverts is 1 320 sq. ft., and, with the water 1 ft. higher on the up-stream than on the down-stream side of the gate, their combined discharge would be 8 500 sec-ft. In addition, a large quantity of water would go through the navigation pass, which is 10 ft. 3 in. wide. When the water is 10 ft. above the top of the culverts, it is necessary to close the gates within 3.8 ft. of the bottom to hold the discharge through them down to 10 000 sec-ft., when the carrying capacity of the canal below is great enough to allow the water to get away.

The gate was designed to pass the entire low-water flow of the river—which it was assumed would certainly not exceed 10 000 sec-ft.—without any diverting dam in the river opposite it.

Cost of Structure.—Table 12 gives the cost of this structure, with the contract prices for excavation, concrete work, etc.

The cost of the gate, however, was considerably more, because Contractor Leonardt presented a claim, insisting that the prices for earth and rock excavation named in his contract were agreed to by him on certain assurances made by Mr. Rockwood as to the character of the excavation, which had proved more difficult than was expected. This claim was made as soon as Mr. Leonardt's representatives reached the ground, and Mr. Randolph permitted a change to a force account basis because of his desire to hurry the construction in every possible way. The earth excavation in this way cost 64 cents per cu. yd. and the rock \$2.06, thus increasing the figures by \$10 813, making a grand total of \$55 221.08.

Careful accounts were kept, and it was ascertained that the contractor made a profit of \$2 700 on the concrete, and \$741.50 on erecting the gates. What the earth and rock excavation should have cost is a matter of some, though slight, interest to the Profession, as these would necessarily vary according to local conditions. As a matter of fact, with a good pumping plant, a mining nozzle or giant, a hydraulic elevator, and some pipe, the earth excavation could probably have been handled for 20 cents per cu. yd., and possibly less. Much of the rock was fairly soft, and could have been worked easily and cheaply, so that, had the contractor put in power drills and one or two long-

boom derricks to handle the rock out of the cut, it is probable that the cost of such excavation would not have exceeded the contract price. The quantity of water entering the coffer-dam, or rather excavation pit, was surprisingly small.

TABLE 12.

GATE STRUCTURE.	
Earth excavation, 12 687.1 cu. yd. at \$0.25.....	\$3 159.28
Rock excavation, 5 700.81 cu. yd. at \$1.00.....	5 700.81
Cement, furnished by company, 1 335 bbl. (Olsen, Gillingham, and Independence brands).....	4 432.25
Concrete, labor, forms, sand, gravel, and rock, 1 204.83 cu. yd. at \$9.00.....	10 848.47
Reinforcing steel bars, 25 722 lb. at 4 cents.....	1 965.16
Expanded metal for gate facings, 791 lb. at 4 cents.....	31.64
Allowance for 3 days' delay to contractor.....	102.50
Extras.....	807.07
	\$27 042.18
Charges against contractor.....	271.70
	\$26 770.48
IRON AND STEEL WORK FOR GATE.	
Llewellyn Iron Works' original contract for twelve radial gates and one slide-gate (in navigation pass) f. o. b. Los Angeles.....	\$12 000.00
Freight to Yuma, on 212 184 lb. metal in aforesaid gates at \$1.25 per ton.....	132.60
Regulating levers, shaft, and gear (subsequent contract).....	580.00
Erection of gates (Leonardt's contract).....	1 500.00
	\$14 812.60
Total cost of iron and steel work.....	2 825.00
Plans, engineering, and superintendence, 6.7%.....	
	\$44 408.08

Fig. 26 gives a plan and elevation of this gate, and Figs. 24 and 25 are views of the structure.

Purpose.—At the time this gate was designed, the money available for construction, through the Southern Pacific's connection and the loan of \$200 000, justified the immediate construction of permanent head-works, indeed, building this and the Alamo Waste-gate were the chief items for which the loan was made. Furthermore, the entire diversion of the river at the lower intake had shown the folly of trying to get along without them. The gate, while intended as a permanent diverting structure, was, nevertheless, primarily designed for use in endeavoring to re-divert the river; otherwise, of course, it

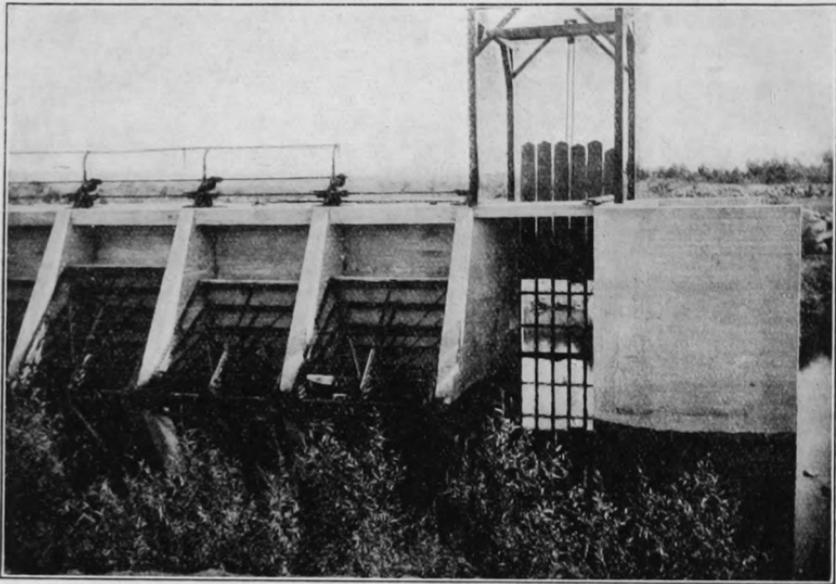


FIG. 24.—CONCRETE HEAD-GATE, JULY 10TH, 1906, SHOWING DETAILS OF GATES, NAVIGATION PASS, AND GATE AND ABUTMENT AT RIVER END.

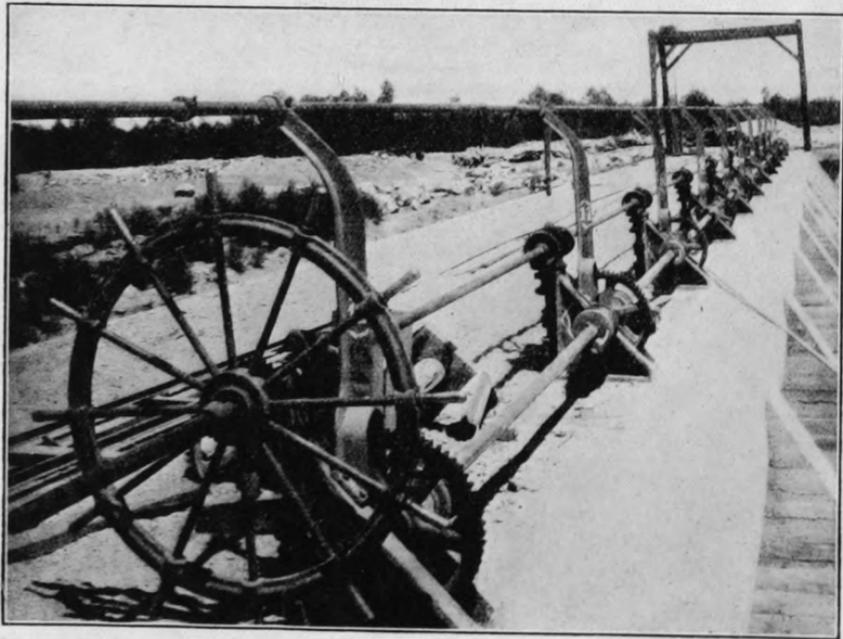


FIG. 25.—GATE RAISING MECHANISM OF CONCRETE HEAD-GATE.

would have been made much less than half as large. Actually, it played no part at any time in diverting the stream.

Operation.—The gate was actually put into operation on November 1st, 1906, when the water going through the break had been reduced to a quantity too small for the requirements of the valley. About 6 weeks later, the flood which caused the second break occurred, and resulted in an accumulation of drift on the up-stream side of the gate which choked up the underground culverts and practically put it out of commission. From that date to this the troubles caused by drift in the river, particularly at high-water periods, have been serious

CONCRETE HEAD-GATE
AT ANDRADE, CAL.

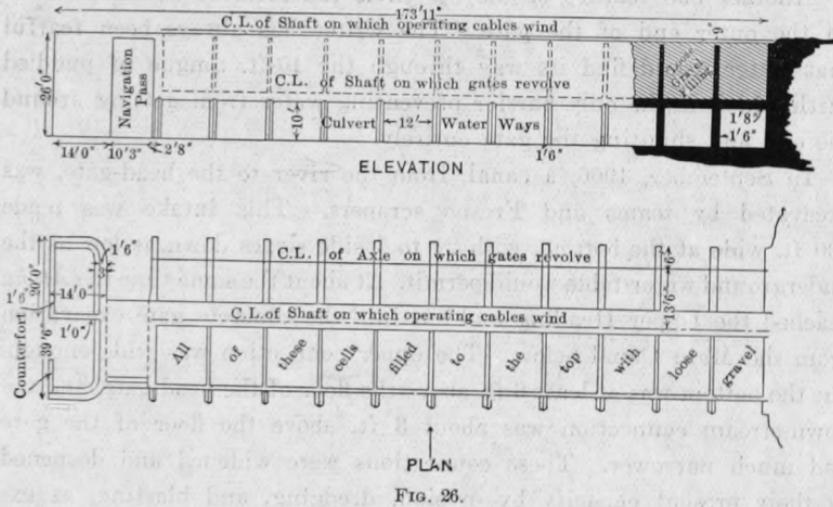


FIG. 26.

and often acute. Gates of this type, for head-works on a river carrying any drift to speak of, let alone as much as the Colorado often has, should be avoided. After considerable experience it is obvious that if permanent diversion of the water for the irrigation of the valley is not made on Mexican territory, then, whenever enough money is available, it will be best to abandon the structure entirely and make diversion through gates similar to those in the sluice-ways of the Laguna Weir.

Aside from the type of gate for such a locality and stream, three unfortunate features in design became manifest. Chief of these was the fault that the drums on which the wire cables for raising the

gates are wound are much too small. The gates themselves were designed for minimum weight with the necessary strength, and are not stiff enough, so that they tend to wedge unless exceedingly great care is taken. The net result is many broken cables. At one time only two of the eleven gates were in operation, some being clear down, some clear up, and some impossible to close entirely on account of driftwood under them. Fortunately, the *Delta* was near by and was used to raise the gates, so that new and strong plow-steel cables could be installed, replacing the original ones of Tobin bronze, $\frac{3}{4}$ in. in diameter, 19 wires to the strand. These plain steel cables corrode badly, of course, but still are much better than any galvanized iron ones of usable diameter.

Another bad feature of the design is the form of abutment built on the outer end of the gate. The writer has always been fearful that water would find its way through the 10-ft. tongue of puddled earth which is the only barrier preventing water from getting around the end and shunting the gate entirely.

In September, 1906, a canal, from the river to the head-gate, was excavated by teams and Fresno scrapers. This intake was made 100 ft. wide at the bottom, with $2\frac{1}{2}$ to 1 side slopes down as low as the underground water-table would permit. At about the same time the *Alpha* reached the Upper Heading and cut into the concrete gate excavation from the Main Canal below. The upper connection was wide enough, but the bottom was at least 6 ft. above the floor of the head-gate, and the down-stream connection was about 3 ft. above the floor of the gate and much narrower. These connections were widened and deepened to their present capacity by erosion, dredging, and blasting, as explained later.

The Dredge, Delta.—The other element in the concrete head-gate plan of re-diversion was a canal from the head-gate to the break, a distance of approximately 4 miles. It was to be of sufficient size to carry the probable minimum flow of the river, 10 000 sec-ft. As it was obvious that this stretch of canal would have to be lower than the bed of the river all along the line, in order to permit of taking the entire low-water flow without a diversion dam in the river opposite the head-gate, a very large part of the cross-section to be excavated would be below the permanent water-table of the region. Therefore, some kind of excavating machinery which could handle large quantities of ma-

terial under water had to be provided. It was taken for granted that the cheapest and quickest method of providing this waterway was to enlarge the existing Main Canal, although the writer thinks this was erroneous. The dipper dredge, *Alpha*, by almost continuous operation in this part of the course, had built up levees on both banks so high as practically to limit its future operation without flattening down these levees with teams and scrapers. Largely on the advice of Mr. Edinger, it was decided to construct a clam-shell dredge of the type used almost exclusively for levee building along the Sacramento River. Accordingly, a contract for machinery, and for plans, bills of materials, etc., of the hull, was entered into with the Golden State and Miners Iron Works, of San Francisco, which makes a specialty of clam-shell dredge machinery, construction, and even operation, on the Pacific Coast. This contract was closed on January 10th, 1906. The 320 000 ft. of Oregon pine lumber and other materials for the hull were bought through the purchasing department of the Southern Pacific Company, and the unusually large timbers required were obtained in Oregon and sent directly to Yuma. In the purchase of both hull material and machinery, time was considered as of the essence of the contracts.

A dredge with a 150-ft. boom, carrying a 5-cu. yd. bucket was decided on, and a hull 120 ft. long, 54 ft. wide, and 11 ft. deep. This width was 2 ft. greater than had ever been built on the Coast, although the tendency is to increase the dimensions, and one is now building in San Francisco, 70 by 140-ft. hull, 205-ft. boom, and 6-cu. yd. bucket. The machinery is a 150-h.p., internally-fired, circular, fire-tube boiler, and a 20 by 24-in. engine on each side. It was decided to build the hull and erect the machinery at Yuma, and float the completed dredge down the river to the intake.

Lumber for the hull began arriving in Yuma late in January, and early in March the company was notified that all the machinery was ready at San Francisco for shipment. Mr. Edinger's connection with the company had ceased soon after the destruction of the Edinger Dam, and Mr. Rockwood had very little confidence in the feasibility of the concrete head-gate plan, or in the desirability or need for the clam-shell dredge, and felt that the great cost thereof would deplete seriously the \$200 000 loaned by the Southern Pacific Company. Therefore, practically nothing was done in the matter, and so it came about

that the great conflagration in San Francisco, following the earthquake of April 18th, 1906, destroyed the plant of the Golden State and Miners Iron Works, in which all the machinery for this dredge was stored ready for shipment. Fortunately, the damage sustained by the apparatus was not extensive, and by May 15th, 1906, all the machinery had reached Yuma.

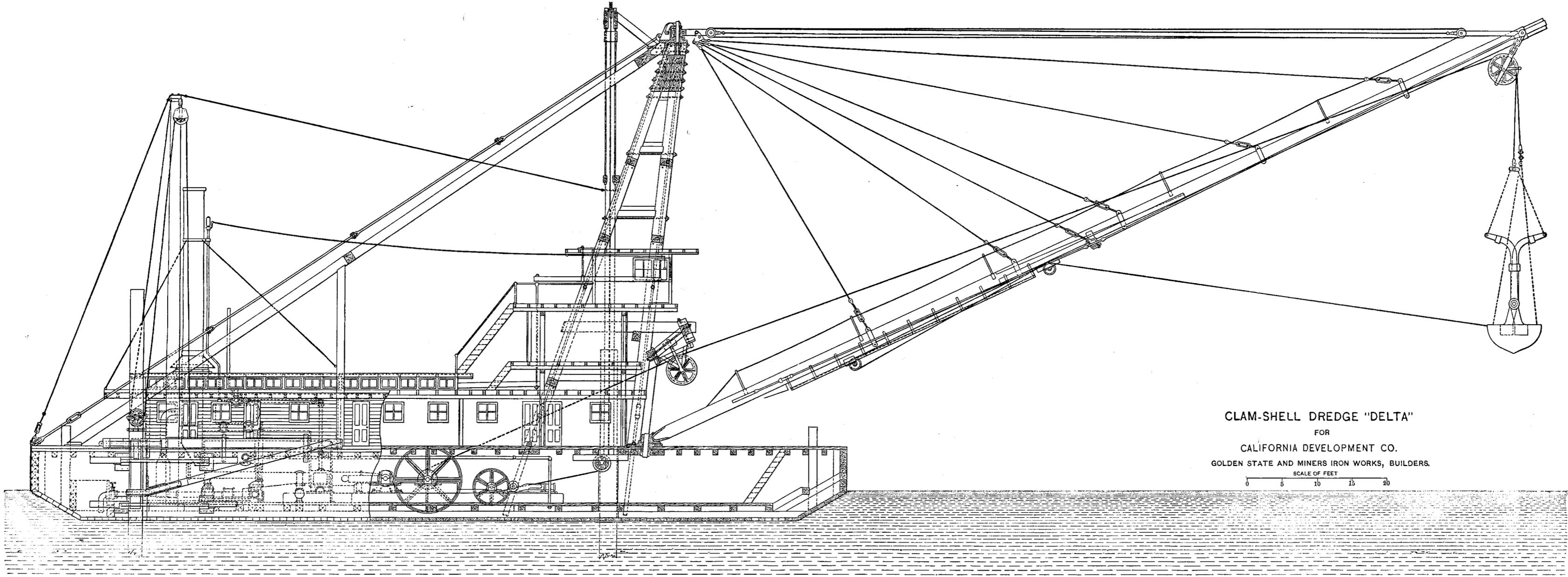
Mr. J. W. Brown, a member of the Golden State and Miners Iron Works Corporation, agreed to take charge of building the hull, and reached Yuma about May 1st, bringing with him a complete crew of mechanics and ship builders. Work was hurried, and with such success that the hull was launched about August 15th, the machinery was in place by the end of October, and the dredge weighed anchor and started down the river. At this time the river was getting low and some difficulty was encountered, but on November 26th, 1906, the clam-shell arrived at the mouth of the American intake. The total cost of the dredge, ready to start down the river, was almost \$80 000; the cost of the machinery being \$34 000, f. o. b. San Francisco. The weight of the craft is about 850 tons.

This dredge, Plate XLVIII, has been an invaluable piece of machinery to the C. D. Co. Had it been ready for use in August, 1905, the cost of doing the earthwork in the Hind Dam would have been wonderfully reduced. As it was, the dredge, after doing a little work in enlarging the intake above the concrete head-gate, was floated down and cut its way into the Main Canal following the upper Mexican intake. It was engaged on this work when the second break occurred, and continued thereon as though this latter event had not happened. Like the concrete head-gate, it played no part whatsoever in the re-division of the river.

For the information of those who are not familiar with the results and cost of clam-shell dredge operation, the following data are given:

Operatives.

1 Captain	at \$125 to \$150 per month, and board.
3 Levermen	" " 85 " " " "
2 Firemen	" " 60 " " " "
2 Deckhands	" " 50 " " " "
1 Cook	" " 50 " " " "
1 Blacksmith	" " 90 " " " "
1 Roustabout	" " 40 " " " "



CLAM-SHELL DREDGE "DELTA"
FOR
CALIFORNIA DEVELOPMENT CO.
GOLDEN STATE AND MINERS IRON WORKS, BUILDERS.
SCALE OF FEET
0 5 10 15 20

Three shifts give a total of 22 hours actual work daily. The average time in operation, when proper repair work is done, is 28 days per month. When in good ground, and with side swings averaging 70° on each side, the time per bucketful is 40 sec. The quantity handled (varying according to the material) is from 3 to 8 cu. yd. as ordinary extremes. On the Sacramento River, under good conditions, 150 000 cu. yd. per month are handled.

Monthly expense.

Maintenance and operation.....	\$2 500
Interest on investment at 6%.....	400
Taxes and insurance.....	200
Deterioration.....	700
	<hr/>
Sometimes as low as.....	\$3 800

Ordinarily, the monthly expense in Mexico is \$5 000. The average cost is 2½ cents per cu. yd. The average cost of the work done by the *Delta* in Mexico is from 4 to 6 cents per cu. yd.

THE ROCKWOOD HEAD-GATE.

As already explained, it was decided to follow both Mr. Schuyler's and Mr. Rockwood's plans for diverting the river, and so, for the second time, on December 15th, 1905, Mr. Rockwood was authorized to proceed with the construction of a wooden head-gate beside the lower intake. The heavy flood of November 29th and its receding waters had widened the intake from 300 to approximately 600 ft., and, after considering the conditions, it was decided to build the gate directly in the old canal about 200 ft. north of the intake channel, in order to reduce the time and the quantity of excavation required, and to divert the relatively small quantity of water in the old canal around the gate with a by-pass to be dug by the *Alpha*. The gate, started and abandoned three months before, was originally planned for a width of 80 ft.; this was increased to 120 ft. in order to carry a maximum of 9 000 sec-ft. As the gate could not be completed until the spring of 1906, the length was extended to 200 ft. The over-all dimensions, including the wooden aprons, became 240 by 100 ft. The entire space, of course, had to be inclosed in a coffer-dam, and the excavation had to be made inside of it. The plans are shown on Plate XLIX.

As far as the writer has ever heard, this is the largest and most daring design ever made for a wooden A-frame, flash-board head-gate. Pile-driving was begun on January 7th, and the gate was completed on April 18th, 1906; the work was rushed day and night for the greater part of the time, and no real difficulties whatever were encountered. As in the case of the concrete head-gate, 4 miles above, the quantity of water seeping into the excavation was surprisingly small. The various items of the cost of this structure were not segregated, so that the details cannot be given, but the grand total expense of the gate proper, exclusive of the by-pass, was approximately \$122 500.

The discharge of the river by April 10th, was 32 200 sec-ft., and showed that the annual flood had begun, therefore all idea of attempting to divert the water through the gate by damming the crevasse itself before the summer flood should have been passed, was abandoned.

Change in Engineering Staff.—On May 15th, 1905, the writer was transferred from the Southern Pacific Company in San Francisco to the Associated Harriman Lines in Arizona, with the title of Assistant to the President of those properties. About 5 weeks later Mr. Randolph's duties were increased, as he was put in charge of the C. D. Co. and the Mexican Co., and shortly thereafter the officials of the Southern District of the Southern Pacific Company urged on him the very serious fact that the track beside the Salton Sea would soon be under water, and insisted that aggressive action be taken to close the break on the river. About the middle of July Mr. Randolph sent the writer to the river to confer with Mr. Rockwood, and a day was spent together examining the situation. About August 1st a second trip was made, and after the disastrous flood of November 28th, 1905, a third visit. Toward the end of January Mr. Randolph again sent the writer to the Lower Heading to assist Mr. Rockwood in hurrying the construction of the wooden head-gate. As this work neared completion, Mr. Rockwood suggested that he had found it impossible to handle things in accordance with his own ideas; he believed that the best interests of all concerned pointed to his resignation, and urged that the writer take up the work. After considerable discussion it was agreed that, if Mr. Randolph also desired the arrangement, there would be no objection offered. Shortly afterward these gentlemen met in Los Angeles and agreed to the change, and on April 19th, Mr. Rockwood

resigned as Assistant General Manager and Chief Engineer, and was appointed Consulting Engineer, and the writer was appointed General Manager and Chief Engineer. Mr. Rockwood continued to act as Consulting Engineer until October 1st, 1906, when he severed his official connection with the company.

The San Francisco Fire.—On April 18th had occurred the earthquake which resulted in the great San Francisco conflagration, and exaggerated rumors as to the extent of the disaster made it seem certain that the machinery for the *Delta* was utterly destroyed; but that was the least important result, as far as the C. D. Co. was concerned. It appeared that the key city to the Harriman Lines was practically in ruins, and the Southern Pacific Company, as a railroad organization, was very seriously hurt.

Mr. Randolph hurried to San Francisco to join with the other officials in the West in conferring with Mr. Harriman, who had at once started for the scene. There, in the bustle and confusion of temporary offices, with the ruins of San Francisco still smoking, with the facilities of the road to carry people away from the stricken city taxed to the very utmost, with the wonderful railway system which constituted Mr. Harriman's life work crippled to an unknown extent, and with the financial demands resulting from the disaster impossible to determine, Mr. Randolph succeeded in inducing Mr. Harriman to advance an additional \$250 000 for controlling the Colorado River and protecting Imperial Valley. It has always seemed to the writer that this was really the most remarkable thing in the whole chain of extraordinary happenings.

The Situation.—The wooden head-gate was completed, and the upper and lower by-passes connecting it with the break had been fairly well started with the dredges, *Alpha* and *Beta*; the concrete head-gate was well under way; the material for the hull of the *Delta* was in Yuma, and the machinery seriously damaged in San Francisco; the tracks of the Southern Pacific Railroad along the Salton Basin were nearly awash for a considerable length; the annual summer flood of 1906 had begun, and, from the Weather Bureau reports from the drainage basin, would be a very large one; the irrigation system of Imperial Valley was already threatened at several vital points by the excessive quantity of water going down the Alamo channel or Main

Canal; and friction between the old C. D. Co. stockholders and the new management had commenced.

No very great degree of reliance could be placed on the wooden head-gate, considering the character of its foundations; and the failure or serious weakness of that structure meant the failure and abandonment of the Rockwood plan for re-diversion. The difficulties of the Concrete Gate Plan, under the most favorable circumstances, became more apparent with further investigation, and were very greatly accentuated by the delay in getting the *Delta* into commission. The probability of the withdrawal of financial support at any time through the discouragement of the Southern Pacific officials as to the ultimate success of the work was a serious factor. Transportation facilities from Yuma were very inadequate, consisting of the steamers, *Searchlight*, *St. Vallier*, *Cochan*, and the barge, *Silas J. Lewis*, all of sufficiently light draft to navigate through the shoals and sand bars of the Colorado. There were large quantities of willow brush suitable for fascines and mattress work near the break, but no timber suitable for piling. The nearest point where piles and heavy timber were obtainable was Los Angeles; from there they came by rail to Yuma, from which point they could be floated down the river only at considerable risk, so that it was cheaper to load them on barges and bring them down with steamboats.

Experience thus far had indicated the practical impossibility of closing the break with a piling-brush-sand bag barrier dam, and there were no quarries for many miles either west or east along the railroad, and none, of course, available except with railroad facilities for loading and transportation. Further, rock would require to be transferred to barges at Yuma and be brought thence by river to the scene of operations.

Practically every engineer—and they included many of established national and international reputation—who had visited the break considered a rock fill barrier dam as entirely unworthy of consideration, for two reasons:

First, it was believed that rock would sink into the soft alluvial silt bottom and keep on going down indefinitely, even if more and more slowly. Old river men quoted numerous instances of wrecked river craft. They cited a dredge, bought a few years before by the C. D. Co., which had sunk on its way from Yuma to the upper intake,

gradually settling entirely out of sight in a few months. The consensus of opinion, therefore, was that any rock fill would certainly settle out of sight unless built on a very strong brush mattress foundation, and the probabilities were great that such a mattress would break under the load and fail of its purpose.

The second vital objection urged against a rock fill barrier dam was that the water going over it while building would dislodge some portion of the fill or some one rock at the top, thereby increasing the overpour at this point, which would dislodge more rock and in this way quickly result in a breach which could not be closed.

It was thought that these considerations not only quite precluded the idea of a barrier dam, should the wooden gate fail, but rendered very doubtful the construction of a diversion dam or obstruction in the channel opposite the gate which would cause a difference in head, above and below it, great enough to throw all the water through the by-pass and gate. This head was variously estimated at from 3 to 6 ft.—the head on the finished dam would be about 15 ft. at low-water stage.

On one point there seemed to be accord, namely, that the situation was a desperate one and without engineering parallel, and that there seemed to be little more than a fighting chance of controlling the river. No two, of the nearly fifty eminent engineers who visited the scene and examined into the situation more or less carefully, agreed on any one plan as offering the greatest chances of success, but pointed out fundamental weaknesses in practically all other methods suggested. This feature was so marked that when the writer suggested to President Randolph that the immensity of the interests dependent for their safety on the re-diversion of the river seemed to render advisable a Board of Engineers, he answered that he would regard 100 ft. of good strong brush mattress in place on the river's bottom as more valuable than the report of any Board of Engineers which could be gotten together.

The immediate menace, however, was from the summer flood in passing through the Imperial Valley to the Salton Sea. The Weather Bureau's reports from the upper drainage basin then indicated a very great total discharge, and a peak perhaps as high as 100 000 sec-ft. The crevasse had now enlarged, and the old channel below had filled up, so that practically all this water—several times as much as had ever yet entered the valley—must go the new way.

Summer Flood of 1906.—Plate XLVII shows that, compared with recent floods, the summer flood of 1906 was very large, although it has been greatly exceeded since then, notably in 1907 and 1909. The increased fall down the Alamo River channel resulted by August 1st in lowering the river at the diversion point approximately 4 ft., but it silted up as the flood receded, leaving a net lowering of between 2 and 3 ft. (Fig. 3.)

It widened the break from 600 almost to 2 700 ft., and rendered far more expensive, in time, equipment, and money, the task of putting the wooden head-gate into commission. The most important effect, however, was the danger it caused in various ways in the Imperial Valley proper.

Such a vast quantity of water going down the Alamo channel was, of course, never contemplated in designing the new waste-gates near Sharp's Heading discharging down the Alamo River (built June to August, 1905), and at Station 134 on the Central Main, and they were taxed to their absolute limits. So much passed the Alamo Waste-gate that it caused a recession of the grade in that channel below, so that the structure was, figuratively speaking, on stilts. Twice the chute below the structure had been extended, the last time in February and March, 1906, when the equipment was removed just as the water began to go over the top of the gates.

By a peculiar and most fortunate coincidence, when the Alamo Waste-gate was discharging approximately 3 500 sec-ft. and Sharp's and the Encina Head-gates were being utilized to the capacity of the canals below them, the water in the Alamo above this point spread overbank for miles, going to the west and south sufficiently deep to save the situation. Thus it happened that when the peak of the flood was reached, and approximately 75 000 sec-ft. were going down the Alamo channel toward the Salton Sea, all but about 5 000 sec-ft. were going overbank to the south and west. Had not this most fortunate condition existed, the Imperial Valley irrigation system would early have been broken into the deep channel of the Alamo below the waste-gate, and at once cut the water out of every canal.

Most of this overbank flow to the south and west collected in the various sloughs and low lands, particularly Beltran's and Garza's Sloughs, and flowed into the New River. The small channel of this watercourse was overtopped, of course, and the water spread out, just

south of the Boundary Line near Calexico, for a maximum width of about 10 miles. Some of the water overtopped the divide of the delta cone, gained the Paredones channel, and thence ultimately reached the Gulf.

The most critical points were where the New River channel crossed the Boundary Line, and a little farther down along the Central Main. At Calexico and Mexicali this broad sheet of water rose until it covered the ground about 4 ft. in depth. (Fig. 28.) The danger was not appreciated in time to throw levees to the west of the railroad track and thus protect that property. The disposition of the towns and the railroads was to wait for the C. D. Co. to build protective levees, in spite of that company's announced intention of doing nothing of the sort.* When the situation was finally realized, about 5 miles of levee—maximum height 5 ft.—encircling the two towns and connecting at the north and east with higher ground, was hurriedly built. Strong winds blow in the spring for two and three days at a time, and when such storms swept over a wide stretch, even though the ground had a considerable quantity of brush, waves were caused which made the maintenance of these levees at times very critical. They were held successfully, however, until the recession of the New River grade made them no longer necessary.

Along the Central Main, from near the branch railroad crossing west to beyond the "Five Gates" (where the canal turns to the north), the water rose so high during the last days of February that it overtopped the south bank of the canal (Fig. 29), and only by the most desperate work was it prevented from overtopping the north bank and sending water northeastward across the country to the Mesquite Lake Basin and the Alamo channel. Had this occurred, the Town of Imperial would have been most seriously threatened, perhaps destroyed, and the New River and Alamo chasms would have been joined by a third one, about 25 miles long, diagonally across the valley northeast and southwest. The C. D. Co. then greatly strengthened this north bank and raised it 4 ft. for a distance of nearly 3 miles. When the situation was most threatening the citizens of Calexico and Mexicali were called out to help hold the levees, while the people of Imperial rushed down to aid in the fight along the Central Main.

* This was because the company's attorney advised that it was not responsible legally for damages caused in the United States by operations of the Mexican Company in Mexico, and to avoid carefully any action which might be considered as an admission of responsibility by the company.

Both the Alamo and New River channels cut back, owing to the large quantity of water flowing in them, and the Salton Sea began to rise at the rate of approximately 7 in. per day. The Southern Pacific main line there was being shifted from time to time, by means of "shooflies." Along the branch line from Imperial Junction to Calexico the trouble at the crossing of the Alamo channel was far greater than should have been permitted. At no time was more than 3 500 sec.-ft. going down the Alamo, yet this small quantity was permitted to eat away approximately 300 acres of land, in a semi-circular form, from the right bank of the channel where it is crossed by the branch railroad into the valley, and caused the railroad to "shoofly" its tracks five times. The alluvial soil of the Imperial Valley is very easily eroded, especially on the concave side of river bends, but it should have been possible to control at reasonable cost a stream of 3 500 sec.-ft., with a velocity never exceeding 7 ft. per sec.

The Inter-California Railroad from Calexico toward Yuma had been constructed as far as Cocopah and practically all of this was under water. The Holtville Interurban Railroad, crossing the Alamo River, was cut out from time to time, the channel at that point being lowered more than 30 ft. This caused serious trouble with the discharge pipe of the Holton Power Company, the plant being left rather high, and considerable work was required to keep it from being undermined by side cutting. The head available, however, was increased by 30 ft.

When the grade of New River had receded to a point about 3 miles above the International Boundary Line, a large area of adobe formation was encountered, and the fingers of the stream began to eat away in various directions and threatened to tear up the country throughout that region in a frightful way. The rate of recession was also greatly slackened. Long before the peak of the flood had been reached, it was evident that the situation along the Central Main and at Calexico was very serious and must become much more so, until grade recession might give relief. It was decided, therefore, to use dynamite liberally in an endeavor to localize the New River's grade recession and to facilitate its progress.

From observations and soil and other data at the time available the probability seemed slight of such recession extending more than 6 or 7 miles beyond Calexico, or far enough to endanger lowering

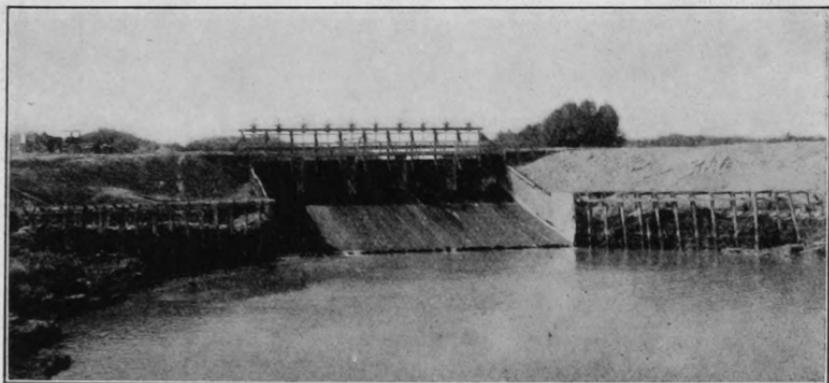


FIG. 27.—ALAMO WASTE-GATE, NOVEMBER 17TH, 1906. ABOUT 30 FEET HEAD AGAINST GATE.



FIG. 28.—PORTION OF 4-MILE LEVEE PROTECTING CALEXICO AND MEXICALI, IN FLOOD OF JUNE, 1906.



FIG. 29.—OVERFLOW AGAINST WEST AND SOUTH BANKS OF MAIN CANAL NEAR FIVE GATES, 2½ MILES NORTHWEST OF CALEXICO.

the water surface in the Alamo above the controlling works and so menacing the water supply of the valley before the summer flood of 1908. It was known that very large areas of adobe soil existed in the Garza's and Beltran's Slough country, so that the cutting there would be very much slower. There thus seemed to be considerable leeway, while the strain on the irrigation system of the valley was so severe at several critical points that it was utter nonsense to think it could be held through another flood season.

In this dynamiting, from eight to sixteen $\frac{1}{4}$ -lb. sticks of dynamite were tied in a bundle about a fulminating cap connected with from 8 to 12 in. of water-proof fuse. The fuse was then lit and the bundle tossed into the water. A little practice and careful observation enabled one to become quite proficient in estimating how far the bundle of dynamite would be washed down stream by the current before the cap exploded the charge, and in placing the charge to get maximum results. Undoubtedly, the course of the grade recession was considerably checked and bad erosion somewhat mitigated by this work, but it is very doubtful whether the time of the grade recession's passing Calexico and Mexicali was markedly accelerated.

When this occurred the results were spectacular in the extreme, the rate of cutting back at this point being fairly uniform at 1 ft. per min. The side cutting of the east bank of the wide, deep barranca for several days threatened Calexico, and carried away a considerable part of Mexicali, including the railroad station, brick hotel, and a number of smaller buildings. The actual damage sustained was about \$15 000 in Calexico and \$75 000 in Mexicali.

For a short distance past Mexicali the cutting back followed the borrow-pits of the Inter-California Railroad, utterly destroying it and carrying away much of the track and trestle material. About a mile out of town, the grade rose slightly above the flood-waters, but farther on, for several miles again, the roadbed was practically destroyed, although no more track material was lost.

These flood-waters covered about 6 000 acres of cultivated farms, of course, utterly ruining the crops. Greater damage, however, occurred as the grade receded and the water rushed from each side toward the newly-made channel, resulting in cutting back fingers or side cañons from the main stream to distances and depths depending on the length of time required to drain off the contributory water.

Some of these side cañons extended back from 2 000 to 2 500 ft. It thus happened that about 3 000 acres of improved and 10 000 acres of unimproved land were eroded to such an extent as to be practically ruined for agricultural or any other purposes. Of this area, about 7 000 acres were public land. The area occupied by the New and Alamo channels themselves was increased by about 7 000 acres.

The greatest damage in the Imperial Valley proper, however, was caused by the destruction of the flumes in the West Side Main over New River in Mexico and the Central Main over New River northwest of Imperial, leaving Mutual Water Companies 6 and 8 without water until January, 1908. These two districts contained about 30 000 acres in actual cultivation, and were rendered practically uninhabitable and absolutely waterless for about 1½ years.

Except as noted, agricultural operations in the valley were facilitated by the flood, there being at all times plenty of water in the canals. Prospective settlers, of course, were kept away almost entirely, but the inhabitants of the valley displayed a remarkable confidence that the trouble would be overcome, and business was not affected very seriously. Indeed, during these very times, the new and independent town site of El Centro was the scene of really wonderful building activity, and the Holton Power Company, directly and indirectly, practically doubled its plant and holdings in the valley.

The effect of this flood, in a geological way, was of extraordinary interest and very spectacular. In 9 months the runaway waters of the Colorado had eroded from the New and Alamo River channels and carried down into the Salton Sea a yardage almost four times as great as that of the entire Panama Canal. The combined length of the channels cut out was almost 43 miles, the average width being 1 000 ft., and the depth 50 ft. To this total of from 400 000 000 to 450 000 000 cu. yd. must be added almost 10% more for side cañons, surface land erosions, etc. Very rarely, if ever before, has it been possible to see a geological agency effect in a few months a change which usually requires centuries.

PREPARATION FOR DIVERSION WORK.

All measures to prevent avoidable damage to the irrigation system in the valley from the flood-waters having been arranged, operations were resumed on the river. The break opposite the wooden head-gate

had been widened during the flood from 600 ft. to more than $\frac{1}{2}$ mile, and necessitated work on a far larger scale than had ever been suggested. The opinions to the contrary notwithstanding, the ability to get rock in large quantities and rapidly seemed to the writer to be so essential, and it was so obvious that much better transportation facilities were required, that it was decided to build a branch railroad from the Southern Pacific main line at a point 7 miles west of Yuma (now known as Hanlon's Junction) to the break.

The located line of the Inter-California Railroad, construction of which had been stopped by the overflow waters at Cocopah, ran only a few hundred yards west of the wooden head-gate and 150 ft. west of the concrete head-gate. This Inter-California Railroad is a Mexican subsidiary of the Southern Pacific Company, and it was not difficult to arrange a change in its alignment to cross the Alamo where the best location for the diversion dam could be found and to build at once that portion from the break north to the concrete head-gate. Thence northward the permanent alignment was expensive and would require considerable time to construct, therefore it was decided to make a temporary connection of about 6 000 ft. from Hanlon's Junction to the concrete head-gate. It was arranged that the Southern Pacific should build the entire branch line and charge the total cost, on a force account basis, to the C. D. Co., and when later, if ever, the Inter-California Railroad should be completed, all that portion of the branch which could be incorporated with the permanent alignment of the road would be taken over by it at such a figure as it would cost at that time. The stretch from Hanlon's Junction to the western line of the lands of the C. D. Co. is in the Yuma Indian Reservation, and, according to the rules and regulations of the Interior Department, it would have taken some time to acquire a right of way for this portion. As it was feared that special permission might not be quickly obtainable, nothing whatever was said, but the line was simply built. Such a course was deemed justifiable, considering the gravity of the situation, the necessity for haste, and the very small discretionary powers given to Government officials in such cases. As soon as the existence of this track was no longer absolutely vital, permission was requested in the usual way and in due course was obtained. Construction of this branch line was begun on July 1st, and

on August 15th the first train load of materials passed over it to the Lower Heading.

Quarry.—The granite point of rock on which the concrete head-gate was founded seemed favorable for quickly developing a quarry where a large quantity of rock might be obtained, and instructions were given to do the best possible with it. The rock is a second-class granite, and, before the first closing was completed, a quarry had been developed with a 600-ft. face averaging 40 ft. in height. The development of this quarry and track room for outfit cars, locomotives, etc., called for the building of a large yard of sidings and spurs. This quarry was entirely on C. D. Co. land—that bought from Hall Hanlon at the very beginning.

Clay Pit.—Between the quarry and the Boundary Line, and about $\frac{1}{4}$ mile west of the branch railroad, there was an opportunity to develop rapidly a clay pit. Advantage was taken of this, and by the time the first closing was completed, there was a steam shovel face 600 ft. long and averaging 60 ft. in height. The clay in this bed is rather hard and requires some blasting, but it melts down in water, and when mixed in about equal proportions with the cement gravel from the Mammoth gravel pit makes a very impervious material for dam construction.

The Mammoth Gravel Pit.—This pit is on the Southern Pacific Railroad 41.08 miles west of Hanlon's Junction. It had been thoroughly developed at that time and had been used for ballasting the main line for more than 100 miles in each direction. It is the property of the railroad, and the material obtained there is fairly high in clay, the result being essentially a cementing gravel, which makes the surface of the track almost impervious.

Other Quarries Available.—At Declez, a point on the Southern Pacific Railroad 195 miles west of Hanlon's Junction and 49 miles east of Los Angeles, there is a large, well-equipped quarry of very good granite, from which material for the construction of the breakwater at San Pedro Harbor, 19 miles southwest of Los Angeles, is obtained. The output of this quarry is very large, the rock running up to 12 tons.

Near Ogilby, 7 miles west, a large area is covered with lava "nigger-head" rock, essentially one- or two-man size, which had been in part denuded to furnish rip-rap around the railroad bridge over the Colorado

at Yuma. The tracks, however, had been torn up, and no stone had been obtained therefrom in years.

At Tacna, 52 miles east of Hanlon's Junction, there was a quarry formerly used by the railroad but abandoned because the rock therefrom was small and of poor quality.

At Patagonia, on the branch line south from Benson toward Nogales, and 370 miles east of Hanlon's Junction, there was a well-equipped quarry controlled by the Southern Pacific. Its output was a reddish limestone, considerably smaller than that at Declez, but yet frequently turning out 10-ton rock.

These four sources of supply constituted the utmost possibilities, aside from the quarry which might be developed at Andrade.*

Brush.—By no means all the area contiguous to the Colorado is covered with willow brush, but it occurs in spots, often of very large extent. Such areas on the west bank of the river near the Edinger Dam had been cleared away, and west of the old Main Canal there was an old shallow lake which, though now drained, was practically barren. All brush, therefore, had to be obtained from the south side of the break, and with an average wagon haul of about 1 mile. The growths, ranging from 6 to 18 ft. in height, were ideal for fascines and mattress work. Main and branch roads were cut by Indian labor in order to get this material to the front rapidly.

Dredges.—The dipper dredge, *Alpha*, and the suction dredge, *Beta*, were in reasonably good condition, but the former could not be used in the sand bar left exposed in the bottom of the break when the waters receded, because the material slipped down to such a flat slope that it would have imprisoned the craft. After doing all it could in the by-pass and more solid ground, it was started to deepening the old Main Canal toward Algodones. Dams were built behind it from time to time, and water was pumped into the canal at the upper intake to keep the machine afloat. The quantity of water required indicated a surprisingly small seepage loss from this old canal into the surrounding country, and this is in accord with the unexpected experience with the coffer-dams of the wooden and concrete head-gates.

Steamers and Barges.—During the latter part of 1905 the Mexican Co. purchased the steamer, *Searchlight*, 91 ft. long, 18 ft. wide, and

* Andrade is the name of the Inter-California railroad station on the American side of the Boundary Line, Algodones being on the Mexican side.

drawing, without load, 18 in. of water. It had a barge, about 55 ft. long and 25 ft. wide, on which most of its load was carried. The steamer, *Cochan*, 135 ft. long and 31 ft. wide, the largest on the river, belonged to Yuma parties, and as it had been leased by J. G. White and Company for hauling materials and supplies to the Laguna Weir, it was not available. There was another steamer on the river, the *St. Valliers*, 75 ft. long, which was a little smaller than the *Searchlight* and in very poor condition. In addition to these there was the barge *Silas J. Lewis*, 115 ft. long and 35 ft. wide, which was fitted with a donkey engine with which it pulled itself up stream. This barge was rented for \$15 per day, and its deck was cleared for mattress weaving.

Grading Outfits.—The Southern District of the Southern Pacific Company—from Santa Barbara and Fresno, Cal., to El Paso, Tex.—has enough reconstruction and betterment work to keep two or three grading contractors' outfits at work except during the very hot season. An arrangement was made with one of these, Shattuck and Desmond, to supply an outfit on the force account schedule paid by the railroad, with provisions for the payment of all duties and for all stock dying from heat. This firm secured, fed, and housed its own laborers. Inasmuch as there was no very definite plan as to the work which would be required, no contracts were feasible, hence the force account arrangement. At one time about 800 head of this firm's stock, with complete camp equipment, Fresno scrapers, plows, etc., were on the work.

Materials and Stores.—Arrangements were made with the Southern Pacific for equipment, materials, and stores, on the basis of cost plus 10%, and for freight charges of 0.5 cent per ton-mile, until the provisions of the Interstate Commerce Commission prohibiting such freight arrangement went into effect. Two steam shovels were brought in for quarry work and one for the clay pit. Complete work trains were requisitioned from time to time until a maximum of ten was reached. A roundhouse foreman and an assistant master car repairer were sent by the railroad company, and temporary, but effective, plants were installed at Andrade. Three carloads of repair parts and stores for engine, car and air-brake repairs were sent out, used from, and returned when the work ended. All requisition blanks, rules, and other organization methods of the railroad were continued.

When the Southern Pacific built the Lucin Cut-off, consisting of a long trestle bridge and an immense fill across Great Salt Lake, in Utah, there were bought a large number of steel side-dump cars, of 45 cu. yd. capacity, locally known as "battleships," weighing approximately 20 tons, and having a capacity of 100 000 lb. with a permissible 10% overload. These cars were frequently loaded to 125 000 lb. on this work, as the trip between the Andrade quarry and the break did not exceed 4 miles. At first 80 of these cars were secured, and more and more were sent until about 300 were finally in service. Such a quantity of railroad equipment necessitated rather extensive terminal facilities, and these were provided on the American side of the line because of the customs regulations of the Mexican Government.

The railroad from Hanlon's Junction to the Lower Heading, the quarry, clay pit, steam shovels, etc., were under Mr. Eulogio Carrillo, Assistant Engineer of the Southern Pacific Construction Department, from June 1st, 1906, to July 21st, 1907, as a superintendent of the C. D. Co., from which he received his salary, the railroad giving him leave of absence for that period. All the men under his direction, however, were carried on the Southern Pacific payrolls, and bills were rendered later by that corporation to cover this expenditure.

There were two reasons for having the railroad company supply so great a quantity of labor, equipment, materials, and supplies. First, it afforded an opportunity to assemble quickly a thoroughly organized and efficient force of men; the advantage of obtaining materials and supplies at low prices by the purchasing department of the Harriman systems; immediate shipment of repair parts not kept on hand, thus reducing delays to the minimum; and the ability to increase or decrease rapidly the force and equipment without confusion. The second reason was that no immediate cash was required, and as bills of all kinds were not usually presented and approved in less than about 6 months, approximately 3% in interest was saved. All bills were rendered at actual cost plus 10%, which thus meant really cost plus 7%—a very low figure for superintendence, etc.

Whenever any train, equipment, or men left the main line and came on the branch line they reported to and were under the jurisdiction of Mr. Carrillo, who in turn reported to and was under the sole jurisdiction of the writer. In this way no misunderstanding arose, and the entire force obeyed instructions as quickly and fully as though

there were absolutely no connection between them and the Southern Pacific.

Storehouse at Lower Heading.—Duty had to be paid on everything taken into Mexico, but, nevertheless, a very complete storehouse of repair parts, small tools, etc., was established at the Lower Heading. No requisition system was put in, however, because it was felt that the losses which would thus occur would amount to much less than the delay due to any form of red tape, whatsoever. Everything received was charged to the work, and at its closing down an inventory was made and the work was credited with the value of the material left.

Climatic Conditions.—From about June 1st to the middle of September or October 1st, the temperature of this region is so high that until 10 years ago it was not considered advisable to continue large construction work during that season. There can be no doubt that ordinary labor is only from one-third to two-thirds as efficient in such heat, and during this particular year the general average seemed to be about one-half. There is little wind during this period, and the humidity is ordinarily very low, though occasionally it is quite high for periods of two or three days.

Mosquitoes are frequently a terrible pest, very often driving even cattle out of regions near stagnant water. There is relatively little vegetation about Andrade, and at the Lower Heading a large camp compound was entirely cleared and the stagnant pools in the vicinity drained at a slight cost, so that the mosquitoes, while annoying, were by no means serious.

Brush and arrow weed growths are so dense that white men, no matter how well acclimated, cannot work very hard in cutting them down. Men from the central part of Mexico were imported, but they could stand it little better. Indian labor is the only kind for that sort of work.

Labor Conditions.—The work of rehabilitating San Francisco after its disastrous conflagration drew there an immense amount of shifting labor. To the south Los Angeles was growing in every direction. The Harriman Lines, under President Randolph, was employing large numbers of men constructing the West Coast Railroad from Guaymas toward Mazatlan and Guadalajara. Much betterment work was in progress on the lines from Los Angeles to El Paso, and large forces were required for building "shooflies" and shifting track along the

Salton Sea. J. G. White and Company was rushing work on the Laguna Weir, and the Reclamation Service was building the Roosevelt Dam near Phoenix. Thus the labor situation in California as a whole, and in this part of California in particular, was acute. The immigration laws of the United States prevented the importation of Mexicans, except in a very small way, but here the work was in Mexico. It was decided, therefore, to obtain laborers from Central Mexico, ship them from El Paso to Yuma in bond, and back into Mexico at the Lower Heading. Arrangements were made with the Labor Agent for the Southern Pacific, Southern District, Mr. Ben Heney, of Tucson, to ship 500 men. This plan was an utter failure, for two reasons. The Mexican officials did their best to prevent Mr. Heney's agents from getting men started, and the 75 men who arrived were unable to stand the climate.

Attention was then turned toward getting Indians in large numbers, and arrangements were made with Mr. C. E. Dagenette, United States Indian Outing Agent, with the result that, by the time work was in full swing, practically all the men, women, and children of six Indian tribes were on the work—the Pimas, Papagoes, Maricopas, and Yumas, from Arizona; and the Cocopahs and Diegueños, from Mexico. These six tribes fraternized and got along together without any difficulties whatever, and constituted a separate camp of about 2 000 people. About 400 workmen could be depended on from this collection. They were paid 20 cents an hour, and every 9 men received in addition one man's pay to go to a squaw for cooking their food. The Indians bought their own supplies, and to avoid duty built their camps on the Arizona bank, crossing the dry channel below the break to and from work.

Indian labor was very satisfactory, and, indeed, just what other arrangement could have been made is very problematical. Under intelligent foremen who understand their peculiarities, chief of which is lack of assurance and consequent timidity in going ahead with work, they are quite satisfactory. They must be paid weekly, and very few can ever be induced to work on Sunday or to put in overtime, regardless of how critical the stage of work may be when the whistle blows.

Very fortunately, indeed, an unexpectedly large amount of floating labor came in from every part of the United States, men who are attracted to any work which has achieved notoriety for any reason.

Once on the ground these men did not work any great length of time. A work train ran into Yuma every night for provisions and supplies, returning early in the morning, and it always carried a considerable number of cheerful capitalists out and sadder and wiser men in. Yuma at that time was "wide open," with all sorts of lures which few of these floaters could resist. To what extent the work would have suffered had Yuma then been a closed town, as it is now, is a question.

The general wages paid were:

Pile-driver foreman	50 cents per hour.
Pile-driver donkey runner.....	43½ " " "
Good pile-driver helpers.....	31½ to 37½ " " "
Ordinary labor.....,.....	27½ to 30 " " "
Work from 8 to 10 hours per day.	
Board deduction, \$22.50 per month.	

Commissary and Camp Plans.—The usual outfit cars were provided for all men carried on the rolls of the railroad, and many were boarded in the dining cars, which were a part of Mr. Carrillo's permanent construction outfit. The remainder of the men were boarded by Mr. M. C. Threlkeld, of San Francisco, who had and still has a contract with the railroad to board all gangs engaged in maintenance of way and betterment work on its lines. Mr. Threlkeld took an essentially similar contract for feeding the white laborers of the C. D. Co., the first contract being for 25 cents per meal in the United States and 40 cents in Mexico, the contractor to pay all customs duties on material and supplies. After the second break, and when the work was continued at President Roosevelt's request, it was deemed probable that the Mexican Government would refund duties on provisions thereafter, so that the contract was changed on January 1st, 1907, to 25 cents per meal, the Mexican Co. to pay the duties. This contract covered meals for all white laborers, including men on dredges, on the steamer *Searchlight*, etc., and gave Mr. Threlkeld the exclusive selling of clothing, tobacco, notions, etc., to the laborers. The Indians bought relatively little from him, however, preferring to deal with Yuma merchants with whom the local Indians were very well acquainted.

Excellent board for the men was insisted on and furnished. It was believed that good board, especially with lots of fresh vegetables, would be a large factor in keeping men on the work, and this was found to

be the case. Large numbers of mosquitoes were feared, in spite of precautions taken, so bunk houses were built, with brush ramada roofs, and carefully and effectively screened all round. These precautions were not exactly necessary, but were nevertheless well worth their cost.

Policing of Camps.—The many different classes of laborers on the same job and under Mexican laws made it essential to have effective police arrangements, and bar liquor from the camp absolutely. The Yuma Indian Reservation extends to the line, and, in addition was then and until 1908, a part of San Diego County, and a "dry" region. Across the river in Arizona is "wet," but the United States laws against selling liquor to Indians are rigorously enforced. In Lower California, however, the idea of liquor control has not even germinated, and it was necessary to promise to prevent American Indians from getting liquor in Mexico before permission could be obtained to take them out of the United States—and this was quite proper. Accordingly, arrangements were made with the Mexican authorities to put the entire region under martial law, and send a force of rurales with a military commandant at their head to police the camps. This proved extremely efficient and satisfactory, and there was absolutely no disorder at any time.

Customs and Duties.—Except for the operations of the C. D. Co., there was no development in Mexico along the river; therefore, until 1908, the nearest custom house in Lower California was at Mexicali. A garrita was maintained at Algodones, however, where material going down the river to land in Mexico was passed. During the construction of the Edinger Dam, all camps and supplies were kept on Disaster Island in the middle of the river, so that there were no customs charges. When the construction of the wooden head-gate was begun, endeavors were made to get the Mexican Government to establish a customs office at Algodones temporarily, but without success. Accordingly, all bills of material to be passed had to be sent to the custom house in Mexicali; there the charges were assessed, and the manifest was returned to Algodones before the goods could be taken over, which was very cumbersome and slow.

Another method of getting goods across the line was taken advantage of, namely, by boletas. The Mexican Government permits each individual, on payment of duties, daily to take across \$20 (Mexican) worth of dutiable stuff without manifest, and the authorities agreed to

permit goods to be passed at the Algodones garrita by this boleta method, having individual employees of the company sign the boletas. In this way emergency stuff was passed.

Under the concession of the Mexican Co., machinery and materials for permanent construction was to be admitted without duty, but the intention of this provision was plainly for the company to make out a list of what would be required once for all, and that such freedom from duties would apply to the original entry of the machinery and material, and not to subsequent repair parts, etc. Obviously, it did not contemplate the refund of customs charges in such a case as closing the crevasse. Nevertheless, it seemed probable that the customs charges for material and supplies other than provisions would be refunded, because the Mexican Government itself was vitally interested in stopping the break. Tentative negotiations toward this end were started, but the procedure for securing such permission is a long one, and it was advised that the work be prosecuted and the request for refund made after its completion. It was also made plain that no refund would be given for duties on provisions, as it was impossible to determine that the provisions passed were all actually used on the work. When the work was completed a request for a refund was made, and, on President Diaz's recommendation, the National Congress, by vote, refunded approximately 75% of all duties paid, amounting to more than \$40 000.

The chief objection, therefore, was the red tape involved in passing goods, and the delays which followed any slight technical mistake in classification. As an illustration: an inspector investigated the customs transactions of the period about a year later, and assessed a fine against the company for \$3 000 for utilizing the boleta method of passing emergency materials and supplies. On proper presentation of the facts, however, this fine was remitted. Stock with harness and grading equipment was permitted to be passed into Mexico under bond for a period of 6 months, as also was machinery, which provision assisted very greatly in the work.

All payrolls, time checks, receipts, and legal papers require stamps to be affixed and cancelled, inspectors from time to time visiting all corporations and checking the books. If any irregularities are found in the books or papers for the 6 months immediately preceding, such inspector is then permitted to go back to the period of 6 months imme-

diately preceding that, etc. If, however, everything is regular for the first 6 months preceding, that operates to prohibit inspection prior to that time. These inspectors get a considerable percentage of fines assessed and collected, and are consequently quite zealous, so that it is profitable to obey the stamp law scrupulously.

Necessity for Mexican Corporation Doing Work.—On taking charge of the affairs of the Mexican Co., the writer found that up to that time work done in Mexico had been paid for on the American side of the line through the C. D. Co., and in this way no Mexican stamps were required for payrolls, time checks, etc. In other words, the C. D. Co. had its forces go over into Mexico and do work on the canals of the Mexican Co. directly. As this was obviously contrary to the spirit of the Mexican laws on the subject, arrangements were made at once whereby the Mexican Co. did all work in Mexico and billed the C. D. Co. therefor at actual cost, the C. D. Co. turning over all materials and supplies required on the Mexican side of the Line at its expense.

Mr. A. F. Andrade, now Depositario for the Mexican Co., and Assistant General Manager of the Inter-California, was made General Agent of the Mexican Co., and was in charge of all negotiations between that corporation and the Mexican Government, and to his tact, energy, and ability is attributed the relatively small amount of irritation and delay encountered.

Occasionally, rules and regulations had to be disregarded, and this was done when it was deemed quite necessary, knowing that the local officers would report such infractions of the laws, but that the higher officials would view such infractions very sensibly when sooner or later brought to their notice with full explanations. For example, before permission was given to run trains into and out of Mexico after dark, a serious situation developed just at sundown, immediately requiring rock at the Lower Heading, and the Mexican officials at the Boundary Line would not permit trains to pass. Their protests were disregarded, for while the officials under the circumstances could not act otherwise, it would have been folly not to have disregarded their orders, considering the urgency of the matter. Proper explanations were at once made, and the company was not criticized in any way for the action.

Difficulties in doing work in Mexico are largely due to ignorance of Mexican conditions, customs laws, and personal characteristics, and doubtless are no greater than a Mexican would encounter in doing work in the United States. It is very desirable for the highest officer in charge of work to speak Spanish well, as minor Mexican officials are far more impressed with a statement coming from him than from any subordinate officer.

METHODS OF DIVERSION OF RIVER THROUGH ROCKWOOD HEAD-GATE.

The triangular space between the two faces of the **A**-frame and the horizontal cross-bracing of the wooden head-gate was made into a long pyramid, by flooring the bottom and sides, which was filled with sand taken in by wheel-barrows, in order to give additional weight to the gate in resisting the buoyant effect of the water.

By August 5th the discharge of the river had fallen to 24 500 sec-ft., and directly beside the Rockwood Head-gate the receding waters had exposed sand bars on each side of the main channel—the situation being as represented by Fig. 23. When these sand bars had dried sufficiently, teams were used in throwing up an embankment on the line of the diversion dam. Brush jetties were also used to narrow the channel, the *Beta* assisting. In a little more than a week the stream was narrowed to 600 ft., the river gradually falling. Work was then begun on weaving a brush mattress, 100 ft. wide up and down stream, and sinking it on the bottom of the river. The decks of the barge, *Silas J. Lewis*, were cleared and skids were rigged thereon; $\frac{1}{2}$ -in. steel cables, 8 ft. apart, were anchored to "dead men" in the north bank and unwound from spools beneath the skids, such cables constituting the longitudinal strength of the mattress; and to these were fastened brush fascines averaging 18 in. in diameter and 100 ft. in length. These fascines were built up between vertical pins at the upper end of the skids and bound with baling wire, and as they were completed they were pushed down to the last one in the mattress and sewed to it and to the supporting cables with $\frac{3}{8}$ -in., 9-strand, galvanized-iron cable and cable clamps. Fig. 30 shows the method of sewing and fastening. When a length of mattress equal to the width of the barge was completed, the barge was slowly pulled from under it, and it caught the silt and at once settled heavily to the bottom. No kind of weighting whatsoever was required. Another



FIG. 30.—WEAVING BRUSH MATTRESS.



FIG. 31.—DOWN-STREAM END OF BRUSH MATTRESS ABOVE WATER BECAUSE OF SILTING ACTION.

barge width of mattress was then woven and sunk, and so on. Figs. 30 and 31 show the method of constructing the mattress and the number of men employed.

It required 20 working days, with two shifts, to weave and sink two mattresses, one on top of the other, across the bed of the stream, or a total of 1 300 ft.; thus the average rate was 65 lin. ft. or 6 500 sq. ft. daily. The work went ahead without interruption or difficulty except that once the anchor lines controlling the barge were not handled with sufficient care and the first layer of mattress was not sunk across in a straight line, but curved down stream in the middle perhaps 20 ft. at the maximum point. This, however, was not important.

The prevailing idea as to the necessity for such bottom protection in the river may be better realized from the fact that several engineers with the longest experience on the river joined in urging that a solid canvas back be sewed on the under side of the mattress. It was feared that the water might start a wash through a break in the mattress, that such a stream would carry the sand from below, cause a depression for the mattress to span, and result in breaking it when weight should be put on above. This, however, was deemed unnecessary.

While the mattress work was being completed, a 4-pile railroad trestle with 10-ft. bents was started across the center line of this foundation, decked, and a railroad track built thereon. This trestle was driven from both ends, and was ready for the passage of trains on September 14th, 6 days after the completion of the mattress. In the mean time, the earthwork across the north sand bar had progressed sufficiently to connect the rails, so that trains could run out on the trestle. On the south side, the jetty work and the *Beta* had built up a sand bar on which a frame trestle on mud-sills was erected, connecting the earth embankment on the south sand bar to the trestle, thus affording tail room for trains. This frame trestle was filled in with material from the clay pit at Andrade.

At this stage, brush fascines were put in between the bents of the trestle over the channel, laid longitudinally with the stream, and sunk by rock from the quarry at Andrade. The rock was loaded into "battleships" with a steam shovel, hauled down, and dumped from the trestle. In this way a difference of 6 ft. in water elevation above and below this diversion dam was attained with no difficulty whatsoever.

Meanwhile the by-pass in which the Rockwood head-gate stood was being enlarged in several ways. The *Alpha* had cut a small channel from the crevasse to the gate from above and from below, through the solid ground, and the *Beta* had enlarged these cuts until it was taken over to assist in the jetty work on the south side of the river. A small ditch was cut with teams and scrapers across the sand bar, as an extension of the down-stream end of the by-pass. This channel was excavated to the water-table with Fresno scrapers, and made as narrow as possible, reliance being placed on enlarging it by the erosion of the water. In two or three places adobe deposits of considerable extent were found, and in these dynamite was used, as already explained.

The steamer, *Searchlight*, was anchored in the upper by-pass for two or three days with its rear end against the bank and the stern wheel kept going as fast as possible. This greatly hurried the erosion. The increasing head on the diversion dam aided these methods of enlarging the capacity of the by-pass until on October 10th only about 1 450 sec-ft. of the river's total discharge of 14 300 sec-ft. was not going through the gate.

The alignment of the by-pass was unfortunate, as it had quite a sharp curve, and the upper end left the river at a sharp angle. At this point cutting began, and to prevent it a small brush mattress was woven and weighted down with rock.

It was soon seen that, with the 4-ft. openings between them, the A-frames of the gate caught the drift in the water very badly. Anticipating this, cables had been stretched across the entrance of the by-pass and fitted with grab-hooks, like fish hooks on a trout line. These grab-hooks were of $\frac{3}{8}$ -in. wrought iron fastened with from 6- to 8-ft. lengths of sewing cable to the cable spans at intervals of about 8 ft. It was hoped that these would catch drift where it could easily be removed, and prevent trouble at the gate. However, they did very little good.

When the current through the gate increased to 6 or 8 ft. per sec., a scour developed both above and below. Soundings showed that the scour below the gate was not at all serious, but was really far less than had been anticipated. The eddies at the ends of the gate caused side-cutting, as is always the case, but really nothing alarming. The scour above the gate, however, was surprisingly great; some was expected, but not nearly as much as occurred. Brush and

rock extension of the apron, as shown on the plans, had not been put in as it had been the intention to use rock from Andrade in lieu thereof. When soundings, which were taken frequently, showed that the by-pass bed was eroded to the level of the floor of the gate, approximately 1 000 cu. yd. of rock were loaded on a barge which was swung in front of the gate and held by cables until unloaded.

FAILURE OF WOODEN HEAD-GATE.

On October 3d a serious settlement of the earth filling in the north abutment suddenly occurred. Excavation was at once made to ascertain the cause, and some small leaks in the end wall on the up-stream side of the **A**-frame were found. These were stopped up, and the earth was leveled to only a few feet above the water surface on the outside. Two days later the lower wing-wall in this same abutment spread out at the bottom on the west side. The gate itself buckled up about 0.3 ft., about one-third of its length from the abutment, such buckling apparently occurring very slowly within 24 hours, ending on October 5th. These signs of weakness were accompanied by the tearing up of the up-stream apron in relatively small sections, which were at once thrown against the **A**-frames by the current. With great difficulty these were taken out piecemeal, and then only in part. These, together with the drift which accumulated, caused a head of 4.4 ft. on the gate on October 11th. At this time the discharge through the gate was about 12 000 sec-ft.; the maximum discharge through it was about 13 000 sec-ft. on October 8th.

These indications of weakness showed that it would not be safe to use the gate after closing the break, and that it would be very fortunate if it held until this could be accomplished. Furthermore, the drift made it very difficult, if not impossible, to set the flash-boards. Accordingly, on October 5th, a pile bridge was begun just above the gate and connected with the track to the south by a frame bent trestle supported on mud-sills—the same construction as had been utilized on the south side of the channel. This trestle was finished in the morning of October 11th, and it was intended to dump rock from it and fill up the gate in this way and not attempt to use the flash-boards.

When the first rock train was slowly pushed over the trestle, at 11 a. m., three bents of the frame trestle settled and wrecked the train,

fortunately injuring no one seriously. Just why construction, which on apparently the worst ground on the south side of the main channel was entirely satisfactory, should have failed here, is not known—things happened thereafter too rapidly to find out. At any rate, had the trestle stood and had the large number of loaded "battleships" held ready been dumped, the writer has always believed that the head-gate would not have failed utterly. Be that as it may, at 2:30 p. m., without any warning, the gate suddenly buckled up at a point about one-third of the way from the south abutment (Fig. 46), and the larger portion—from there to the other abutment—floated down stream about 200 ft., where it lodged. The remainder of the gate stayed in place, although it settled in the central end. When the gate went out, the 4.4-ft. head above it caused a destructive wave of water, carrying large quantities of drift and débris from the wrecked gate against the railroad trestle crossing the by-pass about 300 ft. below. In about 5 min. this damaged the trestle seriously, and would have marooned a locomotive and train standing on the south side of the by-pass had not the engineer taken chances and pulled across before the piling began to go out.

The pond above the diversion dam extended some distance up stream and contained a large quantity of water which had to run out before the flow through the by-pass was reduced to the discharge of the river. By the time this occurred, considerable inroad had been made at the point where the upper by-pass left the river—which had been protected by a small brush mattress—and for a time it threatened to work down to and through the earth portion of the dam. Aggressive work was centered there, and such action was finally arrested.

CLOSING THE BREAK WITH ROCK FILL BARRIER DAMS IN SERIES.

The lowering of the water above the diversion dam left it dry, except for a surprisingly small quantity of leakage, and enabled examination of the rock fill which had been produced by an ever-increasing proportion of rock with respect to brush. This condition of affairs seemed to indicate that the reasons urged why a rock fill dam of considerable height could not be built in a running stream were not altogether strong, and suggested the possibility of very quickly controlling the situation with a series of rock fill dams, each of which should sustain a head of not more than 4 ft. This particular dam

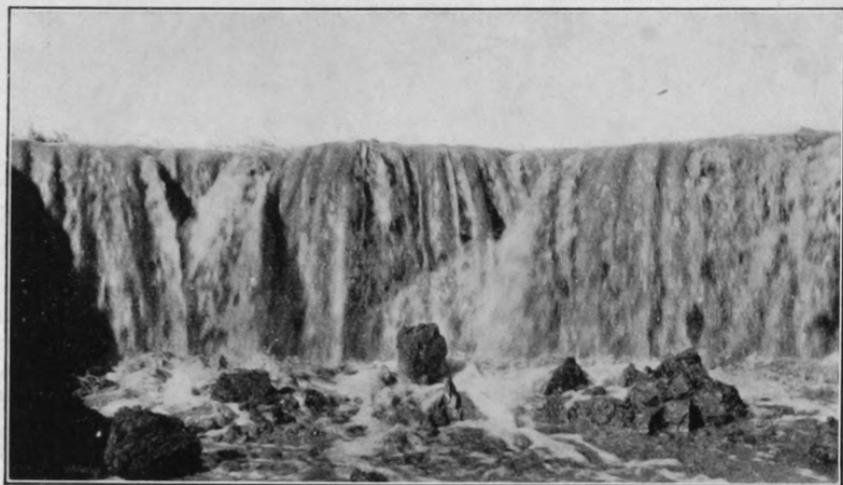


FIG. 32.—GRADE RECESSION IN NEW RIVER NEAR CALEXICO. MAXIMUM RATE OF RECESSION, 1 FOOT PER MINUTE. DROP, 28 FEET. JUNE, 1906.

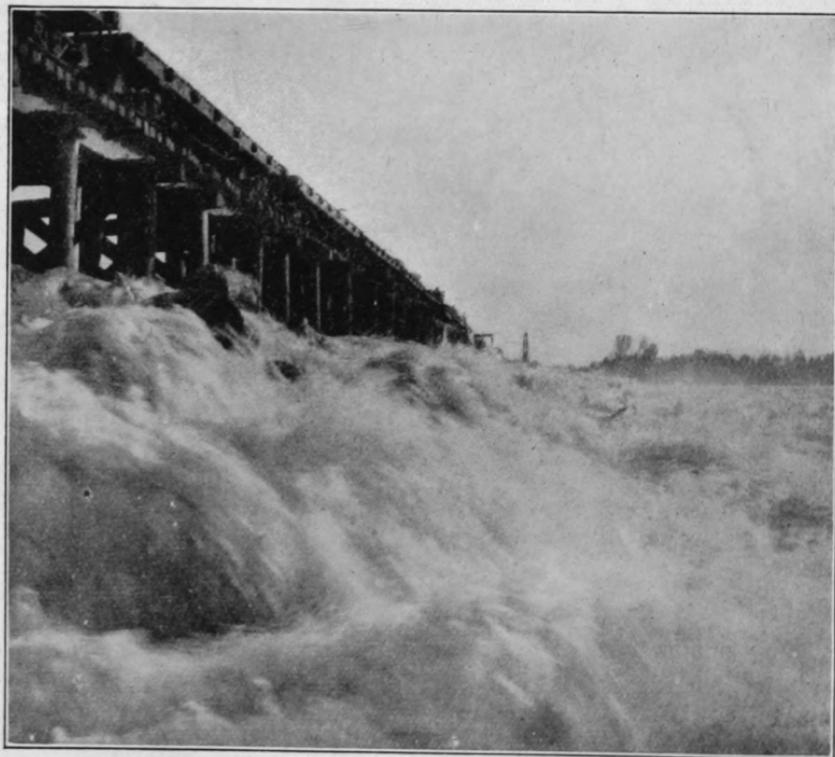


FIG. 33.—THE HIND DAM, PASSING 7 000 SECOND-FEET. HEAD, 10 FEET.

had stood successfully a head of 6 ft. without any of the troubles prophesied for constructing rock fill dams in streams. Furthermore, the tracks of the Southern Pacific Company on the Salton Sea were in an extremely critical condition, and the southern transcontinental line would soon be interrupted, at an estimated cost of \$1 000 000 a month. It was obvious that, if this were to be prevented, very quick action was necessary, and if hope should be abandoned, withdrawal of financial support in controlling the river was almost a certainty. Furthermore, other plans of controlling the situation possessed most serious difficulties, as already explained.

As a matter of insurance, however, a rush order was wired for additional sewing cable for building a diversion dam across the Colorado directly opposite the concrete head-gate, exactly as had been done successfully opposite the wooden head-gate to divert the river through the former structure, and as had been done with the other, trusting to dynamiting, dredging, erosion, etc., for enlarging the 4 miles of Main Canal thence to the break. This done, the trestles across the by-pass, above and below where the wooden head-gate had been, were repaired, and a third trestle, 30 ft. above the lower one, was hurriedly thrown across this stream, which was carrying the entire flow of the river, the waterway through the opening of the gate being only 120 ft. wide.

Such method of closing the break and forcing the river down the old channel by three rock fill barrier dams in series was therefore considered problematical only because there was no mattress under any of them, and the brush mattress idea had always been regarded as essential. The branch railroad from Hanlon's Junction to the Lower Heading was now in excellent condition, and the Andrade quarry was sufficiently developed to permit the use of the two steam shovels, producing about 5 000 cu. yd. of rock daily, by working night and day. It was felt that with these facilities, together with the rock which could be obtained from quarries within a distance of 400 miles to the east and west, rock could be put into the stream faster than the water could carry it away.

As a matter of fact, these three dams were built up so rapidly and successfully that only 10% of the water was going through the by-pass by October 29th, most of the remainder—8 600 sec-ft.—going over the diversion dam with the mattress foundation. Here, a sec-

ondary trestle, with 4-pile bents, 15 ft. apart, parallel to and 30 ft. up stream from the first, had been rushed, and from the two a rock fill dam was completed, turning all the water—9 270 sec-ft.—down the old channel and actually closing the break on November 4th. That is, after working on other lines continuously for 15 months, the stream was controlled by a rock fill dam in 24 days. In other words, the rock fill barrier dam plan, which had not been advocated, or indeed seriously considered, by a single man, proved to be a very simple and efficient, though expensive, method of re-diverting the river. The fact that there was a very substantial brush mattress foundation, however, was deemed by many as of vital importance.

Leakage through the structure was stopped by dumping "battle-ship" trainloads of gravel from the Mammoth gravel pit and clay from the clay pit, the whole being puddled with fire streams. The *Beta*, which was kept above the diversion dam in order to be taken up the river and used in the intake above the concrete gate, was used in widening the up-stream toe of the dams.

A week and a half after the failure of the wooden head-gate, the success of the series rock fill dam plan seemed assured. The *Alpha* had finished its trip up the Main Canal and cut into the excavation in which the concrete head-gate had been built. The intake from the river to the concrete head-gate was completed, and by October 29th the river at this point had been raised approximately 4 ft. by operations at the break. The dam holding out the river here, and those which had been left by the *Alpha* on its way up, were blown out, and water commenced to flow through the concrete head-gate and Main Canal into the Alamo channel below the diversion operations. The initial discharge was about 150 sec-ft., and had increased but little when the river re-diversion was complete. At that time (November 4th) the water height at various points was as follows (C. D. Co. datum):

Above the dam.....	113.0 ft.
Below the dam.....	97.3 "
Opposite concrete head-gate....	114.5 "
Floor of concrete gate.....	98.0 "

By November 15th only 300 sec-ft. were flowing in the Main Canal, the fall of 17 ft. in these 4 miles not having resulted in much erosion, because of several stretches of adobe deposits, though the current was

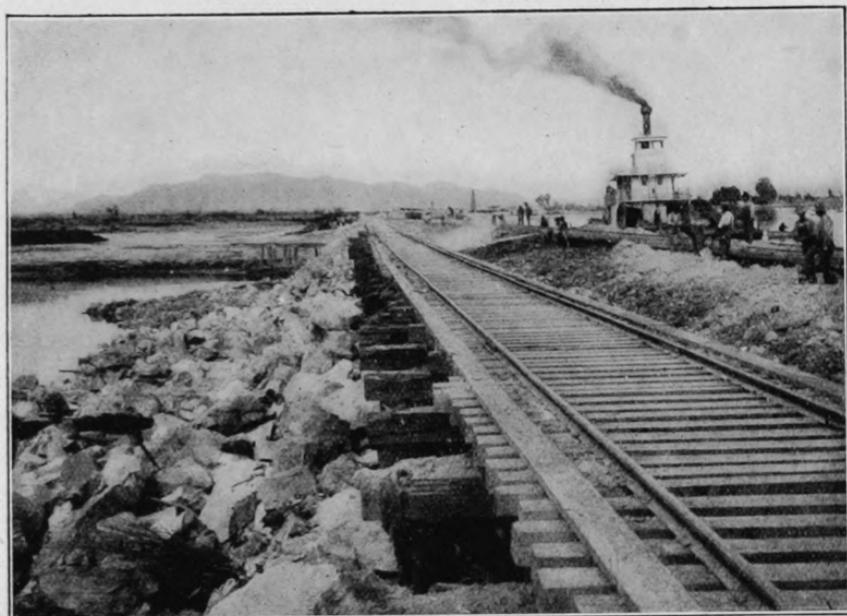


FIG. 34.—SEALING THE HIND DAM WITH GRAVEL AND CLAY BY HYDRAULIC JETS, NOVEMBER, 1906. NOTE SLOPE OF DOWN-STREAM SIDE OF ROCK FILL DAM.

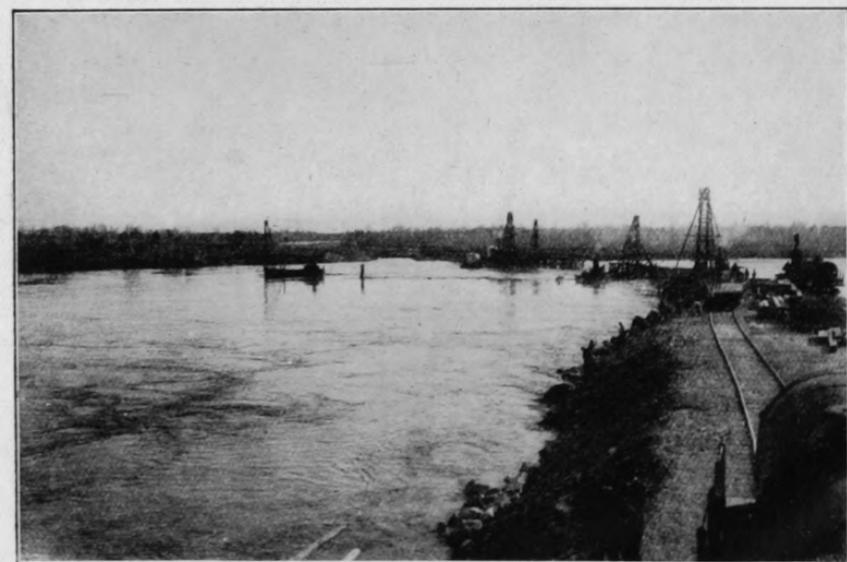


FIG. 35.—GENERAL VIEW OF THE SECOND BREAK, JANUARY 20TH, 1907.

quite strong. Dynamite was used liberally, and by December 5th the grade recession was within 1 mile of the head-gate. In this way continuity of supply into the valley was kept up, and the water users suffered relatively little inconvenience.

In making the first closing, rock was unloaded from the three trestles across the by-pass and two trestles over the main channel. Records were kept daily of car loads of rock from Andrade and from the distant quarries unloaded from each trestle, but this record, unfortunately, has been misplaced, and the totals obviously signify nothing. As the quantities of various materials used during the entire period from August 1st to November 4th may be of interest, they are given in Table 13.

COMPLETING THE HIND DAM.

The dams across the break and the by-pass were hurried to completion with material from the Mammoth gravel pit and the clay pit at Andrade. It was decided that the structure should have a top elevation of 124, and that meant increasing its height fully 8 ft. The tracks over the trestles were raised so rapidly that no attempt was made to recover the stringers or caps.

TABLE 13.—APPROXIMATE DATA OF CONSTRUCTING
DIVERSION WORK ON COLORADO RIVER.

2 200 cords of brush and 40 miles of steel cable used in mattresses and shore protection.
3 800 ft. of railway trestle.
15 200 ft. of 8 by 17-in. Oregon pine stringers.
1 100 piles.
1 690 cars (50 000 cu. yd.) of rock (90% used from October 11th to November 4th).
841 cars (32 000 cu. yd.) of gravel.
808 cars (33 000 cu. yd.) of clay.
300 000 cu. yd. of earth, placed by teams.
200 000 cu. yd. of earth, placed by dredges.
200 to 500 head of mules and horses working from July to November 20th.
200 men in June, increasing to 1 000 men on November 4th.
Discharge of river, June 27th, 99 200 sec-ft.
Discharge of river when actual work of constructing channel was begun, August 6th, 24 400 sec-ft.
Discharge of river on November 4th, when final closing was made, 9 275 sec-ft.
Elevation of water above dam, 113.1 ft. above sea level (C. D. Co. datum).
Elevation of water surface below dam, 97.30 ft. above sea level (C. D. Co. datum).
Total head on closing, 15.8 ft.
Elevation of water surface above dam one week after closing, 112.60 ft. above sea level.
Elevation of water surface below dam one week after closing, 95.85 ft. above sea level.
Total head on dam, November 11th, 16.75 ft.

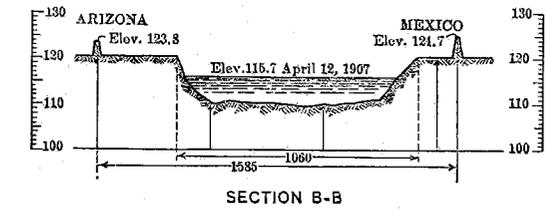
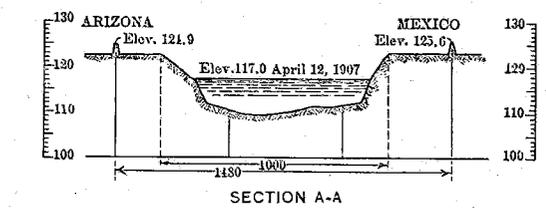
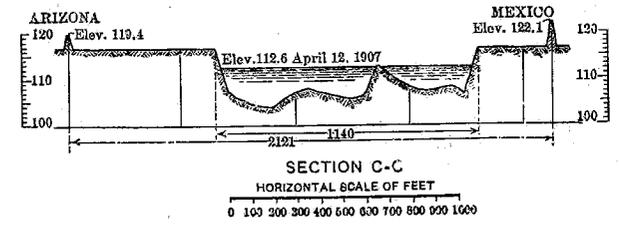
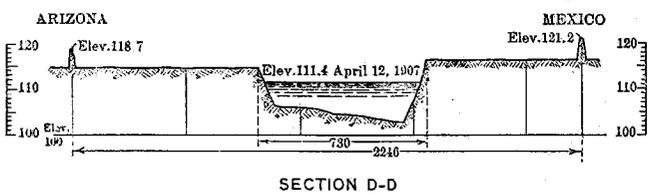
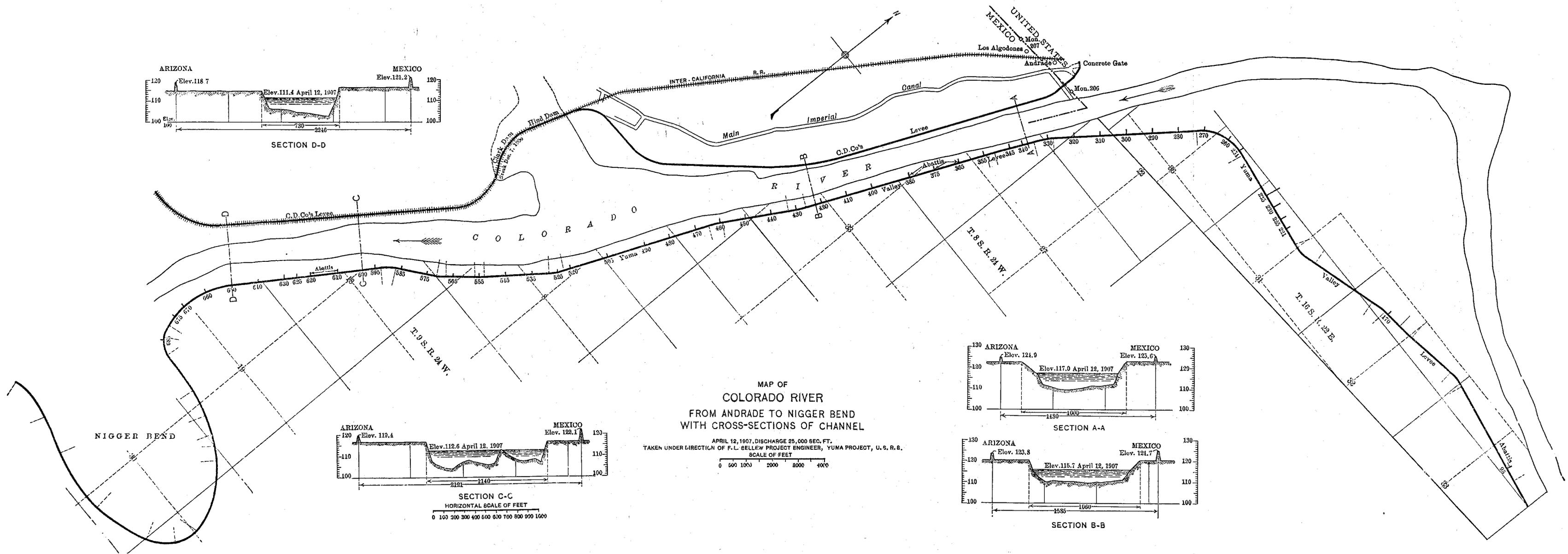
The tracks were gradually pulled together to a final 13 ft. between center lines, which helped somewhat, but the proper side slopes were chiefly obtained with fire streams, five 1½-in. nozzles, each throwing about 225 gal. per min., being used. The mixed materials as dumped assumed a slope of about 1½ to 1, as a rough average, and

these were very quickly and cheaply flattened down hydraulically to about $2\frac{3}{4}$ to 1 on the river side and 2 to 1 on the land side. Furthermore, the slopes were really well finished with very slight additional care and expense.

In its final form the dam has about 400 ft. of 15° curve at the north end, and 2 275 ft. of tangent; the dam is connected at each end with the levees extending along the river. At the north end there are 200 ft. of high dam with a rock fill core to within 8 ft. of the top—where it crossed the by-pass. A little more than half way toward the other end there is 600 ft. of another high stretch with a rock core on brush mattress foundation; the remainder is from 16 to 20 ft. high. This is known as the Hind Dam, so called after Mr. T. J. Hind, Superintendent of the work at the Lower Heading after June 1st, 1906, to distinguish it from the Clarke Dam, closing the second break, so called after Mr. C. K. Clarke, Superintendent of the second closing, December 20th, 1906, to February 20th, 1907. About 80% of this dam was complete on December 7th, 1906.

LEVEE CONSTRUCTION.

The original plans had been to connect the north abutment of the wooden head-gate with the embankment along the river side of the Main Canal, and to build a short section of levee to the south to prevent a flank movement of the river around the diverting dam. The enormous channel which the summer flood of 1906 created in the old Alamo made it obvious that, not only must the break be closed, but that, by a rather elaborate levee system, all overflow water must be kept from getting around into the Alamo. Surveys and examinations showed the necessity of an additional levee from the wooden head-gate to the concrete head-gate, and a levee from the diversion dam south for from 5 to 6 miles. J. C. Allison, Assoc. M. Am. Soc. C. E., Assistant Engineer of the Mexican Co., was assigned to make surveys for these levees on August 1st, and their location was completed early in September. The elevation of the top of the concrete head-gate was 124, and it was decided to put a track over this structure and extend it down the levees, so that the grade was made 126 at Andrade, 124 at the Lower Heading and over the Hind Dam, and thence for 4 miles south, generally 6 ft. above the old high-water marks. At all points the grade was kept approximately $2\frac{1}{2}$ ft. higher than that



MAP OF
 COLORADO RIVER
 FROM ANDRADE TO NIGGER BEND
 WITH CROSS-SECTIONS OF CHANNEL

APRIL 12, 1907, DISCHARGE 25,000 SEC. FT.
 TAKEN UNDER DIRECTION OF F.L. BELLEW PROJECT ENGINEER, YUMA PROJECT, U. S. R. S.
 SCALE OF FEET
 0 500 1000 2000 3000 4000

of the levee opposite the Yuma Project, because, should the latter break, the damage would be far less than if the levees on the west side were to fail, with re-diversion of the river to the Salton Sea. Between the head-gate and the Lower Heading it was necessary to locate the levee very close to the river, because it must obviously be between the river and the Main Canal, and some large areas of bad adobe, damp, and impossible to work with teams, lay close to the canal and extended well toward the river. Below the break, the levee was also close to the river, because of the similar soil conditions for about 4 miles.

LEVEES CONSTRUCTED BEFORE DECEMBER, 1906, WHERE
GROUND SURFACE WAS SMOOTH, WITH NO INDICATION OF
FORMER SLOUGHS FORMED BY RIVER OVERFLOW

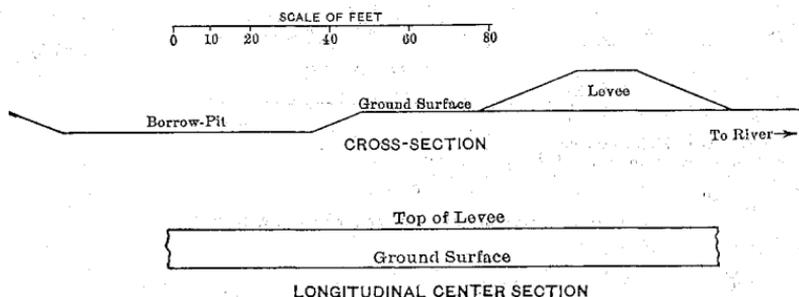


FIG. 36.

The levee was designed with a top width of 8 ft. and slopes of $2\frac{1}{2}$ to 1 on the river side and 2 to 1 on the land side. The ground for the base of the levee was cleared and grubbed, but no "muck-ditching" was done. The desirability of muck-ditching was fully realized, and it was a part of the levee design. Experience in the valley had always shown that, not only ditch and canal banks, but low borders of irrigated fields, etc., leaked badly when water was first applied. Indeed, interesting cases were cited of water in considerable volume disappearing into the ground for several days, doubtless flowing away under the surface through partly opened cracks of buried layers of cracked adobe.

On the other hand, the money supplied by the Southern Pacific Company was for closing the break, and only for that purpose, until the re-diversion of the river was assured. No narrow construction was placed on this, to prevent building levees at all, but it was not considered proper to incur any avoidable expense in this direction until it should have been clearly demonstrated that it was physically

possible to close the break. No muck-ditching had been done in levee building on the Yuma Project up to that time, and, besides, experience in the valley had always been that cracked adobe layers when thoroughly saturated and under the weight of a few feet of earth soon soften and the underground interstices automatically close. It was thought that the levees could probably be maintained until their bases would thus soak up tight, although it was certain that they would leak like sieves when water first came against them. For these reasons the muck-ditch work in the levee plans was ordered to be omitted.

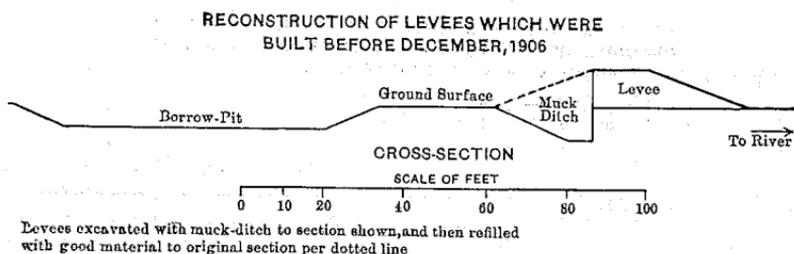


FIG. 37.

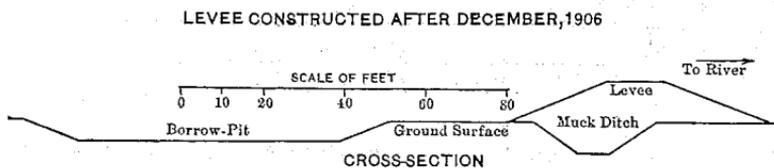


FIG. 38.

Material for the levees was taken from borrow-pits on the land side. It was fully realized that this was not in accordance with the usual practice, but it was decided on after careful consideration of the advantages and disadvantages. The location of the levee was forced very close to the river for a great portion of the way, and the levees of the Yuma Project on the opposite side were also so close to the stream that the distance between was in many places only 1 400 ft.—an exceptionally narrow waterway for such an unruly stream as the Colorado. As it was certain that the current at flood stages would be very great in such sections, it was extremely desirable not to disturb in any way the rank vegetation between the river and the levee, as it could not help but greatly break up and retard currents and thus protect the levee from erosion.

Experience with the levees of the Yuma Project showed that the hope that borrow-pits would be silted up was vain, and instead, that

LEVEE SECTION
 RECOMMENDED BY CONSULTING ENGINEER BOARD
 OF RECLAMATION SERVICE

→ To River



CROSS-SECTION ON CENTER LINE OF BORROW-PIT

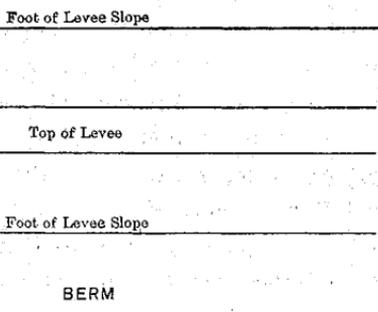
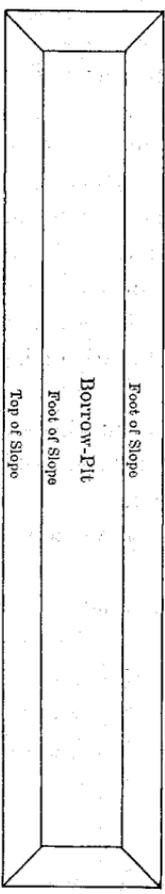
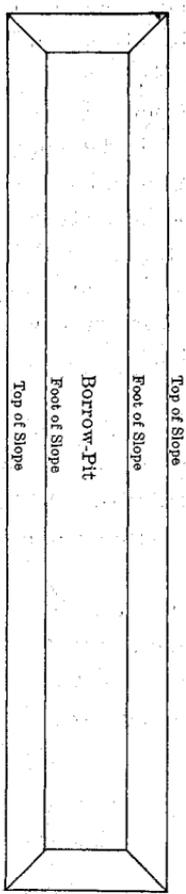


Fig. 80.

GROUND PLAN

they would be cut together to form a continuous canal having eddying currents below the traverses during high floods, unless extensive brush abatis work was used. This sort of protection was deemed very unsatisfactory, because, though the Mexican Co. actually owns the land on which the levees were located in Mexico, it is practically impossible to exercise very much control over the Indians, owing to the indifference of local Mexican authorities. The Indians have always utilized any overflowed areas along the river as they wished, for their little garden patches, and these levees must absolutely cut off such water. For a long time it was utterly impossible to keep these nomads from planting seed in the borrow-pits, where the ground remains wet the longest, and from destroying all brush growths that start therein. It was considered impracticable to maintain brush abatis work, which, when dry, would only make it easier to burn off the area in front of the levee for a garden clearing.

On the other hand, the land spoiled in making borrow-pits was of little value, being non-irrigable under existing conditions. There are no quicksand pockets above the water-table in that region, and, the soil being alluvial silt with more or less sand intermixed, there was consequently no fear of water-soaked material running, such as occasionally causes levee trouble elsewhere. There is also along the river no surface soil crust, which it is undesirable to disturb in levee building.

The only pertinent objection to land-side borrow-pits in this case, therefore, seemed to be the matter of increased total head, which it was decided did not outweigh the advantages of an undisturbed rank vegetation as a protection against the erosion of the water slope by swift currents.

These levees were built by the Shattuck and Desmond grading outfit on force account, with the intention of changing to a yardage basis as soon as possible. On December 6th, 1906, about $1\frac{1}{2}$ miles above and below the dam, respectively, had been completed, 5 miles more were under construction, and the ground was cleared for another 2 miles.

SITUATION OF THE CALIFORNIA DEVELOPMENT COMPANY AND THE MEXICAN COMPANY.

About November 15th, 1906, the various operations along the river were making satisfactory progress, and the writer for the

first time since June 1st left the river, hurriedly investigated the condition of the C. D. Co. and the Mexican Co. and reported his findings toward the end of that month. As a result of this, when the second break occurred a few days later, he advised against further advances by the Southern Pacific Company, and President Randolph concurred and so reported to Mr. Harriman. The fact that such a decision was made by the Harriman interests unqualifiedly has not been generally accepted without some mental reservations. It may be interesting, therefore, to make some excerpts from this report. The balance sheet for the combined C. D. Co. and Mexican Co. was approximately as follows:

ASSETS.

<i>Real estate</i> (chiefly in Mexico).....	\$545 037.26
<i>Stocks</i> (chiefly unsold water stock).....	175 600.00
<i>Plant:</i>	
Machinery and equipment.....	\$179 621.82
Branch railroad track.....	63 000.00
Canals in Mexico.....	375 000.00
Canals in United States.....	308 616.37
	926 238.19
<i>Accounts receivable</i> (chiefly notes secured by water stock).....	235 137.02
	\$1 882 012.47

LIABILITIES.

S. P. Co.—Audited bills and interest.....	\$1 532 595.73
General audited bills and interest.....	73 786.72
Bonds and accrued interest.....	515 200.00
	\$2 121 582.45
<i>Damage claims</i> (probable):	
New Liverpool Salt Co.....	\$50 000.00
Land owners	200 000.00
Water Companies Nos. 6 and 8.....	500 000.00
S. P. Co.....	1 000 000.00
Inter-California R. R.—S. P.....	250 000.00
	2 000 000.00
	\$4 121 582.45
Net liabilities.....	2 239 569.98

The possibility of extending the canal system and selling additional water rights was discussed, and the opinion was offered that such possible returns would probably just about suffice for building a canal from the river into the valley, to take the place of the Alamo channel, which might be necessary in 5 or perhaps not for 20 years; and for building new controlling works on it in the valley.

The conclusions were that maintenance and operation expenses, properly estimated, would take up the returns from the sale of 600 000 acre-ft. per annum. The cost of protecting the region from the Colorado flood-waters was set down as problematic, probably averaging \$100 000 per year, and fluctuating enormously, and it was advised that the task of controlling the river was too serious a tax on the enterprise under any possible circumstances, while international complications would probably mean considerable delay in arranging for such work equitably and satisfactorily.

THE SECOND BREAK.

On December 5th, 1906, a severe flood came down from the Gila, as shown by Plate XLVII. Superintendent Hind and the writer, who were in Imperial Valley at the time, received telegraphic notice from the water-shed, and went at once to the river. For reasons already explained, trouble was expected from water getting under the levees, because no muck-ditch protection had been provided, and a large force of men was detailed to watch the sections for a mile on either side of the Hind Dam day and night as soon as water came even near the river toe of the levee. Information from the upper stations throughout the Gila water-shed frequently indicate floods which never materialize, and this was another case of the "truth itself" being not believed. There was so much accumulated work in the valley that there was no time to watch a discharge of 30 000 sec-ft., although a river stage which would test out and soak up the levees was obviously of great importance. Mr. Hind and the writer were in Yuma, returning to the valley, when the flood reached the Lower Heading, where the river began rising at midnight and rose at the rate of 1 ft. per hour until the peak was reached early in the morning. At 3:30 A. M. Mr. Hind and the writer left Yuma on the work train, reaching the Lower Heading about 5:15 A. M., and found three serious and distinct breaks within 100 yd., the first one being about 2 400 ft. from the south end of Hind Dam. In addition water was finding its way under the levee in

about ninety other places, within the stretch where the water reached the toe of the levee, or about $\frac{3}{4}$ mile above and an equal distance below the dam. Mr. J. Calvert, General Foreman, had fully obeyed instructions, and when the water began to reach the toe of the levees at the lowest point, had commenced work with his force of about 75 men, doing all that seemed possible. The trouble was not that any one break could not have been easily handled, but that so many points of weakness were developed practically at the same time. Indeed, it is really remarkable that the situation got beyond control in only these three places.

A part of the general arrangements with the Inter-California Railroad was its use of the Hind Dam. On the south end of this dam the proposed alignment turned a small angle to the right, and it was planned to have the fill for the next 2 miles without any openings—constituting thus a spur levee to prevent any water which passed through the main levees from reaching the old channel of the break beyond the dam. Had this fill been ready, or had the first serious break been 500 ft. farther along, sand bag diking across the traverses and out into the brush to force the water to spread out and follow an old and well-defined swale which entered the Alamo 2 miles beyond, would have been easily possible. In either case, the damage would have been limited to losing less than 1 000 cu. yd. of levee section.

As it was, however, the water coming through the breaks filled the borrow-pits on the land side, overflowed the intervening traverses, and, as the land in general sloped westward, over-topped the last traverse by the channel of the break below the dam, and caused a rapid grade recession from there, following the borrow-pits through the nearest break. When Mr. Hind and the writer reached the scene, the first of the three breaks was beyond control, and the situation was hopeless.

By the time the grade recession had reached and passed through the break, the flood had crested, and the water had risen against the levee to a depth of about 4 ft. The water rushing through rapidly increased, and cut into the far side of the bank, and was deflected and began cutting into the land side of the levee. This soon breached the dike about 1 000 ft. from the end of the Hind Dam. This breach became the main break, and was rapidly widened and deepened until, within 24 hours, the old channel was again entirely dry and the river had been re-diverted into the Salton Sea.

The men of the grading outfit engaged on levee extension work 3 miles down the river were flooded out, and the steamer *Searchlight* was sent to relieve them. The re-diversion into the Salton Sink occurred so rapidly that the steamer was left grounded there in the old channel, and inasmuch as it was the only craft on the river not controlled by the contractors on the Laguna Weir, this was a serious matter.

THE SOUTHERN PACIFIC QUILTS.

This disaster brought to the higher authorities of the Harriman Lines a thorough realization of the size of the great task of controlling the Colorado. The imperative need of invulnerable levee construction for at least 10 miles along the river was made evident, and the difficulty and cost of building and maintaining such a system was emphasized. Entirely aside from the very great cost of bank protection work to prevent the breaching of levees through the side cutting of the banks, was the difficulty of building in such bad soil a line of defence which would be absolutely dependable.

The financial condition of the C. D. Co. and the Mexican Co., as just explained, was very bad, and, under the most favorable circumstances possible, the chances of the Harriman interests ever being able to get back very much of the moneys already advanced were extremely remote. In addition, however, it was apparent that an unusually efficient and expensive levee system would be required, the first and maintenance cost of which was too large a burden to undertake.

The stockholders of the irrigation properties notified the Southern Pacific management controlling them that the properties could not be expected to do such overflow protection work, and indeed should not pay more than a proportional part based on the total value of the property interests in jeopardy, especially in view of the immense amount of work which had already been done at its expense. Urging that the irrigation company had caused the menace (which may or may not be entirely the case) had not the slightest significance to the Southern Pacific interests, which were really the only ones with any funds, collateral, or equipment, and were in no possible sense responsible for any changes in physical conditions along the Colorado River, except to make them very much better than they otherwise would have been.



FIG. 40.—LEVEE FAILURES RESULTING IN SECOND BREAK, DECEMBER 7TH, 1906.
NOTE THE SHORT LENGTH OF THE TWO GAPS.

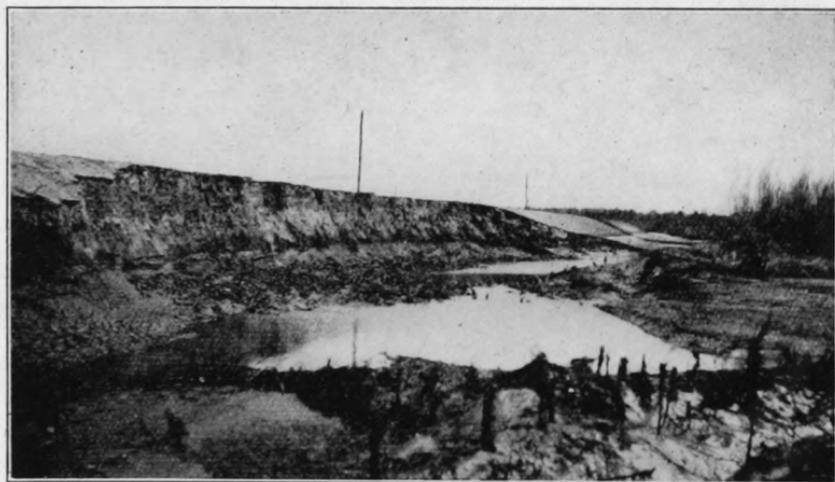


FIG. 41.—EFFECT OF FLOOD OF DECEMBER 7TH, 1906, ON LEVEE OF U. S.
RECLAMATION SERVICE, OPPOSITE LOWER HEADING.

On the other hand, it was recognized that something would have to be done very quickly because the summer flood of 1907 would in all probability cause such grade recessions as to force a hurried exodus from Imperial Valley which would be without a parallel in history. The chances of such grade recession extending far enough to render the control of the river after that flood very much more difficult, were remote. The matter was made complex by the fact that all work had to be done in Mexico and practically all property interests in jeopardy were in America; and there were no provisions, State or National, to handle such a curious situation. Unless the river was turned and kept going to the Gulf, the Southern Pacific would suffer the loss of its traffic from the Imperial Valley and would have to change its line and build 100 miles of track, but, to obviate these losses would certainly not justify it in undertaking to control the river single-handed.

Accordingly, the people of Imperial Valley were notified that, while the Southern Pacific would be very glad to place such equipment and organization as it had along the river at the disposal of any party who wanted to proceed with the work, and would be willing to contribute toward the expenses thereof in proportion to the value of its interests as compared to all others in jeopardy, it would not advance additional funds without a definite arrangement for being reimbursed. Work on a roadbed following the —100-ft. contour was ordered and rushed to completion. The cost of grading was very small, and such a line would preclude the possibility of the interruption of transcontinental traffic by the Salton Sea for at least 4 or 5 years, during which time a line lying entirely above sea level could be economically constructed.

On December 13th a mass meeting of the people of Imperial Valley was held in Imperial, and subscriptions for river control work, totaling \$950 000 were made by various interests. These were the Imperial Valley Improvement Company (the practical successor of the Imperial Land Company) \$100 000; the Holton Power Company, \$100 000; the C. M. Co., \$250 000, and the directors of the mutual water companies together a bond issue of \$500 000. All these were made promising payment 90 days after the break should have been closed successfully, the railroad to assume all risk of the work.

While considering these subscriptions, it was urged in opposition that the mutual water companies might not be able legally to issue

bonds or expend money for river protection work at all, or indeed that the people of the valley could raise money, except by individual subscription, for work to be done in Mexico. Requests were sent out in all directions, resulting in numerous civic and political bodies and authorities of the State wiring to President Roosevelt asking to have the United States Government act in the emergency. The President acted promptly, and as the result of telegraphic correspondence with Mr. Harriman, instructions to start work on the river were received on December 20th.

In the meantime the organization at Andrade and at the Lower Heading had been kept intact. The quarry was developed, sidings just across the border in Mexico were lengthened to 7 000 ft., and material and equipment of all possible kinds which might be needed were gathered in readiness to proceed whenever orders might be received.

SENATOR FLINT'S BILL.

Immediately after the holidays, Senator Frank C. Flint, of California, introduced a bill in the Senate providing for the appropriation of \$2 000 000 to handle the situation. Under the provisions of this bill, whatever sum might be found just should be paid to the Southern Pacific Company for work then under way, and the remainder should be utilized to establish an irrigation project for Imperial Valley by the U. S. Reclamation Service. The idea was that the irrigation of American land in the Salton Basin and the regulation of the Colorado River were inseparably connected, and that as soon as the situation should be under control by the Southern Pacific Company, the entire matter should be turned over to the Reclamation Service for future handling. Director Walcott sent Professor A. E. Chandler, of the University of California, then with the Reclamation Service, to the scene to make a special report, and President Roosevelt, on January 12th, 1907, sent a special message to Congress severely criticizing the promoters of the C. D. Co. and the management of the properties, and urging the passage of the Flint bill in order to relieve the settlers of Imperial Valley from the "injustice" they were enduring.

When the bill reached the House, Hon. S. C. Smith, Representative from the Eighth California Congressional District—in which Imperial Valley is located—opposed it, advising that he did so because of re-

quests from his constituents in the valley. There can be no doubt that, with very few exceptions, the farmers in the valley objected to the bill, preferring the existing irrigation arrangements to those which would follow under the Reclamation Service,* and desiring governmental assistance in river protection work, and in that only. Largely due to Mr. Smith's efforts, the bill failed to pass.

CHANGE IN ORGANIZATION.

In spite of the opinions of visiting engineers, experience during the first closing left little doubt that there would be any particular difficulty in making the second closing without any brush mattress foundation. Even had such been deemed desirable and worth the delay in time, very little brush was available nearby because of the large quantity used for the first closing. It was felt that the work was standardized and consisted in throwing ordinary railroad trestles across the break and from them making rock fill dams in series. The levee construction work to be done, however, was very much of a problem in every way. Superintendent Hind was transferred to the levee reconstruction and extension, and Mr. Clarke, formerly Resident Engineer of the Tucson Division, Southern Pacific Company, came to the work as Superintendent of the second closing on December 20th, 1906.

At the same time, an entire change in the accounting system was ordered, effective December 7th, the date of the break. Prior to that time the work had been done by the Mexican Co., with material and funds supplied by the C. D. Co., and the latter corporation from time to time borrowed money from the Southern Pacific Company. This was changed so that the Mexican Co. was furnished money by Epes Randolph, Agent of the Southern Pacific Company, and the C. D. Co. had nothing to do with the matter whatsoever. On the American side of the line, the operations were exclusively under the name of "Epes Randolph, Agent, S. P. Co." The railroad furnished supplies and material to him under the same arrangements and conditions as it had furnished them to the C. D. Co., namely, at cost plus 10 per cent. One marked difference, however, occurred in making these charges, namely, that after January 1st all freight bills were rendered at traffic

* Among the objections, the two most important were the probable increase in cost of water and the necessity for reducing individual holdings probably to 40 acres or less.

rates instead of at $\frac{1}{2}$ cent per ton-mile, this being made necessary by the provision of the Interstate Commerce Commission which took effect at that time.

CLOSING THE SECOND BREAK.

The work of closing the second break was in several ways interesting. To begin with, the current struck where the south end of the Hind Dam had been, and was there deflected sharply, resulting in very serious erosion. Few people who saw the break at this stage believed it possible to hold this erosion from going entirely through the structure, but by unloading immense quantities of rip-rap, the fill was held, the water in front cutting to a depth of about 42 ft.

Two trestles were decided on and started, five pile-drivers being used, one at each end of each trestle and a floating machine in the middle of the stream. These trestles had to be thrown in a curve concave up stream to connect with the levee on the south side, therefore the piles had to be driven in a very strong quartering current. The channel was narrowed and the bottom cut down to a maximum depth of 38 ft. In driving 90-ft. piles under these conditions, there was constant danger of overturning the driver and losing the machinery, therefore two complete pile-driving outfits were kept in reserve and two boats waited below the trestle to pick up any men who might be thrown overboard.

On December 28th one line of trestle was practically completed, when a flood, shown on Plate XLVII (which, by the way, let the stranded steamer *Searchlight* get back up the river to the work), carrying unusual drift, tore out about one-third of it. Three times this occurred, resulting in the loss of a large quantity of bridge material. All this was obtained through Mr. R. H. Ingram, General Superintendent, Southern District, Southern Pacific Company, and the following telegram from him is interesting:

"H. T. C.—

"Los Angeles, 1/14/07.

"We have exhausted all available supply of piles in San Diego and Southern California. There is very little hope of getting any in Northern California. If you feel that you will need any more please let me know at once as we must make arrangements with the Atlantic System.*

"R. H. INGRAM."

*The lines from New Orleans to El Paso.

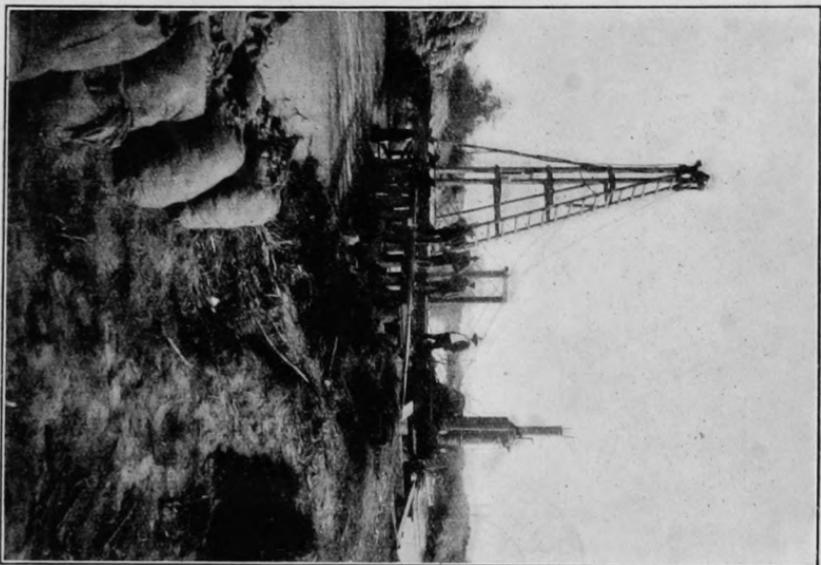


FIG. 42.—CLOSING THE BY-PASS AROUND ALAMO WASTE-GATE. DISCHARGE, 2 500 SECOND-FOOT. PENAL HEAD, 10 FEET.

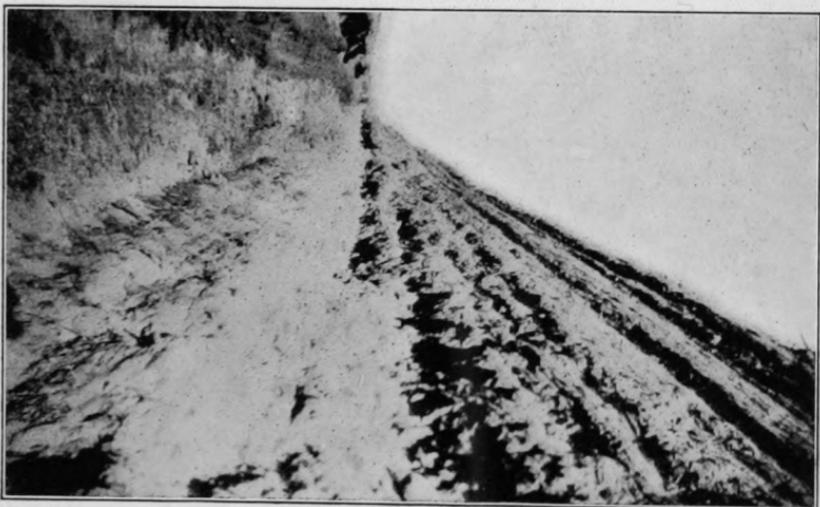


FIG. 43.—RECONSTRUCTION OF LEVEES, SHOWING MUCK-DITCH.

On January 26th, 1907, the first trestle was finished for the fourth time, all stringers were in place, and the track was two-thirds laid. In the second trestle, 50 ft. above the first, seventeen bents remained to be driven. The fill on the south, connecting the trestle with the levee, was 60% completed. Stored on the branch line in Mexico and the United States there were 175 "battleships" of rock, loaded at the quarry of the C. D. Co. by steam shovels, and 100 flatcars of large rock from the distant quarries. At each end of the dam, $\frac{1}{2}$ mile of the levees had been reconstructed, and $1\frac{1}{2}$ miles more opened up, while there were 1 100 men and 1 000 head of stock engaged at Andrade and on the river.

On January 27th, the first trestle was completed, and dumping rock from it began at 5 p. m. By daylight 145 "battleships," containing 6 600 cu. yd. of rock had been unloaded as another flood from the Gila began arriving, but it caused little trouble. On February 10th at 11 p. m. the second break was closed, and all the water was again going down the old channel.

The following materials were used in the second closing:

4 000 ft. of railroad trestle—of this, 1 800 ft. were carried away by floods before either trestle could be completed or any rock could be dumped. When rock dumping began, no more trestle was lost; the final result was two trestles, 50 ft. apart, and each 1 100 ft. long, or 2 200 ft. of trestle.

16 000 ft. of 8 by 17-in. Oregon pine stringers—8 000 ft. of these were removed.

1 200 piles.

45 000 cu. yd. of earth placed by teams—making 960 ft. of earth dam to connect with the levee, 31 000 cu. yd. being placed by February 2d.

2 157 car loads, or 55 000 cu. yd., of rock used prior to actually closing off the water.

221 car loads, or 7 735 cu. yd., of gravel.

203 " " " 8 840 " " " clay.

The discharge of the river when work began on December 20th, 1906, was 12 500 sec-ft.

Dec 31st.....	48 900	sec-ft.
Jan. 7th.....	15 200	"
Jan. 12th.....	44 300	"
Jan. 18th.....	16 300	"
Jan. 20th.....	33 400	"
Jan. 27th (when first rock dumping began)	13 800	"
Feb. 3d.....	31 300*	"
Feb. 7th.....	17 700	"
Feb. 11th.....	20 800	"

After the break was closed, 956 car loads, or 38 240 cu. yd., of clay and 873 car loads, or 33 555 cu. yd., of gravel were used to complete the Hind-Clarke Dam. The rate of dumping rock, etc., is shown by Table 14.

TABLE 14.—CAR LOADS OF MATERIAL.

	"Battle-ship."	Flatcar.	Clay.	Gravel.
January 27th to February 2d.....	606	501	8	15
February 3d to 9th.....	489	285	58	140
February 10th to 10th midnight.....	85	91	88	28
	1 180	977	104	173
February 11th to 15th.....	323	77	99	48
	1 503	1 054	203	221

The water was shut off on February 10th at 11 P. M. and the flatcar rock then on hand and *en route* was unloaded in order to release the cars, the rock from Andrade being used until the 18th in raising the dam hurriedly to protect it against possible floods. The total car loads of material used in the closing and in the finishing up of the Clarke Dam were:

" Battleship."	Flatcar.	Clay.	Gravel.
1 490	1 182	784	873

During the entire operations subsequent to the second break, including finishing up the Hind-Clarke Dam complete, but exclusive of the rip-rap to hold the grade before the completion of the trestle over the break on January 27th, the following car loads of material were used:

" Battleship."	Flatcar.	Clay.	Gravel.
1 517	1 240	956	2 052

*4 300 sec-ft. down the old channel.

The clay pit was closed on March 3d, and the Hind-Clarke Dam was finished, except for the final surfacing with the spreaders, on March 15th.

Two steam shovels, and part of the time three (not including the one in the Mammoth gravel pit) were engaged from September, 1906, to May, 1907, at \$7.50 per day, prior to January 1st, 1907, and at \$12.50 thereafter. During the period, there were from 1 to 12 locomotives, at the following rates:

American, light.....	\$ 8.00 per day.
Moguls.....	10.00 "
Consolidation.....	12.00 "
Car pile-drivers, working 40 days at..	10.00 "
Donkey engines.....	1.50 "
Skid-drivers, complete.....	2.50 "

TABLE 15.—SOUTHERN PACIFIC EQUIPMENT USED ON RIVER, FROM DECEMBER, 1906, TO JULY, 1907, EXPRESSED IN CAR-DAYS.

Month.	Ballast cars, at 28 cents per day.	Steel side dump cars at 50 cents per day.	Caboose, at 50 cents per day.	Water cars, at 50 cents per day.	Outfit cars, at 30 cents per day.	Home freight car detention (box and flat), at 15 cents per day.	Foreign freight equipment detention.
December, 1906....	595	3 271	80	141	42	371	306
January, 1907....	690	4 972	30	174	....	675	600
February, 1907....	219	4 609	15	153	....	47	78
March, 1907.....	54	5 565	27	321	....	47	71
April, 1907.....	....	5 255	4	323	....	28	2
May, 1907.....	2	4 792	9	440	....	17	2
June, 1907.....	....	2 635	53	264	....	32	....
July, 1907.....	....	1 336	12	24	....	....	....
Totals.....	1 560	32 435	230	1 840	42	1 217	1 059

The Clarke Dam extends from the south end of the Hind Dam across the second break to the levees on the south. These two dams, consequently, constitute one continuous structure, which is known as the Hind-Clarke Dam.

RESULTS OF EXPERIENCE IN CONSTRUCTING THE HIND-CLARKE DAM.

The experience obtained in making these two closings, according to the methods used, afforded some information regarding work of this class which is believed to be entirely unique and in some respects

unexpected. In the first place, it was shown that the brush mattress bottom protection is not only unnecessary, but adds to the cost, both in time and money, provided rock is thrown in at a reasonably rapid rate. In discussing the possibility of handling the situation along the lines decided on, the opinion was freely expressed that the rapid current would carry smaller rocks indefinite distances down stream, and that the larger ones would quickly settle into the soft, water-soaked, alluvial soil to indeterminate but very great depths. As a matter of fact, a relatively small quantity of "battleship" rock sufficed to blanket the bottom of the stream with a mattress of rock which fulfilled essentially the same function as a mattress of brush.

In this type of construction it is desirable to have rock of various sizes, such as obtained by blasting large quantities in the quarry and loading with a steam shovel. Large stones (from 1 to 7 or 8 tons), which can be loaded on flatcars only with derricks, are effective, but not absolutely necessary in raising short sections where, through carelessness or a little unexpected settling, an unusual quantity of water is going over a low place in the dam with consequent menacing velocity. Such large rocks were unloaded by a great number of men using pinch-bars, and, to prevent upsetting, the cars were chained to the stringers when unloading especially heavy rocks. One man was killed during each closing by going overboard with a large rock, and these were the only serious accidents. No equipment was lost during either closing.

Two trestles were used in both cases. These were 30 ft. apart in the Hind Dam, and 50 ft. apart in the Clarke Dam, the idea being that the current would prevent building a rock mattress extending far enough up stream by merely dumping rock from the trestle on which the closing was made. Careful examination of the resulting cross-section, when the water was shut off the first time, seemed to indicate pretty clearly that it was a needless precaution to have two trestles for final heads of 14 ft. or less. As there was to be no mattress in the second closing, it was decided to use two trestles, in order to take no avoidable chances. Everything worked so well that it seemed safe to do a little experimenting, and, practically speaking, the second break was closed from the lower trestle alone.

In both cases the fills at both ends were kept well above the possibility of being overtopped, and of uniform heights across the re-

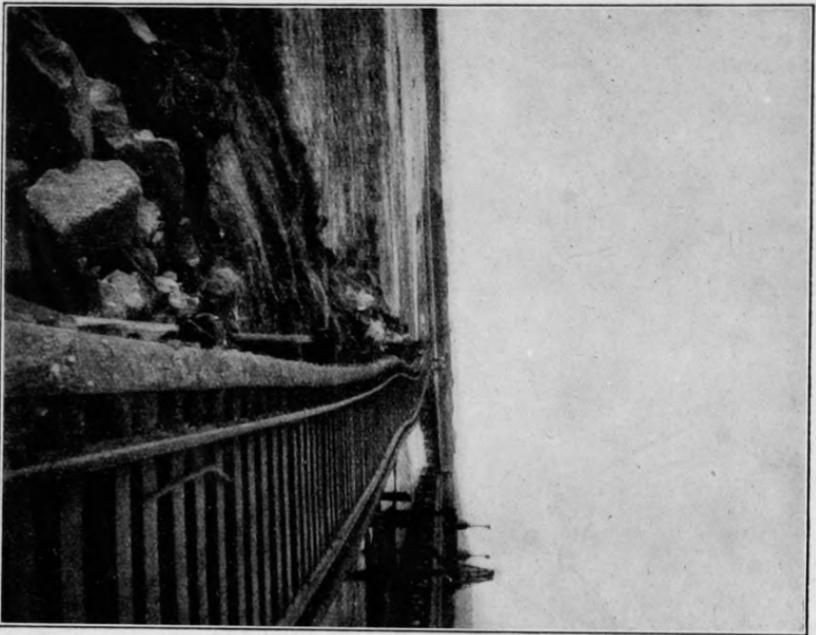


FIG. 44.—KINK IN LOWER TRESTLE CAUSED BY DRIFT BREACHING AND TAKING OUT FOUR BENTS OF UPPER TRESTLE.

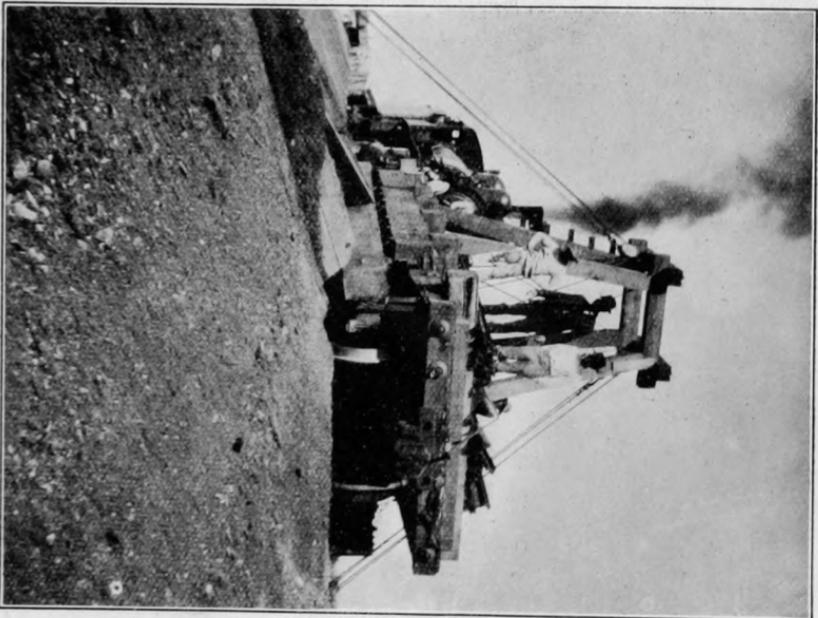


FIG. 45.—GRAVEL SPREADER IN OPERATION.

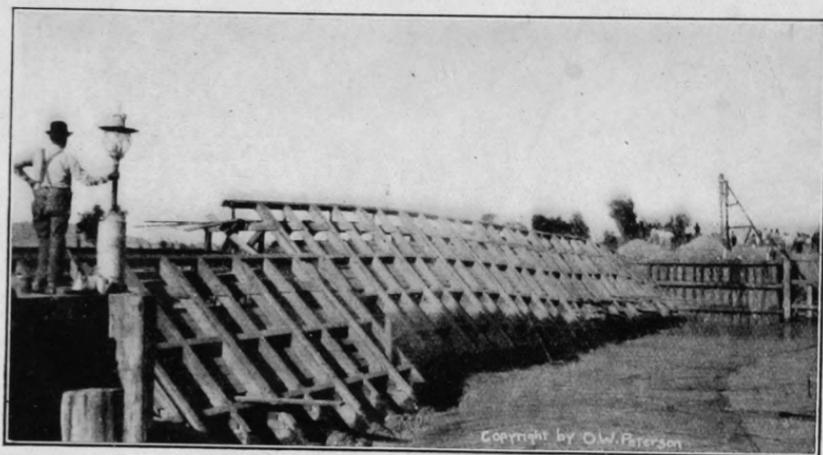


FIG. 46.—FAILURE OF ROCKWOOD GATE, OCTOBER 11TH, 1906.



FIG. 47.—MUCK-DITCH CONSTRUCTION IN LEVEE EXTENSION WORK, 1907.

maining length. Train loads extending entirely over the trestles were unloaded most of the time; but short sections of the fill which were low were promptly filled in, and great care was exercised to distribute the overpour evenly. Once, in the building of each of these structures, a local settlement occurred, resulting of course, in large quantities of water going over the relatively short lowered section. The same experience was had in making the upper coffer-dam wall for completing the gap in the Laguna Weir. The construction of a rock fill barrier dam was regarded as impracticable by engineers, because of just such occurrences surely breaching the barrier hopelessly. In point of fact, continued dumping of even small rock soon stops such so-called breaks, although that results in the waste of much material.

The chief difficulty is caused by drift in the stream being caught by the trestle. Theoretically, such drift should be very easily broken up and carried to the bottom by dumping rock. In practice, however, there is difficulty in keeping drift accumulations from seriously threatening the trestle. In Fig. 44 a very sharp kink will be observed which is due to drift accumulations throwing the entire trestle out of line. Two or three bents were taken out of the upper trestle from this cause.

It was found that a cross-section of the dam under the trestle is about as shown in Fig. 48, so that it is the inevitable little breaks and slides, rather than actual settling, which occurs in such cases. Local readjustments or settlings were easily handled with an estimated quantity of 100 sec-ft. per lin. ft. of dam going over the rock fill. How much more could be handled safely with the rock available is not known. The writer would say that experience along the Colorado River would not justify using the rock fill barrier dam method for quantities in excess of half that flow, on an average, although possibly much greater rates of discharge over such a structure might be safe. The quantity which went over the 680-ft. crest was 27 000 sec-ft.

The total length of rock fill dam used in the

trestle was 1 125 ft., and the water was allowed to pour over 680 ft. of it; the trestle consisted of 4-pile bents, all piling vertical, 15-ft. spacing

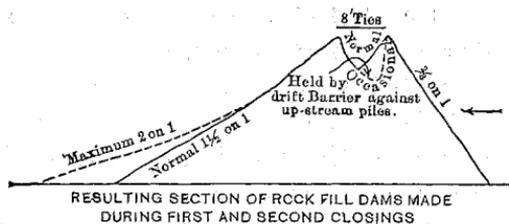


Fig. 48.

between bents, average penetration of piling about 18 ft. The total head, or the difference in water surface above and below the dam, was 12.45 ft., all developed in place in 13 days and 5 hours.

By way of comparison, the building of the upper and lower sides of the coffer-dam within which the central or channel portion of the Laguna Weir was completed is most interesting. One line of trestles, 740 ft. long, was thrown across the stream just above the upper edge of the weir, and another trestle, 728 ft. long, below the lower edge, the trestles being about 400 ft. apart. From these trestles rock fills were built up, and all the water in the river was forced through the sluice-gates at the ends of the weir, the Arizona sluice-way being 2 700 ft. distant and the California sluice-way 1 500 ft. There were well-developed quarries at each end of the weir, and the haul was from 1 500 to 3 500 ft. The following equipment was used:

One 2½-cu. yd. Atlantic type steam shovel (in California quarries).

One 2½-cu. yd. Marion steam shovel (also in California quarries).

Seven 12½-in. American steam hoists, mostly in the Arizona quarries.

Six 18-ton standard gauge Davenport locomotives.

Fifty 6-cu. yd. dump cars.

Eighteen 5-cu. yd. steel dump cars.

Fifty flatcars.

By December 10th, openings to and from the sluice-ways were completed, and the rock fills were advanced until the head was 2.8 ft. On December 19th, the head had been increased to 6.9 ft., of which about 3.5 ft. were on the lower rock fill, while 8 500 sec-ft. were going over these and 3 200 sec-ft. through the sluice-ways. On account of a reported flood, due to heavy rains on the Little Colorado water-shed, work was concentrated on the upper coffer-dam, and by noon of December 21st the gap was closed and the river—9 950 sec-ft.—was turned through the sluice-ways, the head being 3.5 ft. on the lower and 5.4 ft. on the upper fill, or a total head of 8.9 ft.

The river began to rise 30 hours later, and crested at daybreak on the 23d, the discharge being 35 250 sec-ft. Water passed over the entire length—4 200 ft.—of the completed dam, 3.2 ft. deep, but lacked 10 in. of reaching the general level of the upper rock fill. The lower coffer-dam was injured considerably by water running length-

wise of the dam on the down-stream side, so that the upper rock fill stood all the head, which reached a maximum of 10.1 ft. Two weeks later the damage sustained by the railroad tracks on top of the finished parts of the structure had been repaired, the lower coffer-dam had been completed above the danger line, and work had commenced on the 650-ft. gap in the main structure within the coffer-dam.

About 600 men were engaged on the closing, working in two 10-hour shifts. The total cost of turning the river through the end sluice-gates and constructing the coffer-dam is given as \$86 072; the total rock used was 59 750 cu. yd. of excavation, making 82 800 cu. yd. in the rock fill. No lives and no equipment were lost, and the time required after beginning to dump rock was about 2 weeks.

The total cost of the rock work in the fills, including trestles, quarrying, train service, superintendence, depreciation, and all overhead charges of the project, was \$1.04 per cu. yd., of which 45%, or \$38 720, was for excavation, Class 1 (quarrying solid rock).

COMPLETING THE CLARKE DAM.

The Clarke Dam was rendered impervious by dumping Mammoth pit gravel and clay from both trestles. No attempt was made to puddle or settle the material by hydraulicking, as was done with the Hind Dam. Small local settlements occurred from time to time for a year after the dam was completed, but nothing disquieting in any way. Imperviousness was very quickly obtained, indeed, long before the structure was raised to grade and widened to its proper dimensions.

In constructing the Hind Dam, every effort was made to hurry the work, and the stringers were not taken out. With the Clarke Dam, all stringers were removed, the tracks were raised and narrowed to 13 ft. from center to center, and the top and sides were finished off with the gravel spreader used on the levee work, leaving the finished structure as shown by Fig. 50.

Spur Levee.—A spur levee, 8 700 ft. long, was built, starting at the elevation of the top of the Hind-Clarke Dam (124 ft.), and with an initial descending grade of 0.5 per cent. The purpose of this levee is to prevent water from any break in the main levee south of the Hind-Clarke Dam from getting into the old dry channel below, as happened when the second break occurred. It is intended to hold such water back and make it spread over the low country in a sheet.

This levee, which was decided on, but not started, before the second break, is located along an old overflow channel slightly higher than the country on either side, and where test-pits showed need for little muck-ditching. Arrangements were made later with the Inter-California Railroad to change its alignment to use this spur levee and the Hind-Clarke Dam, and it was thus extended by this railroad grade for 4 miles without any opening.

CHANGES IN STAFF.

The success of the Hind-Clarke Dam being assured, arrangements were concluded whereby F. C. Herrmann, M. Am. Soc. C. E., on February 1st, 1907, became Assistant Chief Engineer of both the C. D. and Mexican Cos., particularly for the purpose of making surveys and estimates for reconstructing and extending the canal system in Imperial Valley. About March 1st, the Clarke Dam being then well advanced, Mr. Clarke was transferred to the valley and appointed Superintendent of Construction of both companies, Superintendent Hind remaining in charge of all operations along the river until they were finished, when he was transferred to the Harriman Lines in Mexico, on August 1st, 1907. On May 1st, Mr. Clarke returned to the railroad as Resident Engineer of the Coast Division. Nearly two years later he came back to the valley as Superintendent of Imperial Water Company No. 1, and early in January, 1910, was appointed by the Receiver of the C. D. Co. as Assistant General Manager and Chief Engineer, which position he resigned in April, 1911. The writer remained as General Manager of the properties, but relinquished the title of Chief Engineer in both companies in July, 1908, and issued circulars advancing Mr. Herrmann to the positions which he held until he left the companies, in March, 1910, after the appointment of a receiver. His successor in the Mexican Co., and its present Chief Engineer, is Mr. C. N. Perry, who first came to the valley with Mr. Rockwood in 1892, and was Resident Engineer of both companies from October, 1901, to August, 1906, and so was in immediate charge of most of the existing canal construction in Imperial Valley. Since April, 1911, Mr. J. C. Allison has been Chief Engineer of the C. D. Co.

LEVEE RECONSTRUCTION.

On December 20th, 1906, reconstruction on the existing levees was begun by tearing away the land side of the levee and excavating a

continuous muck-ditch as deep as the test-pits indicated to be necessary. The usual location of a muck-ditch is under the center of the levee section, but, in reconstruction work, this was not practicable, and besides, there were several reasons for location nearer the land toe, which will be mentioned later. The excavation was made as narrow as possible with the use of 4-horse Fresno scrapers, and it was found that the walls, not only of the natural soil, but of the recently constructed levee section, stood practically vertical without any caving. (Fig. 43.) The muck-ditch was excavated 1 ft. lower than the lowest layer of cracked adobe soil lying above the permanent water-table, and was refilled with the material removed, care being taken to keep out roots and clods of adobe exceeding 3 or 4 in. in greatest dimension. When the muck-ditch was completed, the land side of the levee was replaced to the slope of 3 to 1, instead of 2 to 1, as originally built. This work was started on force account, but was soon changed to a yardage basis, on the following schedule:

Levee section removed and replaced in embankment, 12 cents per cu. yd.

Muck-ditch excavation and refill, $17\frac{1}{2}$ cents per cu. yd.

Reinforcing levee section, 19 cents per cu. yd.

The total earth handled was 199 000 cu. yd.

Levee Extension.—At the same time, surveys were commenced for extensions of the levee to the south. From Mile 7 the original alignment continued closely paralleling the river, and here all clearing had been done for 2 miles, and about 20% of the fill had been made. At the south end the flood caused three breaks, close together, through almost completed levee section. These breaks were due to bad material, that is, adobe which in working had broken up into small, hard clods. Directly across the river, similar breaks had occurred in the levee of the Yuma Project. In addition, the river during this flood showed a marked tendency to cut into the west bank immediately opposite.

The surveying party found that the most suitable soil and the highest ground, west of the river bank itself, lay along the Paredones overflow channel, which turned away more than a safe distance from the river. This channel was followed beyond the undergrowth to open country, and a hurried reconnaissance showed that at some future time, by building approximately 20 miles of levee, most of it relatively low,

connection could be made with the mountain chain on the west side of the delta at Cerro Prieto.

It was felt that the work now in progress was not merely to prevent flood-waters from quickly getting around the end of the Hind-Clarke Dam, but that very soon a system of dikes constituting a continuous line of defence for the Imperial Valley must be provided. President Roosevelt had not requested or authorized Mr. Harriman to construct anything so elaborate, but only what would form a protection for a few years at most, or until suitable permanent arrangements could be made to control the river properly. Such levees as were to be built, however, obviously should be constructed with a view to being incorporated in their entirety in the final scheme.

Two plans for keeping the overflow waters of the Colorado from getting into the Salton Sea are at once seen to be better than any others. One is a levee line along the Paredones ridge and north of Volcano Lake to Cerro Prieto, and the other is a line of levees parallel to the river practically to tide-water. These two plans are shown in Fig. 4. The first would protect all American interests and all that territory in Mexico lying to the north and west; the second would also protect the very large area lying between. This additional area is the property of the C. M. Co., and is in an extremely good location for irrigation from the Colorado. The C. M. Co., on being approached regarding the matter, thought that its present interests would be best served by the northern line of defence, which thus precluded the possibility of financial assistance from that company in giving additional protection, and the matter resolved itself into a decision as to which of the two lines could be built and maintained at least cost. The instrumental data regarding the region were insufficient to decide between the two possibilities, and, incidentally, the same condition of affairs unfortunately exists to-day. However, something had to be done, and at once. Based solely on careful reconnaissance, the northern line of levees was decided on, and the portion to be immediately built was located to a point about 10 miles below the Hind-Clarke Dam, this being enough to prevent water from getting around into the Alamo channel during flood stages. Aside from the desire to do only what was absolutely required and could certainly be finished before the summer flood, it was felt that the officials of the Mexican and American

Governments should have the greatest freedom in determining on future work for controlling the river.

The grade was determined from existing high-water marks along the line of the levee, checked by high-water marks along the line of the river; and several miles at the lower end has a grade of 3 ft. per mile. The cross-section decided on was a top width of 10 ft. and slopes of 3 to 1 on each side.

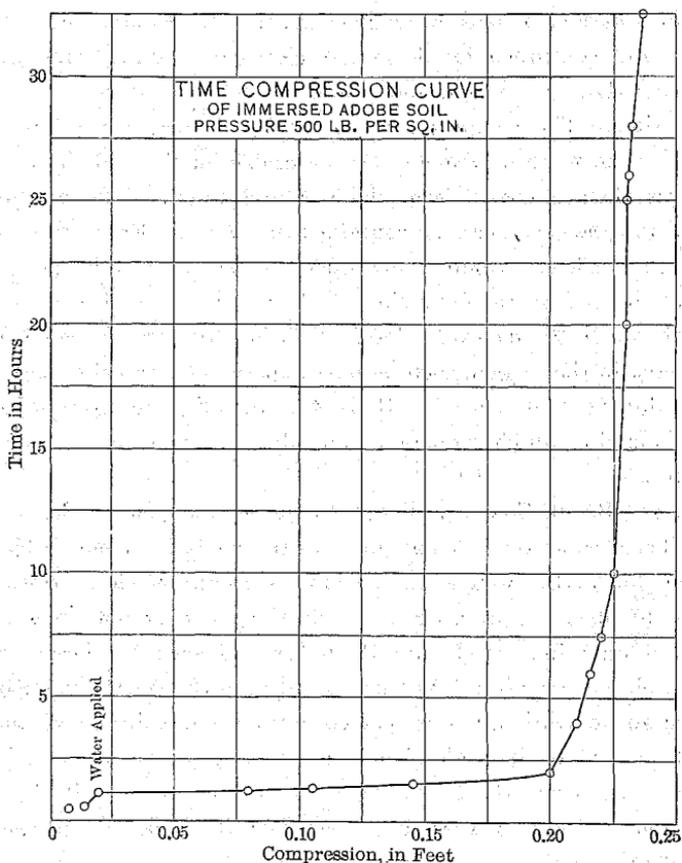


FIG. 49.

Muck-Ditches.—The Yuma Project, U. S. Reclamation Service, loaned one of its engineering corps, the method being to grant leave of absence to the members and have them carried on the payrolls of the Mexican Co. This corps was in charge of Mr. C. W. Ozias, Assistant Engineer, and was assigned to levee location work. Mr. Ozias was

instructed to make tests for determining the time at which efficient compression of adobe soil would take place with distributed loads, as under a levee when immersed in water. For these tests some hard chunks of adobe were taken from the muck-ditch excavation, 2 ft. below the surface at Station 178, and placed in a box 1 ft. in each dimension, in as nearly natural condition as possible, and kept under a continuous pressure of 500 lb. per sq. ft. At the end of 1 hour $\frac{1}{2}$ cu. ft. of water was added, part of which leaked out. Compression started rapidly, and continued for 1 hour, due to the chunks being pressed closely together in the box, and slower compression started at the end of this time. The compression continually decreased until the 40th hour, when no more movement was noticeable on the scale beam. The mass was then removed from the box and found to be plastic and pressed together so that it contained no voids. From this it appeared that efficient compression under a load of 500 lb. per sq. ft. starts at the end of an immersion of about 3 hours, and continues indefinitely until all the voids close. This is why borders, canal banks, levees, etc., in that region soon become impervious if breaks can be prevented during that period. It is the inability to prevent breaks over a long line which renders a muck-ditch of some form practically necessary.

The results of this experiment suggested dampening the slickens under the levee section enough to have the voids in it closed by compression due to the weight of the levee section. Such wetting could be brought about by digging a trench along one or both toes of the levee and pumping water into it, and would save the large cost of muck-ditch construction. As this levee line was too vitally important for such an innovation, it was decided to use a muck-ditch 6 ft. wide on the bottom and having side slopes of 2 to 1, the excavation to extend at least 1 ft. below the lowest layer of cracked adobe soil above the water-table. Test-pits were dug every 200 ft. to determine the necessary depth.

The muck-ditch, however, was located under the land toe of the levee, as shown in Fig. 38, because it was not deemed desirable to prevent water from getting under the levee, but, on the other hand, to allow water to go under it as far as possible and still certainly hold it back with the muck-ditch. In this way the cracked adobe layers under the

levee section would become impervious as a whole in the minimum time after the water came as high as the toe of the levee.

The muck-ditch, except for two short stretches, was filled with the soil taken from it, only a few places being found in the 17 miles constructed where bad material occurred in such masses as to render it at all difficult to mix the adobe clods with satisfactory material taken out of the excavation.

Borrow-Pits.—Borrow-pits were located on the land side, leaving a berm of 40 ft. and traverses 20 ft. wide at intervals of 250 ft. It was specified that borrow-pits be left in workmanlike condition, with a maximum depth of $2\frac{1}{2}$ ft. on the side nearest the levees and 4 ft. on the farther side. The reasons for borrow-pits on the land side have already been given. The occurrence of the second break was not considered to indicate any good reason for change in this particular.

Contracts and Contractors.—All levee extension work was done on a yardage basis, a contract being let to W. K. Peasley and Company, of Los Angeles, for $18\frac{1}{2}$ cents per cu. yd., for the entire levee cross-section, including the muck-ditch, and 10 cents per cu. yd. for refilling the muck-ditch section. The price for clearing and grubbing was \$2 000 per mile. The contractor assumed all risk of expenses due to delays caused by flood, and the company paid all customs charges at the Boundary Line.

The Yuma Project, U. S. Reclamation Service, permitted the use of 120 head of its rented stock in order to assist in completing the work before the summer flood. This outfit worked under the usual regulations of the Reclamation Service, on a rental basis, and the levee contractor put it on the work and paid the Mexican Co. what the latter paid. The Reclamation Service engineers advise that levee construction on the Yuma Project has been found to cost much less than Mr. Peasley's contract, but, for some reason or other, the levee contractor and the company's timekeepers, who checked the work, show that the contractor's price for the work done by this grading outfit on this job was less than its cost. The great hurry had a marked effect on the expense to the contractor, however. At any rate, the writer had an opportunity to examine the contractor's books later, and found that his profit on this job, with proper overhead and equipment deterioration charges, was 17.3%, and none of the possible delays due to floods, etc., occurred.

All work was very carefully inspected by an unusually large corps of men, and every precaution was taken to prevent any roots or rubbish from getting into muck-ditches or fills, and to see that all muck-ditch construction was carried to the depths ordered.

Railroad Track.—When completed, all levees, both as reconstructed and extended, were laid with a railroad track consisting of new 6 by 8-in. Oregon pine ties 8 ft. long and good old 56-lb. relaying steel obtained from the Southern Pacific Company. This was done partly because of the great advantage in maintenance work in future and partly to distribute a blanketing of Mammoth pit gravel.

On the completed work 15 miles of track were laid on the main levee, $1\frac{1}{2}$ miles on the spur levee, $5\frac{1}{4}$ miles from Hanlon's Junction to the Lower Heading, 2.6 miles of sidings, quarry tracks, etc., in California, and 2.7 miles of sidings and double track over the Hind-Clarke Dam in Mexico. No part of this track has been taken up, but the main line and sidings between Hanlon's Junction and the end of the spur levee have been sold to the Inter-California Railroad.

Gravel Blanketing.—Vegetation, springing up like mushrooms on fills in the region, very soon precludes any possibility of inspection. The roots also attract burrowing animals. Furthermore, the danger of erosion on the water face by swift currents due to the fall of 3 ft. per mile made it exceedingly desirable to provide a better surface for the eddy currents. For these reasons all levees were blanketed on the top and both sides with a 15-in. layer of gravel from the Mammoth gravel pit, which, as has been said, supplies a cementing material which packs into an almost impermeable surface. It was practically impossible—and would have cost more money—to have blanketed the water face only, or to have put a greater depth on it than on the land side, because all the gravel was hauled in "battleships" which dumped equal quantities of material on each side. Ordinarily, two cuts of cars were unloaded, a considerable portion of the first being used on the top and to surface the track. The remainder was spread evenly over the two slopes of the levee with a home-made spreader devised and constructed with an ordinary flatcar temporarily taken for the purpose by Superintendent Hind at a total cost of \$300. Its construction is shown by Figs. 45 and 52. With this the gravel was spread in an extraordinarily workmanlike manner at a cost of 0.1 cent per cu. yd. It worked in either direction, and the ordinary process was to have one cut of gravel

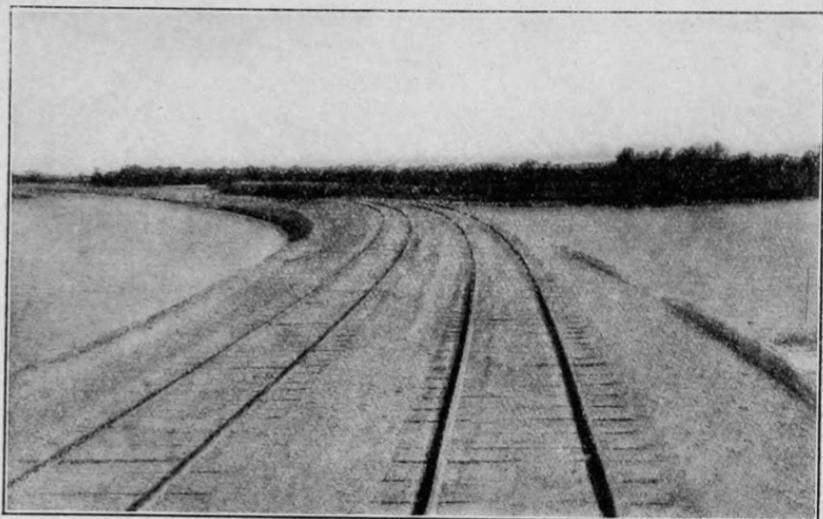


FIG. 50.—SOUTH END OF HIND-CLARKE DAM, SHOWING LOCATION OF SECOND CLOSING.

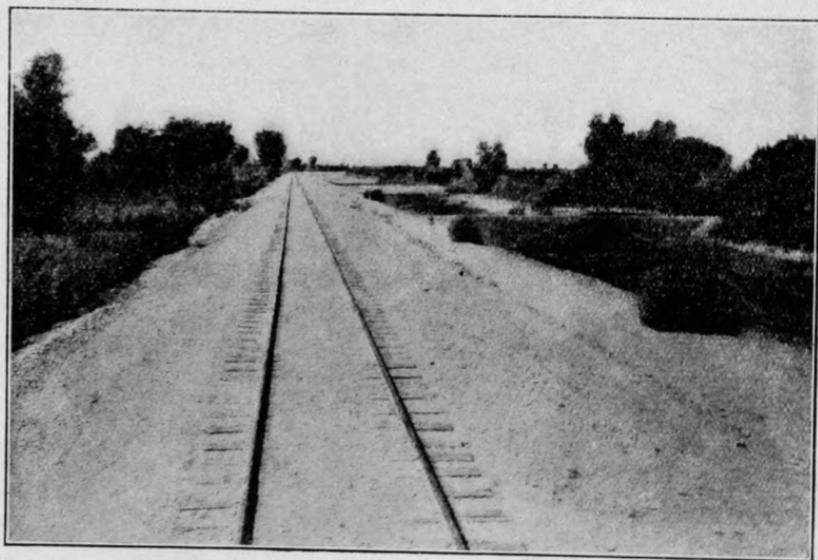


FIG. 51.—TYPICAL SECTION OF COMPLETED LEVEE WITH LAND-SIDE BORROW-PITS.

dumped along from 3 000 to 6 000 ft. of levee, and have a locomotive take the spreader on two round trips, the usual speed being from 10 to 12 miles per hour.

Very much more permanent and expensive blanketing of levees is to be found on the Sacramento River, California. In Reclamation District 307, near Lisbon, about 15 miles below Sacramento, a length of a little less than 3 miles of levee has recently been completed. This keeps out the back waters, in which there is little current, but, on account of the width, the wave action is relatively severe. The blanketing was begun about July 1st, and finished about December 1st, 1911, and consists of 700 000 sq. ft. of reinforced concrete 4 in. thick. (Fig. 56.) The reinforcement was a No. 10 gauge wire, 6 by 6-in. mesh, known as the Clinton Electrically Welded Fabric. The concrete was a 1:2:5 mixture, with rock brought by train from Oroville to Sacramento and thence by barge to the work, and cost there about \$1.50 per cu. yd. The Reclamation District furnished the cement and reinforcing material, and the contractors, Richard Keating and Sons, of San Francisco, did all the other work. Mr. P. N. Ashley, County Surveyor of Yolo County, Woodland, was engineer. This covering cost 13 cents per sq. ft., or a total of about \$94 000, or approximately \$32 000 per mile. The average height of the levee was 22 ft.

TABLE 16.—STATEMENT OF CHARGES ON ACCOUNT OF OPERATION OF MAMMOTH GRAVEL PIT, FROM OCTOBER 15TH, 1906, TO JULY 15TH, 1907, INCLUSIVE.

Labor of gangs in pit getting out gravel.....	\$23 312.46
Use of tools, 2% on above labor.....	466.25
Wages of trainmen in pit.....	3 108.91
Wages of enginemen in pit.....	2 111.65
Wages of operators, etc., at pit.....	897.19
Rental of engine in pit.....	2 202.50
Rental of steam shovel in pit.....	2 457.50
Fuel furnished for pit engine.....	4 495.14
Fuel furnished for steam shovel.....	1 594.41
Material purchased for pit engine repair.....	\$184.63
Material purchased for steam shovel.....	648.90
Miscellaneous supplies.....	6 890.88
Miscellaneous pit engine supplies.....	237.98
	7 862.89
On store department expense, 5%.....	393.10
Shop repairs to steam shovel.....	727.19
On shop expense, 10%.....	72.72
Freight on material shipped to pit.....	6 345.86
Miscellaneous credit.....	119.74
	Total.....
	\$55 927.53

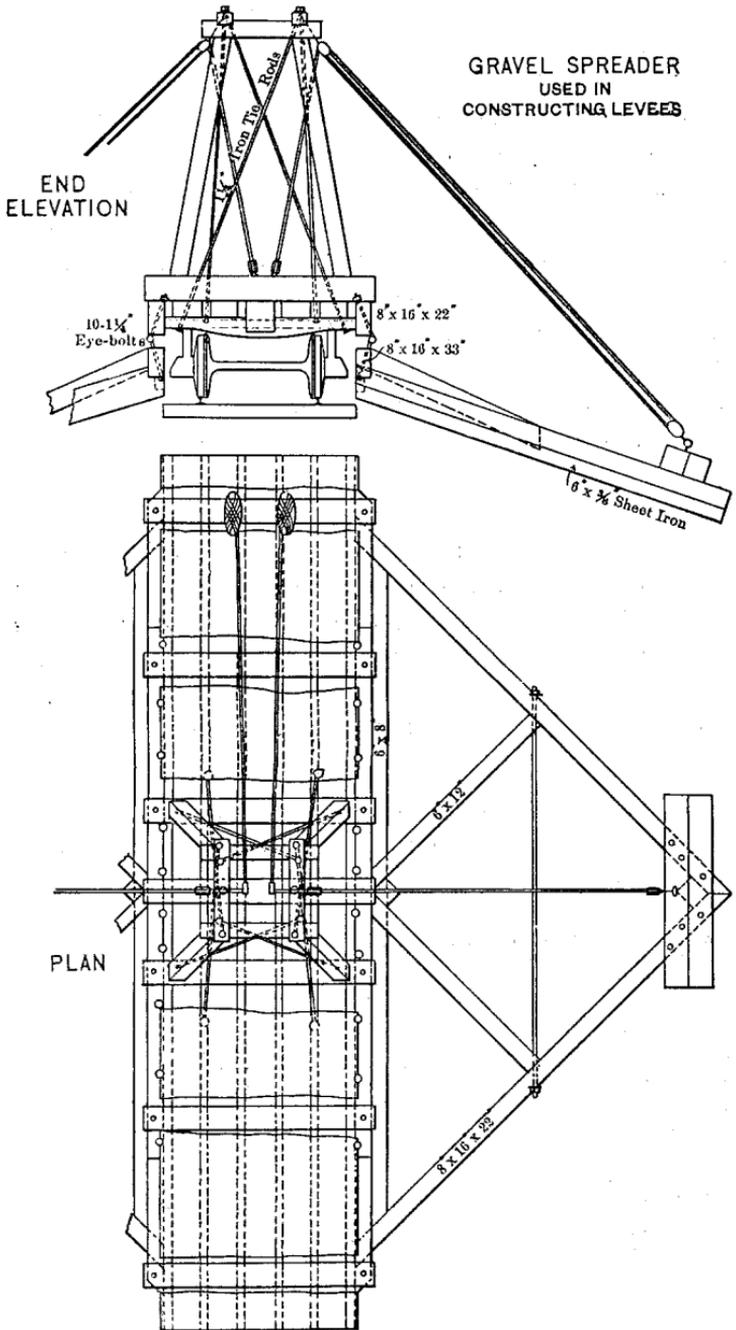


FIG 52.

TABLE 17.—CARLOADS OF GRAVEL SHIPPED.

Month.	To California Development Company.	To Epes Randolph, Agent, S. P. Co.	To Southern Pacific Company.	Totals.
1906.				
October.....	857	.....	.....	357
November.....	1 171	.....	18	1 189
December.....	.....	593	718	1 311
1907.				
January.....	.....	479	644	1 123
February.....	.....	756	726	1 482
March.....	.....	1 849	300	2 149
April.....	.....	2 178	114	2 292
May.....	.....	2 092	293	2 385
June.....	.....	1 082	527	1 609
July.....	.....	239	59	298
Total.....	1 528	9 206	3 330	14 073

The following is a detail of charges for royalty to Epes Randolph, Agent, S. P. Co.:

Value of tracks in Mammoth gravel pit, property of S. P. Co.....	\$16 832.00
Interest on \$16 832.00 for 1 month at 6% per annum.....	\$75.74
Depreciation on \$16 832.00 for 1 month at 5% per annum.....	70.13
	\$145.87
Interest from December 1st, 1906, to July 15th, 1907, 7½ months.....	1 094.03
Total number of cars removed by Epes Randolph, Agent, S. P. Co., 9 206, or.....	\$0.11883 interest per car.
Charge for gravel, 1 cent per cu. yd., 30 cu. yd. per car, or.....	0.30 royalty per car.
Total royalty charged per car....	\$0.41883
Average cost per car, \$55 927.53 divided by 14 073 ==	\$3.9741014 per car.

In blanketing the levees, 5 285 carloads, or 185 000 cu. yd., were used. Of this, 4 803 carloads, or 168 000 cu. yd., were used on the 15 miles of main levees, or 16 800 cu. yd. per mile, and 482 carloads, or

17 000 cu. yd., on the 1.6 miles of spur levee, or 10 633 cu. yd. per mile.

Wing Levees.—In addition to blanketing the levees with cementing gravel, wing levees of gravel were built out into the brush, at intervals of about 400 ft. Their purpose is to check the flow of water in the V-shaped section between the trees along the near toe and the water face of the levee. Brush abatis work was not considered sufficiently permanent.

Telephone Line.—A two-wire, metallic-circuit, telephone line was constructed along the land toe of the levee after the gravel blanketing was finished. The location was unfortunate, as the rapid growth of willows and other bulb vegetation just behind the levee caused considerable annoyance and expense. It would have been much better to have put the line on the land slope, about 9 ft. from the center of the levee.

At each mile post a 6 by 8-ft. wooden tool and telephone house was put up, and white boards were nailed to telephone poles at points half way between, to mark the ends of the patrol beats. When floods are expected, sacks, tools, etc., can be distributed and kept in these houses, but between times it was found impracticable to leave anything but the telephones on account of malicious and thieving passers-by. It was also found that the heat in these houses during the summer was sufficient to melt down and spoil many of the rubber receivers, so that only metallic ones are now used.

General Data.—The total length when complete was 15 miles of main levee, having an average height of 8 ft. and an average muck-ditch yardage of from one-third to one-fourth of the main section, and 1.6 miles of spur levee, with a height of from 20 to 4 ft. and a muck-ditch yardage of about 15% of the main section. The quantities and costs of the extension work after the second break were as follows:

154 500	cu. yd. muck-ditch excavation at 18½ cents.
49 700	“ “ “ “ refilling, which was twice handled, at 10 cents.
443 000	“ “ embankment at from 18½ to 25¾ cents.
166 700	“ “ original specification at 18½ cents.
100 800	“ “ wide check at 19 cents.
154 545	“ “ checkerboard system at 25¾ cents.
9.66	miles of clearing and grubbing. \$2 000.

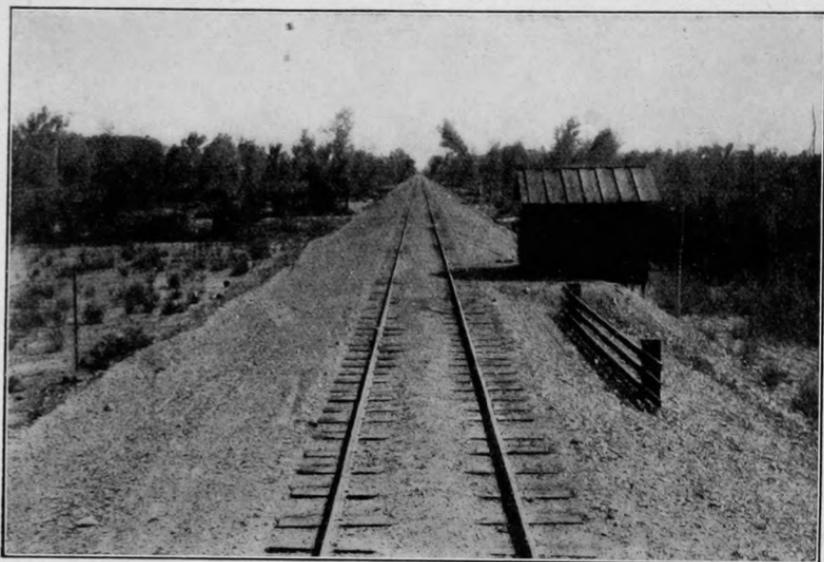


FIG. 53.—TYPICAL SECTION OF COMPLETED LEVEE, WITH INTERRUPTED BORROW-PITS ON THE RIVER SIDE.



FIG. 54.—CONNECTING CHANNEL ERODED BETWEEN INTERRUPTED BORROW-PITS DURING SUMMER FLOOD, 1907.

Enlarging Main Canal and Building Secondary Levee on Canal Bank.—On November 26th, 1906, the *Delta* cut its way into the Main Canal just below the Boundary Line and commenced deepening it and building a secondary levee on its river side beginning at the concrete head-gate and working down stream. It reached the Lower Heading and connected the levee bank with the north end of the Hind Dam in May, 1907, and started back, improving the work at various places and continuing this until July 21st, 1907. This levee was built in exactly the same way as those around the Reclamation Districts of the Sacramento River, and was made with a minimum height of 3 ft. greater than the main levee opposite along the river bank. Though not a very efficient construction, it, nevertheless, will serve to prevent water from getting into the Main Canal from breaks in the main levee until they can be repaired.

Criticism of Levee Work Done.—All parties interested assumed that the Harriman interests were doing work in the capacity of a contractor for the United States Government, and not in any sense in its own behalf, and that the engineers of the Reclamation Service were "available for consultation." Certain of these engineers, individually, criticized the excavation of the borrow-pits on the land side of the levee, and so a request was addressed to the U. S. Reclamation Service for a Consulting Board to consider the situation and make recommendations. Such a Board was appointed, all being members of the Service, consisting of A. P. Davis, W. H. Sanders, D. C. Henny, and Francis L. Sellew, Members, Am. Soc. C. E. This Board inspected the works then under way, and on January 10th reported, recommending among other things that:

"4. Borrow-pits should be on the water side, berms between them of greater width than the pits, and care should be taken not to disturb the vegetation on the berms, which should also be protected at frequent intervals with barbed-wire fences of 4 to 5 wires, the bottom of which is at the surface of the ground * * *.

"7. The levees now built should be provided with cut-off trenches under the water slope and later provided with sheet-piling reaching below borrow-pits * * *.

"8. All levees should be blanketed with gravel on water slope and railroad track maintained on the levee."

The clearing for half of the extension work was done at this time, and the work already started was continued as theretofore. Fear of

erosion trouble, because of borrow-pits on the river side, and correspondence with the New York office of the Harriman Lines, resulted in the appointment of another Consulting Board consisting of Messrs. L. C. Hill, W. H. Sanders, and F. L. Sellew, Members, Am. Soc. C. E., of the U. S. Reclamation Service, and William Hood, M. Am. Soc. C. E., Chief Engineer of the Southern Pacific Company, which met at Yuma, thoroughly examined the work, and reported on February 14th, among other things, as follows:

“Existing Levee Between Cement Head-Gate and Dam Across Lower Intake.

“Spur dikes (traverses between borrow-pits) to be increased in width to at least 50 ft. on top and to be at least 4 ft. in height above the general level of the original surface of the ground, and to extend at least 300 ft. northerly from the northerly edge of the borrow-pits, and in this 300 ft. no borrow to be made on either side of this levee and no brush to be cut outside of the limits of the slope stakes.

“The end of the levee and for some distance on the sides on each side near the end to be thoroughly brushed.

“These cross-dikes to be not to exceed 600 ft. apart, and where now located essentially farther than this, an intermediate cross-dike to be put in * * *.

“An abatis work, being in effect a wire and brush wing dam, shall be built from a point on the slope of the levee nearest the river, situated well above high water, and such wing dam pointing down stream, approximately, per local conditions, at an angle of 45 degrees to the levee.

“This to be made with suitable posts or stakes driven into the levee and between the levee and existing trees and thence by assistance of trees acting as posts or stakes and suitable barbed wire fencing in two lines not less than 2 ft. apart, and the whole filled with brush thoroughly wired down.

“These wing dams to occur at no greater distance apart than 500 ft. * * *.

“Levee Below Dam Across the Lower Intake, This Being Partly Completed and Under Construction.

“The same remarks as to spur dikes and abatis work apply as stated above with reference to existing levee between the cement head-gate and the dam across the lower intake * * *.

“For the levees as constructed, material has been taken from the land side instead of the river side, as recommended by the previous Consulting Board of the Reclamation Service.

"As these conditions now exist, the present recommendations are with a view to make the levees as secure as practicable under present conditions * * *. As to the still unconstructed portion of the 10½ miles of levee now intended to be constructed southwesterly from the dam across the lower or Mexican intake, this unconstructed portion being several miles, we recommend and expect that the recommendations of the Consulting Board of the Reclamation Service as to the position of the borrow-pits, position, depth and character of muck-ditches, and all other matters, be strictly complied with."

Accordingly, the additional levees, constituting 4.11 miles at the south end, were built with muck-ditch under the river slope and with borrow-pits on the water side of the levee. These pits are 100 ft. lengthwise of the levee, with spaces between them 100 ft. in width, on which every care was taken not to disturb the vegetation to the water toe of the levee. This method of borrow-pits is known locally as the "checkerboard" system. (Fig. 39.)

It is obvious that the checkerboard system requires an average haul of excavated material of about 175 ft. in excess of that required by the ordinary plan.

According to comparative tests, this increase in length of haul and inconvenience in handling teams resulted in increasing the cost of work about 6½ cents per cu. yd. for embankment only, or approximately 30% of the cost of team work.

It was deemed advisable to complete the main levee high enough to be beyond danger of overtopping by floods before doing anything on the spur levees between the land side borrow-pits recommended by the Consulting Board on February 14th. About the middle of May bids were asked for constructing them (described in the first item of the report of the second Consulting Board), and the lowest bid was \$40 per acre for clearing, \$80 per acre for grubbing, and 31 cents per cu. yd. for embankment, making their estimated cost between \$12 000 and \$12 500 per mile of main levee. Accordingly, a third Consulting Board was requested, and was appointed by Mr. A. P. Davis, Chief Engineer of the Reclamation Service, consisting of C. E. Grunsky, Consulting Engineer to the Secretary of the Interior; L. C. Hill, and F. L. Sellev, which Board met on June 19th and recommended as follows:

"1. That in lieu of the general system of cross-dikes recommended by the second Consulting Board:

"(a) To complete at once the cross-dikes now being constructed

about 500 ft. southerly from the south end of the Clarke dam, making it 10 ft. wide on the top and giving it the same height as the crest of the spur levee with which it connects;

"(b) To construct a second cross-dike about 500 or 600 ft. southerly from the first, also 10 ft. wide on top and with a height the same as the crest of the spur levee with which it connects;

"(c) To construct cross-levees, with crest at least 4 ft. above made ground (tops 10 ft. wide) between the main levee and the secondary levee [along the east bank of the main canal from the concrete head-gate to the north end of the Hind Dam. H. T. C.], near or on the southerly bank of the old upper Mexican intake, and a second within about 1 000 ft. of the southern end of the secondary levee."

This recommendation was carried out.

SUMMER FLOOD OF 1907.

The levees, including the secondary one along the Main Canal and the cross-levees mentioned in the recommendations of the last Consulting Board of the Reclamation Service, were completed on July 21st, 1907, and the Epes Randolph, Agent, fund was closed. The *Delta* continued deepening the Main Canal and at the same time raising and strengthening the secondary levee on its river side for 3 months longer, but it was estimated that the cost of such work balanced the deepening of the Main Canal done while strengthening the same secondary levee, prior to that date. After that time all charges for maintenance and operation of the head-gates and levee system were made by the Mexican Co. against the C. D. Co.

The flood of 1907 was a record one in total discharge, and probably would have been in gauge height reached at Yuma had it not been for the unusual conditions lower on the river. The old channel of the Colorado was considerably higher than usual, from the point of diversion to the Gulf, the erosion since the diversion and until the coming of the summer flood being of not much importance. It had been silted by the very small quantity of water carried as the re-diversion became more and more a reality, and, in addition, it was appreciably raised by the flood of December 5th which stranded quantities of heavy silt.

The vegetation of the lower delta lands depends on the annual over-bank flows, and these lands had not been covered for two seasons, due to the river diversion north of the delta's dividing ridge, much of the light vegetation had perished, and large tracts of the region had been burned over. In designing the levee system it was deemed conservative

practice not to take into account any such increased overbank flow, and to consider that the whole channel would be much less efficient and would deepen much more slowly than usual under the coming summer flood, on account of the fact that the bed had been undisturbed for 2 years, and hence was compacted and dry. Cross-sections are shown on Plate L. However, the flood of 1907 came up very gradually, and eroded the bed most satisfactorily, and an extraordinary quantity of water went overbank, particularly to the west because of the greatly decreased vegetation. It thus happened that this record flood, confined between levee banks only 1 500 ft. apart, rose to only an average of about $6\frac{1}{2}$ ft. below the top of the levee, varying from a minimum of 6 ft. to a maximum of 7 ft. The water got against the levees for their whole length, however, testing the muck-ditch construction thoroughly, and in no case was any weakness apparent.

The water-table throughout the region was raised above the bottom of the borrow-pits in many places, so that a considerable quantity of water, in some cases $2\frac{1}{2}$ ft. in depth, slowly seeped into these pits. This water was always perfectly clear, came in very slowly, and gauge readings, kept in many of them and in pits nearby, showed that the levels in them fluctuated with the adjoining water-table at all times. As the flood went down, these waters lowered and disappeared, and a rapid growth of willows started, so that a very large part of the borrow-pits is now overgrown with a dense growth, many bushes attaining a height of 20 ft. in 2 years.

Much difficulty has been found in keeping Indians from clearing away such growths and utilizing the borrow-pits as garden patches. Indeed, the Mexican officials practically take the position that, though the land is private property belonging either to the Mexican Co. or the C. M. Co., the nomadic Indian tribes have for many years been free to live their Gipsy life therein; that the levee system has cut off the annual inundation on which these people depended for their garden crops; and that it is unreasonable to insist on preventing them from taking these borrow-pits for gardening purposes, particularly as they are prevented from making clearings and utilizing inundated land in front of the levee.

A very striking occurrence was the complete filling up of the diversion channel between the river and the Hind-Clarke Dam. In many places this was more than 45 ft. in depth and probably averaged

20 ft. for 2 800 ft. up and down the river and 3 300 ft. at right angles thereto, an area of 210 acres. When this summer flood had passed, there was only a little pool about 5 ft. deep immediately above the Hind-Clarke Dam where the water had been deepest. Two years later this area was so densely overgrown with willows that it was extremely difficult to believe that the break ever occurred there. Until this silting up in front of the Hind-Clarke Dam began, numerous small boils appeared in the sand bar formation behind the Hind Dam. These at no time were of any importance, and soon ceased. Behind the Clarke Dam, practically no seepage whatever occurred.

The very slight percolation of water under these structures was rather surprising and very gratifying, considering their non-homogeneous structure and the character of their foundation. Nevertheless, it accords with the experience with the wooden and concrete head-gate coffer-dams, and the pumping of water into the Main Canal to keep the *Alpha* afloat, namely, that seepage through the alluvial soil of the region is remarkably small.

The water-table, for considerable distances on each side of the river, rises and falls with the water surface, especially during the summer floods, with small lag in time. The writer has always considered these two facts incongruous, and has never been able to find a satisfactory explanation.

MAINTENANCE OF LEVEES.

Until the summer flood of 1907 had passed, the levees were very carefully patrolled, watchmen being stationed night and day at each telephone house. A considerable store of timber, large and small, has always been kept at the Lower Heading until recently, and a storehouse containing a large quantity of shovels, picks, crow-bars, track tools, and lanterns has been maintained at the upper end of the Hind Dam. In this, from 20 000 to 50 000 sacks are always kept, being drawn on for use in the valley and replenished to avoid deterioration from long storage. Until a number of flashy floods had passed, a work train was always ordered from the Southern Pacific on reports from the head-waters indicating large rises in the lower river, and sacks were taken from the storehouse and distributed up and down the river, 500 at each toolhouse. Confidence in the effectiveness of the dikes soon grew, so that this is no longer being done.



FIG. 55.—SECOND CLOSING. HEAD DEVELOPED, 8 FEET.



FIG. 56.—REINFORCED CONCRETE FACING, ON LEVEE 25 FEET HIGH, NEAR SACRAMENTO, CAL.

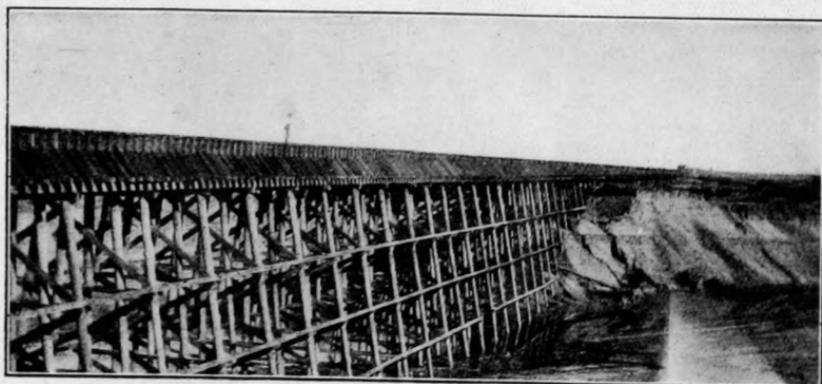


FIG. 57.—WOODEN FLUME OVER NEW RIVER BARRANCA.

In spite of the gravel blanketing, vegetation starts up slowly, and is kept down by constant but relatively inexpensive work. Considerable annoyance is caused by insects, particularly large burrowing ants which make great ant-hills and holes. These are destroyed by pouring gasoline into the holes and burning it.

As the value of rock, in repairing breaks or in river protection work, to prevent the side cutting of banks from breaching the levees, made it advisable to have a large quantity ready in the Andrade quarry, about 50 000 cu. yd. were blown out ready for handling by steam shovels. This was done by "coyoting" or driving 3-ft. tunnels horizontally about 30 ft. into the foot of the rock face, at intervals of 60 ft., and driving cross-tunnels at the ends, 10 ft. on each side. These cross-tunnels were loaded with black powder, which was all exploded at one time. All this rock has been taken away, and has left the quarry with a practically vertical face, averaging 50 ft. in height for a length of 1 000 ft., a very satisfactory condition. An American Hoist Company's 10-ton steel derrick with a 60-ft. boom, erected to handle this rock, proved very efficient and satisfactory. The railroad north of Andrade was raised above flood heights, the quarry lines were thrown over, and a track was laid on the top of the concrete head-gate, stringers being laid on the cellular pier walls. This track was connected with that on the levee, so that a train could be loaded at the quarry and run over the concrete head-gate and down the levee system, using the main line of the Inter-California Railroad only for that portion lying on the Hind-Clarke Dam. In the fall of 1907 this railroad was reconstructed and repaired from Calxico to Cocopah, and extended through to the end of the spur levee. The track from this point to Hanlon's Junction was taken over by the Southern Pacific Company, in accordance with arrangements made when the branch line was built. For this, consisting of 6.1 miles of main line and 2.1 miles of siding, the Inter-California paid the C. D. Co. approximately \$65 000. When this was done the branch line was no longer available for use by the irrigation company, but the right to use the east track or siding on the Hind-Clarke Dam was retained, and the Inter-California was specifically released from any obligation to maintain the dam.

It certainly is not often that a diversion head-gate carries a main-line, standard-gauge railroad, and the fact that this does will give

some idea of its size. By thus utilizing it, the heaviest carloads of rock from the Andrade quarry can be hauled over the levee system, and be independent of the Inter-California tracks.

THE SOUTHERN PACIFIC NOT REIMBURSED BY THE UNITED STATES
GOVERNMENT.

Early in 1907, a bill* was introduced before Congress:

"To reimburse the Southern Pacific Company the amounts expended by it from December first, nineteen hundred and six, to November thirtieth, nineteen hundred and seven, in closing and controlling the break in the Colorado River.

"Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the sum of one million six hundred and sixty-three thousand one hundred and thirty-six dollars and forty cents is hereby appropriated, out of any money in the Treasury not otherwise appropriated, to reimburse and pay the Southern Pacific Company the amounts paid by it from December first, nineteen hundred and six, to November thirtieth, nineteen hundred and seven, in closing and controlling the break in the Colorado River and thereby saving the overflow and destruction of the Imperial Valley in southern California."

This bill was referred to the Committee on Claims, of which Hon. James M. Miller, of Kansas, was Chairman, and consideration was begun on February 24th, 1908. At this hearing Mr. Maxwell Evarts, Counsel of the Harriman Lines, Mr. P. G. Williams, of the Accounting Department, who had been in charge of the accounts of the Epes Randolph, Agent, fund, and the writer, appeared to make explanations and present for examination vouchers covering all items of expense. President Roosevelt was frank and open in urging the justice of the claim, but, of course, was not advised as to whether such amount of money had been expended. Everyone else, however, seemed to be very much afraid of the matter. The Committee on Claims desired information as to the character of the work done and the fairness of the charges therefor, and asked the Secretary of the Interior, James R. Garfield, to have the Reclamation Service Engineers investigate and make a report. The reply was that no funds were available for that particular kind of work. Accordingly, President Roosevelt asked Secretary Garfield, F. H. Newell, M. Am. Soc. C. E., Director of the

* H. R. 13 997, 60th Congress, 1st Session.

Reclamation Service, and Mr. Walcott, formerly head of that Service, to take up the matter and report on what the Government, as a matter of moral and equitable obligation, should pay for the service rendered. President Roosevelt at the time, March 11th, in a letter to the Chairman of the Committee on Claims, advised him that this had been done; recalled the dire need for immediate action at the time; stated that negotiations with Mexico were then under way for future action in concert between the two nations; that he did not think the Southern Pacific people should be obliged to wait for the conclusion of these negotiations between Mexico and the United States with regard to future action, but that a rough estimate should be made as to what the United States should pay as reimbursement to the Southern Pacific Railroad, and that it was an act of justice to deal generously in the matter, for the railroad, by its prompt and effective work, rendered to a threatened community a notable service which could in no other way have been done. To facilitate matters, Mr. Evarts agreed with the Committee that Mr. Grunsky, who had been Consulting Engineer of the Secretary of the Interior on all Reclamation Service matters until a few months previous, and who, of all Government engineers, knew most about the Lower Colorado River and the operations of the Southern Pacific Company, should be engaged by the Committee to report on the work done and the expenditures, and that Mr. Evarts would advance the expenses of such investigation and report.

Mr. Grunsky, with the assistance of the American Audit Company, of New York City, investigated the accounts, and reported on April 1st that the structures along the river were adequate and efficient, and fulfilled their intended purposes; that additional protective work would have to be done in the near future; that charges incurred prior to December 7th, 1906, and subsequent to July 21st, 1907, were not properly chargeable to work done as a result of correspondence between the President and Mr. Harriman; that the quantities of material, such as rock, gravel, and earth, covered by the expenditures could not then be ascertained by measurement of completed structures with any degree of precision; that the records presented by the company showing the quantity of rock, gravel, and clay put into the work from day to day from January 27th to July 18th, 1907, during which time practically all the work of closing the second break and com-

pleting the protection work was done, constituted a reasonable check on the bills rendered, and that the number of carloads of material handled prior to January 27th, 1907, was no doubt correctly reported; that a fair basis for all charges, everything considered, would be cost plus the usual 10% for superintendence, tools, etc.; that this basis had been followed in the accounts, with the exception of the freight, which had been billed at tariff rates and really should have been made at 0.5 cent per ton per mile; that the accounts revised and corrected according to the foregoing showed the total net expenditures to be \$1 083 673.97, exclusive of interest.

TABLE 18.—EXPENDITURES ON THE COLORADO RIVER WORK
SUBSEQUENT TO DECEMBER 1ST, 1906.

Labor.....	\$275 310.12
Materials and supplies.....	261 966.04
Fuel.....	83 839.58
Freight charges on supplies and materials.....	618 150.84
Freight fuel.....	19 079.00
Transportation.....	12 895.23
Work-train service.....	7 627.17
Rental of equipment.....	70 507.54
Commissary supplies and labor.....	8 356.27
Trackage.....	31 981.00
Construction of additional levees (contract).....	255 878.55
Officers' and clerks' salaries.....	8 449.08
Office expenses.....	1 279.20
Traveling expenses.....	1 437.65
Sundry expenses.....	1 091.39
Duties.....	34 717.45
Total.....	\$1 636 063.11

Mr. Grunsky's report was clean-cut and fair, the inclusion of freight charges at tariff rates being done against the writer's advice. The Committee on Claims, therefore, now had definite ideas as to the work and cost. The report to President Roosevelt from Messrs. Garfield, Newell, and Walcott (dated March 17th), and mentioned in his letter of March 11th, as to the fair proportion to be repaid the railroad, was forwarded to the Committee, and, after reviewing the situation, including the exchange of telegrams between Mr. Harriman and President Roosevelt on December 19th and 20th, 1906, states:

"Under the circumstances, we do not feel justified in attempting even in a rough way to approximate the burden, other than to state that the principal beneficiaries are six in number: (1) The settlers in the Imperial Valley; (2) the Southern Pacific Co.; (3) the California Development Co.; (4) the Mexican Corporation; (5) the Republic of Mexico, and (6) the United States. Not considering the settlers in the valley, we have five distinct entities among whom the

burden might be distributed more or less equally. Thus, a rough estimate might apportion to the United States 20 per cent. of the money expended to reimburse the Southern Pacific Company for the actual expenditures of repairing the break in Mexico. Such proportion would fully comply with your suggestion that the United States Government should act generously toward the Southern Pacific Company, for by prompt and effective work it rendered a notable service to the threatened community of settlers in the Imperial Valley, quite regardless of the ultimate benefit of such action to the railroad company itself."

This recommendation has always seemed remarkable to the writer. The land interests in the Imperial Valley on both sides of the Boundary Line represent fully two-thirds of the present property values which had been threatened; the Southern Pacific Company about one-sixth; the United States, through its Laguna Weir, about one-sixth; the C. D. Co. and the Mexican Co. nothing, because they were both bankrupt, and the Republic of Mexico practically nothing because its interests conserved were wholly prospective, as well as those of the United States as far as irrigable land farther up the river is concerned. Furthermore, it was known that \$950 000 had already been subscribed by the people and corporations in Imperial Valley when the President called on Mr. Harriman to start work, as he did, and at once stopped such subscription. It is obvious that the railroad could at this time in no possible way collect anything from any other source than the United States for such work, so that such payment as might be made by the United States will represent the grand total reimbursement. Just why this Committee eliminated the land owners and then considered the remaining five entities as being equally concerned has always seemed remarkable, especially because, when two years later another call for help from Imperial Valley came to President Taft, Congress at once appropriated \$1 000 000 to protect the land owners primarily and almost exclusively.

The Committee took no action in the matter until Congress adjourned, and two years later, at the next session, another bill was presented, this time in the Senate (Senate 417, Sixty-first Congress). The matter was gone over again, and the bill with the amount cut to \$773 647.25, or 71.4% of that reported by Mr. Grunsky, passed the Senate. The House Committee on Claims made a favorable report. Five members of the Committee submitted a minority report on January 28th, 1911, stating that they did not think there was any legal,

equitable, or moral obligation on the part of the Government to pay the railroad company any amount whatever for closing the break; that expenditures were made neither at the request of the Government nor for its benefit; and that the appropriation of such sum would be "purely a gratuity, a gift of the people's money to the Southern Pacific Railroad Company * * *.

"We oppose this proposed gift to the Southern Pacific Railroad Co. as well as all other gratuities to private enterprise."

The bill did not pass the House.

DAMAGES CAUSED BY THE RUNAWAY RIVER.

The first damage caused by the diversion of the river was the flooding of the salt beds and the gradual burying of the entire plant of the New Liverpool Salt Company in the bed of the Salton Sea. The property was probably worth about \$125 000.

As the waters continued to rise, they began to threaten the main line of the Southern Pacific Company throughout the basin, and in July, 1905, they reached the rails for a considerable distance. Shooflying was begun and continued from time to time, nothing very aggressive being attempted because of optimistic advices as to when the river would be under control.

Shooflies Nos. 1 to 7, inclusive, were at an elevation of —250 ft. or more. Shoofly No. 11 is 39 miles long, and follows the —200-ft. contour, being determined on when the probabilities of controlling the river before the summer flood of 1906 seemed to be rapidly decreasing. It was built in February and March, 1906, and was located with a view to being safe from the rising waters for at least two years, the estimates being based on the discharge records of the river at the time of building. As a matter of fact, some sections of the track a few feet below the —200-ft. contour were in trouble in the latter part of October, the water then being 47.5 ft. higher than when the line was surveyed. When the second break occurred, Shoofly No. 12, 48.9 miles long and following the —100-ft. contour, was hurriedly surveyed and graded during January and February, 1907, the outside drainage work being completed on April 1st. Track material for this had been gathered at each end—Mecca and Imperial Junction—during September and October, 1906, when Shoofly No. 11 was threatened. Practically none of the bridging was put in on this latter work, and

when only about 4 miles of track were laid it seemed that the river control work would prove effectual, and work was consequently ordered stopped.

The railroad company also suffered damage along the branch line between Imperial Junction and Calexico. At the crossing of the Alamo River north of Brawley the track was moved five times, the present alignment constituting a shoofly 2 706 ft. long, and introducing 105° of curvature, as compared with 16° 40' originally. A few miles south, the enlargement of the New River channel made it necessary to construct three shooflies, the last one being 9 086 ft. long and containing 121° of curvature, as compared with 11° in the original alignment.

The total expenses incurred along the Salton Sea, exclusive of the cost of grading Shoofly No. 12, were as follows:

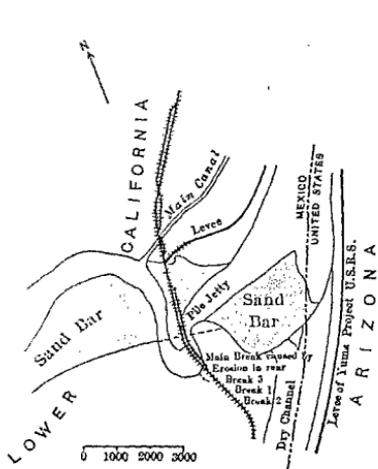
Year.	Labor.	Material.	Totals.
1905	.....	.....	\$148 183.71
1906	\$181 300.37	\$307 763.58	489 063.95
1907	49 875.96	37 678.08	87 554.04
			<hr/> \$724 801.70

The damages sustained on the Imperial Branch were as follows:

Year.	Labor.	Material.	Totals.
1905	.....	.....	\$5 914.01
1906	\$19 222.37	\$9 986.53	29 208.90
1907	2 597.13	142.76	2 739.89
			<hr/> \$37 862.80

The Inter-California Railroad, beginning at the International Boundary Line, was damaged more or less seriously for about 10 miles, the details being as follows:

Entirely rebuilding the road through Calexico and Mexicali and beyond, being cost less value of material re- covered	\$ 82 822.49
Repairs to remainder of first 10 km., in- cluding water supply.....	4 259.76
Repairs from 10-km. point to 14-km. point	21 163.73
	<hr/> \$108 245.98



LOCATION OF THE SECOND BREAK DEC. 7, 1906 AND OF SECOND CLOSING JAN. AND FEB. 1907

FIG.58

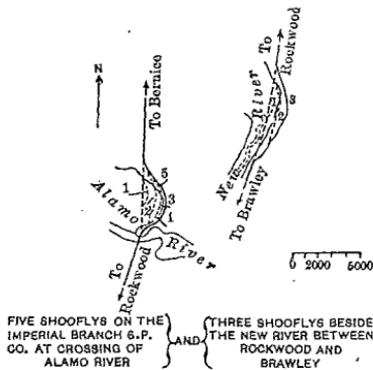


FIG.59

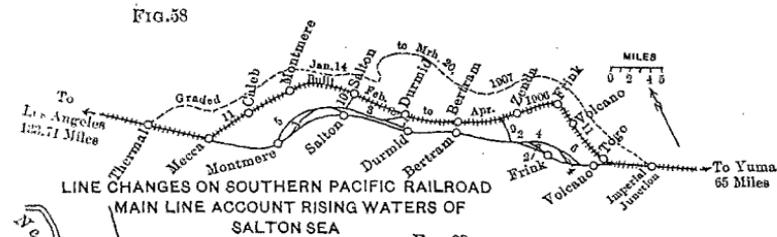


FIG.60



FIG.61

Thus the damage sustained by the Southern Pacific on permanent way alone, and not including interruptions to traffic, or expenses of any kind incurred by delayed trains, etc., was \$762 664.50, and by the Inter-California \$108 245.98, making a total of \$870 910.48.

In addition to such damages, the trains of rock hauled during the 3 weeks of the first closing and more than 2 weeks of the second closing, or more than 5 weeks in all, were given rights of way over all except passenger trains, and the slower of these were very frequently delayed in order to hurry material to the front. The demand on the equipment of the road was tremendous, particularly during the second closing, when there were in rock-train service, 1 000 flatcars, 300 "battleships," 4 steam shovels, 10 work trains, exclusive of rock trains from the quarries other than at Andrade, etc. Indeed, for about 10 days, practically no freight was hauled out of the Port of San Pedro because of lack of equipment. The degree of the strain is shown by a telegram the writer received from the Superintendent of the Los Angeles Division, just before the second closing was accomplished, asking information as far in advance as possible "when work will slow up because I want to make arrangements to resume operating the division."

About 3 000 acres of cultivated land and 10 000 acres of uncultivated and public lands were practically destroyed and rendered unavailable for agricultural purposes under existing conditions, the total value of which depends on whether the present or prospective worth is considered. Perhaps a very fair figure would be \$50 per acre for cultivated land and \$10 per acre for raw lands, making the total damage to the land about \$250 000.

Various individual settlers in Mexico and the United States suffered more or less severe injury from inundation of crops, etc., as distinct from land damages, and these probably amounted to not more than \$150 000. A number of claims for damages sustained on the American side of the line were combined in a suit totaling \$490 000, but this included damaged lands estimated at prospective rather than real and present figures. Judgment has just (October, 1912) been rendered for a total of \$78 000.

The most serious injury done to settlers was the entire stoppage of the water supply in the canals of Districts Nos. 6 and 8 from the summer of 1906 until January, 1907. No claim was ever presented for these damages, and nothing more than crude guesses can be made as to

the amount. The result practically forced the depopulation of more than 30 000 acres of land, of which about 12 000 acres were under cultivation. The effect on the development of the valley at the time was not very great, but fear of repetition of a break, as much as anything else, has, until recently, retarded the region to a considerable extent.

Because of the tremendous expenditure involved in re-diverting and holding the river in its course, up to December 5th, 1907, when the Southern Pacific advanced funds for the work directly instead of to the C. D. Co., the original \$200 000 loan to the C. D. Co. had grown to \$1 100 000, and this was swelled by later bills, interest, etc., to approximately \$1 375 000, by January 1st, 1909. In addition to owing this large sum for cash actually advanced, and for which payment could not be disputed successfully, a judgment for \$458 246.23, in favor of the New Liverpool Salt Company had been rendered in the United States District Court toward the end of November, 1907, and there were claims from the Southern Pacific Company and others aggregating \$1 360 000, two-thirds of which were from the latter company. The runaway river rendered hopelessly bankrupt the C. D. Co. and the Mexican Co.

BENEFITS.

To almost every cloud there is a silver lining, and this is no exception. It is now known that the diversion would have occurred very soon. The event showed the existence and nature of the danger and the necessity for guarding against it. Much more important was the development and standardizing of methods of closing future crevasses which might occur. Incidentally, the information of this character afforded to the Engineering Profession in general will doubtless prove of much value, though this cannot be considered as a benefit to the region in question.

By far the greatest benefit was the erosion of the great Alamo and New River barrancas and the creation of the main features of a complete and comprehensive drainage system for the entire Imperial Valley. The natural slope of the ground is remarkably uniform, with a grade of about 5 ft. per mile, and the very small, shallow channels of the New and Alamo Rivers were the only rudiments of satisfactory drainage, from an irrigation point of view. The Salton Sink is the natural drainage sump for the region, and its absolute control should have been acquired in the very beginning, either by the irrigating

company or by the land holders of the valley. In the litigation which followed the destruction of the salt works, the New Liverpool Salt Company, as owner of the submerged land, obtained a decree perpetually enjoining and restraining the C. D. Co. from diverting water from the Colorado River in excess of the substantial needs of the people dependent on the canal for water supply for domestic, irrigation, and such other lawful purposes as the same may be applied to, and with a further provision as to the control of the water diverted so that it will not overflow on the lands of the complainant. Later proceedings resulted in a most remarkable construction of the last portion of the injunction, so that now the Salt Company practically cannot object to the use of the basin as a natural sump.

TABLE 19.—ANALYSIS OF WATER OF NEW RIVER.

Sample taken at Brawley, June 6th, 1908, and submitted by Mr. F. W. Roeding, Irrigation Investigations, Berkeley, Cal.

		Grains per gallon.	Parts per 1 000 000.
Alkali	Potassium Sulphate very small, and Sodium Sulphate (Glauber's salts), etc. }	12.87	221
	Sodium Chloride (common salt).....	389.40	6 675
	Sodium Carbonate (sal soda).....	0.99	17
	Calcium Chloride.....	14.91	256
	Magnesium Chloride.....	37.26	639
	Calcium and Magnesium Carbonates, etc., large }	94.20	1 017
	Calcium Sulphate (gypsum) chiefly }		
	Silica.....	1.22	21
	Organic matter chars, and chemically combined water }	57.44	985
	Total.....	608.38	10 431

Providing for the region an efficient drainage system to carry all the waters into the Salton Sink would have required a large amount of money—so large that the date of its establishment would have been delayed very far into the future, much too far for the valley's real interests. This is true because it is plainly not the business of an irrigation company to supply a drainage system, and all other interests of the valley are very much divided because of the mutual water company plan of organization, and because of the usual lack of co-operation among farmers. Furthermore, the need for drainage of irrigated land is usually not recognized in time, and not admitted when it is recognized.

Indeed, in spite of the rather alkaline character of the lands in Imperial Valley, as already explained, it was not until November 1st, 1911, that any serious suggestion was made for a community drainage canal—in Imperial Water Company No. 8—the reasons then chiefly urged being:

“The loss of ground and bad appearances caused by the ends of the irrigated lands being covered with weeds or wild grass or perhaps nothing at all as the result of standing water.”

A few spots in Imperial Valley are beginning to indicate an undesirable increase in alkalinity, and it is most fortunate that the magnificent main drainage ways of the Alamo and New River channels exist.

SALTON SEA.

From a geological and spectacular point of view, the creation of the Salton Sea in so short a time was one of the most striking effects of the river diversion. The water filled the basin to a maximum elevation of —197.4 U. S. G. S. datum, or —204.2 S. P. datum, the maximum depth of water being 76 ft. The total area covered at this time was about 445 sq. miles, with a length of 50 miles and a width of from 10 to 15 miles. With the exception of the Great Salt Lake and Lake Michigan, the sea was the largest body of water lying wholly within the United States.

The water rose at the maximum rate during the latter part of June, 1906, when it gained nearly 7 in. per day, or 15.4 ft. during that month. From the reconnaissance map of the Salton Sink, published by the U. S. Geological Survey in 1905, it would appear that the areas of the various contours of the basin are about as follows:

Elevations.	Square Miles.
—280.....	0
—250.....	240
—200.....	445
—150.....	650
—100.....	920
— 50.....	1 150
— 0.....	1 750
+ 30 (old beach line).....	1 950

TABLE 20.—ANALYSES OF WATER FROM THE SALTON SEA
AND THE COLORADO RIVER AT VARIOUS SEASONS.

As made by Dr. W. H. Ross, of the Agricultural Experiment Station,
University of Arizona, Tucson, Ariz.

	Salton water, surface of deepest portion, June 8d, 1907.	Colorado River water, low winter stage, January 10th-March 26th, 1900.	Colorado River water, rising summer stage, from melting snow, March 27th-April 30th, 1900.	Colorado River water, summer flood from melting snow, May 1st-June 28th, 1900.	Colorado River water, low summer stage, June 30th-August 28th, 1900.	Colorado River water, affected by local floods, August 27th-October 1st, 1900.	Colorado River water, summer floods from Arizona, October 2d-November 19th, 1900.	Colorado River water, low winter stage, November 20th-January 24th, 1901.
Total soluble solids at 110° Cent. Parts in 100 000 ..	364.8	92.9	67.4	32.2	36.1	71.4	104.5	87.1

COMPLETE ANALYSIS OF SOLUBLE SALTS, STATED BY IONS.
PARTS IN 100 000.

Sodium, Na.....	111.1	19.0	15.3	5.5	7.6	14.6	18.2	16.0
Potassium, K.....	2.3	1.1	2.1	1.0	1.3	1.8	2.1	1.2
Calcium, Ca.....	9.9	7.5	4.9	4.2	4.6	7.7	12.5	9.2
Magnesium, Mg.....	6.4	3.1	2.0	1.2	1.2	2.2	2.8	2.8
Aluminum, Al.....	0.081	....	....	....	....	....	....	....
Iron, Fe.....	0.005	....	....	....	....	....	....	....
Chlorine, Cl.....	169.7	20.5	13.9	4.5	6.9	15.8	17.5	18.1
Sulphuric, SO ₄	47.6	28.1	19.4	7.2	7.6	19.7	35.6	23.8
Carbonic, CO ₃	6.6	7.4	8.4	7.2	7.7	10.0	12.2	10.7
Silicic, SiO ₃	1.2	4.6	2.1	2.1	3.3	2.3	2.2	2.1
Phosphoric, PO ₄	0.018	....	....	....	....	....	....	....

Practically all the water which enters Salton Sea comes from the Alamo and New Rivers, which, under normal conditions, are now important chiefly as drainage channels for the Imperial Valley. Frequently, however, very heavy precipitation occurs in violent storms over small portions of the area draining into the basin, but the run-off, though occasionally of considerable quantity, is not relatively important. The total annual inflow is at present probably 200 000 acre-ft., or sufficient to cover the surface of the sea about 0.7 ft. in depth, while the evaporation is probably between 5½ and 6 ft. and the percolation insignificant.

TABLE 21.—COMPOSITION OF OCEAN WATER.

(This table gives the mean of 77 analyses made by the Challenger Expedition, Challenger Report, Physics and Chemistry, Vol. 1, 1884, p. 203.)
Stated by Ions. Parts per 100 000.

Sodium (Na).....	1 071
Potassium (K).....	39
Calcium (Ca).....	42
Magnesium (Mg).....	130
Sulphate (SO ₄).....	270
Chloride (Cl).....	1 935
Bromide (Br).....	6
Carbonate (CO ₃).....	7
	3 500

Quite a little speculation has been indulged in regarding the length of time which would have been required to fill the Salton Sea had the Colorado River not been re-diverted. Most of such computations are based on too low an average flow of the river past Yuma, which it now

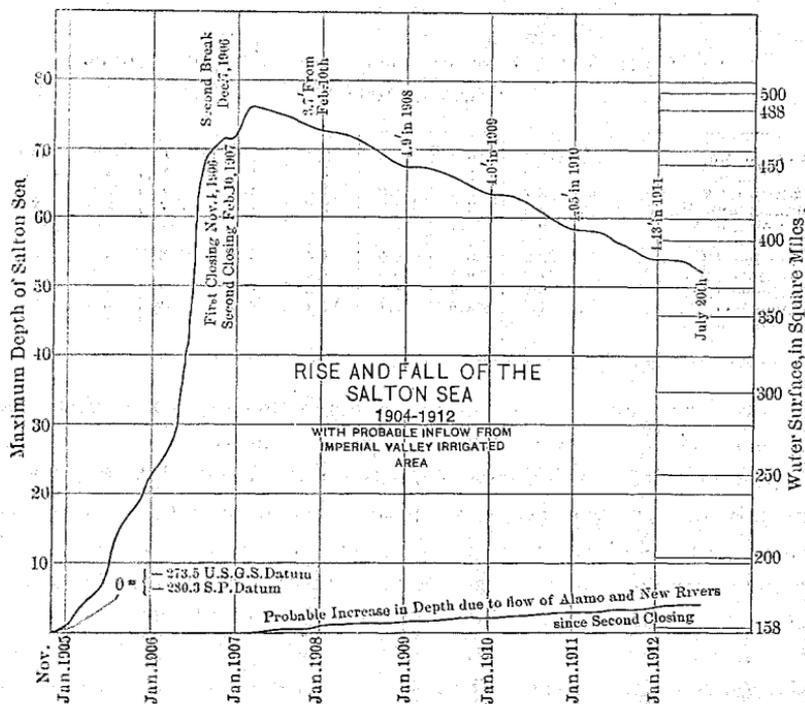


FIG. 62.

seems is in excess of 12 000 000 acre-ft. per annum. As a matter of fact, however, the inflow from the Imperial Valley region will constantly increase, and the quantity evaporated will decrease directly with the decrease in water surface exposed, so that a balance will be reached probably in such time as the inflow will average between 350 000 and 500 000 acre-ft. per annum from all sources, and the exposed surface will cover between 60 000 and 80 000 acres. At such time the maximum depth of the sea will be between 8 and 10 ft.

The sea has already (January, 1912) fallen about 22 ft., and has exposed approximately 115 sq. miles which were under water. The salt beds were dissolved to such an extent as to render the water of the sea quite salt, unfit entirely for drinking purposes, and it was assumed that the land which it covered would be hopelessly alkaline. This does not seem to be the case, and a very considerable acreage of such exposed land is being cultivated with entire success.

Much speculation was indulged in regarding the effect of this body of water on the rainfall and climate of the Southwest. A careless consideration of the precipitation on the drainage area of the river, particularly that of the Gila water-shed, before and after January, 1905, might lead to the conclusion that the effect is quite marked. The period from January 1st, 1905, to date has been one of very heavy rainfall throughout the Southwest, its most remarkable part being early in January, 1905, which was before the formation of the Salton Sea. Professor Alfred J. Henry* points out the fallacy of such an opinion, as follows:

"Admitting, for the sake of argument, that a body of water * * * existed * * * 60 miles long, 8 miles broad, and say 25 feet deep on the average. * * * The cubic contents would therefore be $60 \times 8 \times 0.0047 = 2.2$ cubic miles of water. The normal annual rainfall of Arizona * * * is 11.75 inches [while in 1905 it was 26.6 inches], or an excess of 14.85 inches, an amount more than equal to the normal annual rainfall. * * * As the area of the Territory is 113,956 square miles, * * * the number of cubic miles of rain that fell in Arizona in excess of the average was * * * 27, * * * twelve times greater than the total volume of the Salton Sea. In other words, the total volume of the latter would barely suffice to produce one-twelfth of the surplus rain that fell in Arizona, to say nothing of the rainfall in adjoining regions. The total

* "The Salton Sea and the Rainfall of the Southwest," *Monthly Weather Review*, Washington, December, 1906.

amount of water now in Salton Sea, if uniformly distributed in Arizona, would cover the Territory to the depth of about an inch and a quarter, or the equivalent of one good soaking rain."

As a matter of fact, the area of the Salton Sea and Laguna Maquata combined are insignificant when compared with that of the Gulf of California, and are just about as far from Arizona. Professor Henry concludes that the Salton Sea has increased the relative humidity in the immediate vicinity in a slight measure; that it is improbable that any considerable portion of the vapor it gives off passes beyond the immediate confines of the desert; and that there might be a tendency toward lower maximum and higher minimum temperatures in a narrow zone immediately surrounding the sea, particularly on the leeward side.

INTERNATIONAL NEGOTIATIONS.

When the Mexican Co. obtained its concession from the Mexican Government, Col. Jacobo Blanco, then Chief of the International Boundary Line Commission for the Mexican Government, with headquarters at El Paso, was appointed Inspector of the Mexican Co. and its operations. In 1906, Col. Blanco died, and his successor on the International Boundary Line Commission was Señor Fernando Beltran y Puga, who was also appointed his successor as Inspector of the Mexican Co. The writer considers this appointment an exceedingly fortunate one, as Señor Beltran y Puga is an exceptionally efficient, aggressive, and fair-minded man, and an engineer, with whom it has always been a satisfaction to transact business. Immediately on his appointment he acquainted himself with the conditions along the river and with the affairs of the Mexican Co., and has always acted promptly and with decision.

In the spring of 1908 the United States State Department appointed Mr. Louis C. Hill, Supervising Engineer of the U. S. Reclamation Service, to represent the United States on a joint commission to work out the provisions of a treaty with Mexico for the control of the Lower Colorado River and an equitable distribution of its waters. This appointment was in line with President Roosevelt's promise to Mr. Harriman, and was doubtless in a measure brought about at this particular time by the failure of Congress to take any action on the bill to reimburse the Harriman interests. At the re-

quest of the United States, the State Department of Mexico appointed a Commissioner, and rather naturally selected Señor Beltran y Puga to represent the Mexican Government, this gentleman's appointment being made on May 7th, 1908, and practically simultaneous with the appointment of Mr. Hill. Both gentlemen were instructed to act together and make a study of the works and operations necessary to complete international control of the lower Colorado River and render impossible a repetition of the recent disaster and the complete utilization of the waters of the river, such study to be in whatever detail might be deemed necessary.

This Commission never had a formal meeting, which is very much to be regretted, considering the importance of the matter. Very shortly after their appointment, the Commissioners had an informal meeting at which, according to private conversations which the writer had with both gentlemen, it appears that Señor Puga submitted, in the form of a written memorandum as the basis for discussion, the suggestion that both Governments cancel the existing treaties regarding the navigability of the river; that regulation of the flow of the river by extensive storage works in the upper portions of the drainage basin was desirable; that both Governments determine the priority and extent of existing water rights and fix rules for granting future water rights; that a joint international commission should make all engineering and other investigations necessary, and divide the costs thereof; that all plans or projects existing or proposed along the river should be submitted to the investigation of the joint commission; that a report be made outlining, in a general way, the work to be done, for the purpose of having a full and complete treaty arranged and the necessary definite appropriations set forth; and that it would be agreeable for Mexico to negotiate a treaty, either preliminary or final, at the earliest possible moment. It seems, however, that Mr. Hill could not find time to attend to the matter, nor were special funds placed at his disposal to defray the necessary expenses. At any rate, two years later, nothing having been done, on May 17th, 1910, the United States Department of State replaced Mr. Hill with Mr. Wilbur Kablinger, Secretary of the American side of the International Boundary Commission, with offices in El Paso and Washington. This change of American Commissioners, however, has not had any apparent result thus far.

It is hoped that discussion of this paper may bring out the explanation for the failure of these representatives of the two governments even to have a formal meeting in the 4½ years which have elapsed since the Joint Commission was appointed at the request of the State Department of the United States. Such explanation would be particularly interesting, because the writer knows Mr. Hill to be an unusually tactful, courteous, and aggressive gentleman, and an efficient engineer, and understands that Mr. Keblinger is also an unusually capable man.

In any event, there seems to be no doubt that the Mexican Government has been, and is, not only willing, but anxious, to arrange for a satisfactory joint control of the Lower Colorado River, and that the responsibility for nothing definite having been accomplished in this direction; in large measure at least, rests with the United States.

BUILDING OF VOLCANO LAKE LEVEE.

The extraordinary quantity of water which got into Volcano Lake during the summer flood of 1907 raised it higher than it had ever before been known to be, and a large quantity of water passed northward through the New River outlet. Furthermore, a reconnaissance showed that the large quantity of overflow water had started cutting back fingers from the Volcano Lake region toward the river, which indicated the probability of the diversion of the Colorado River below the divide of the delta cone, along the Pescadero, Abejas, or Paredones. Therefore it seemed that another portion of the complete levee system, as originally planned by the writer to hold back the overflow waters of the Colorado from the Salton Basin, should be constructed—that portion from the mountains on the west side of the valley eastward along the north of Volcano Lake to the low-lying divide or ridge farther on. The C. M. Co., however, objected to this, as Volcano Lake is entirely on its land and its utilization for irrigating a portion of that company's lands was considered, but found impracticable because of the great variation in the water surface, the inundation of a part of the land, however, at flood times was simple, and permitted securing considerable pasturage. The C. M. Co., however, was willing to give the right of way and permit the construction of the protective works provided a permanent head-gate were installed at Cerro Prieto through which water might be let into the New River when the lake was

full. This was finally agreed to, and arrangements were completed under which the Southern Pacific Company agreed to pay the Mexican Co. for constructing this gate on condition that the Mexican Co. would arrange to have 8 miles of levee to the east built. This was done and the gate and levee were completed just before the summer flood of 1908 began to throw its waters into Volcano Lake. After one season the Mexican Government compelled the removal of this intake gate and the levee to be built around in front of it, so that it is not now in service. Plans for the gate and levees were presented informally to the Mexican Government Inspector of the Mexican Co., Señor Puga, and it was understood that their construction was approved and permission verbally given to begin work before filing maps and drawings and having them approved or changed as required by the Departamento de Fomento in such cases—this on account of emergency. It was not so understood by Señor Puga, and the construction of the gate was a needless expense.

All this work was arranged for and practically done while Congress was considering the payment of the bills for the second closing and subsequent protective work, and when there was no reason to doubt that a fair adjustment would be made.

RECONSTRUCTION OF IRRIGATION SYSTEM.

As soon as the river control work was assured, arrangements were made to ascertain the exact condition of the irrigation system of the valley, and what was necessary and advisable to do in connection with it. Accordingly, Mr. F. C. Herrmann, who was added to the engineering staff on February 1st, 1907, was placed in charge of this work. The damage done by the flood was confined almost entirely to carrying away the flume by which the West Side Main Canal crossed New River, and a similar flume, 20 miles north over New River, carrying water from the Central Main to supply Imperial Water Company No. 8. To rebuild the latter was impracticable on account of the immense barranca which had been created at the old crossing, and it was decided to enlarge the West Side Main and extend it northward so that all the territory west of New River would be served thereby.

A wooden flume, supported by wooden piling, was designed to cross the New River gorge very close to the location of the original flume,

carried away about March, 1906. Work was begun on the structure and rushed to completion. This flume is worthy of note because of its height, length, and cost, as a quasi-temporary structure. It is 1 860 ft. long and the maximum height of the trestle is 55 ft. It supports a rectangular flume, 16 ft. wide and 6 ft. deep, built of 2-in. redwood lumber with ship-lap joints. It has given excellent service, and the leakage has been notably slight from the time it was first put into service.

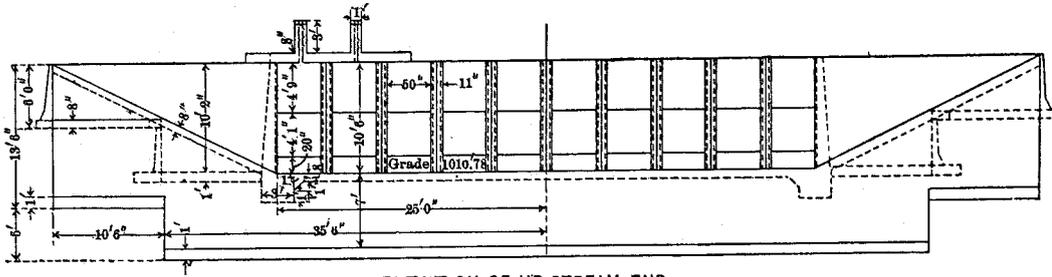
Surveys for the reconstruction, enlargement, and extension of the West Side Main were hurried, and contracts were let for the work, which was well under way when the financial panic of November, 1907, occurred. The contractors were forced into bankruptcy, and the work was completed by their bankruptcy trustee, which caused considerable delay, but water was turned through the reconstructed West Side Main late in December, 1907. This canal is 28 miles long—7 miles in Mexico and 21 in California—and has a capacity varying from 800 to 400 sec-ft., with 760 000 cu. yd. of earthwork moved at a total cost of \$86 000, and \$5 000 for two temporary structures.

Some little time later the Rose Levee, across the Alamo channel at Holtville, was reconstructed, with a waste-gate to pass the excess of water coming through the Holton Power Company's plant and through the Alamo Waste-gate farther up that channel in Mexico, and a head-gate for the Rositas Canal. Both of these are of reinforced concrete, the waste-gate being of interesting design and capable of passing 2 000 sec-ft. with a total drop of 20 ft. In this way water which must be furnished to the Holton Power Company under its contract is picked up below the plant and utilized for irrigation, as was the original intention when the contract was made. These two permanent structures and the earthen dam cost \$55 250.

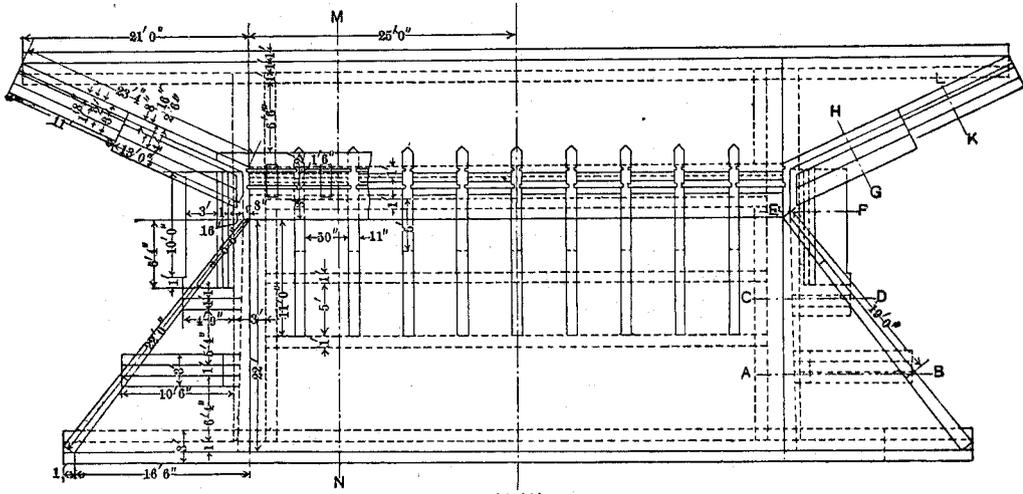
Another important permanent structure, known as the Seven-Foot Drop (Plates LII, LIII, and Fig. 63), was built in the Central Main just south of the Boundary Line at a cost of \$23 760, including three small structures adjacent to it, but not exactly a part thereof. This structure takes the place of a wooden 10-ft. drop nearly 2 miles farther on, which, by the way, had passed considerably more water than it was designed for and was in fairly good condition when removed after 8 years of service.

The chute of the Alamo Waste-gate was repaired and again extended down stream, the result being a quite remarkable construction, Plate

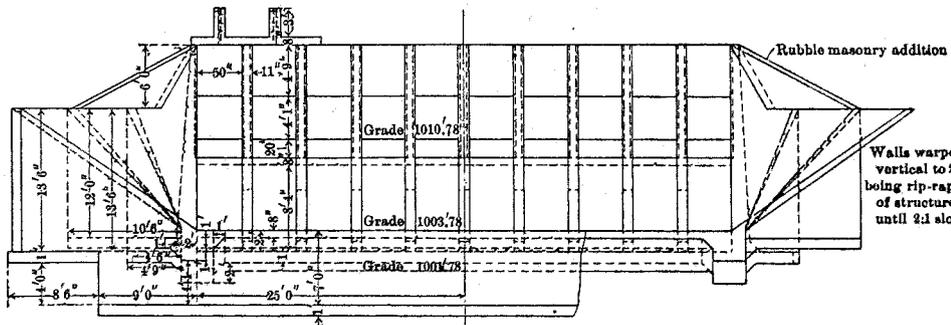
PLATE LII.
 TRANS. AM. SOC. CIV. ENGRS.
 VOL. LXXVI, No. 1270.
 CORY ON
 IRRIGATION AND RIVER CONTROL,
 COLORADO RIVER DELTA.



ELEVATION OF UP-STREAM END



PLAN



ELEVATION OF DOWN-STREAM END

Rubble masonry addition

Walls warped from vertical to 2:1 slope; being rip-rapped from end of structure as shown, until 2:1 slope is reached.

LI, which has never shown any signs of weakness against a head of approximately 35 ft.

Surveys and Designs for Extensions.—At the same time, surveying parties were assembled and topography was taken, with 1-ft. contour intervals, on 230 sq. miles. This included the west side of New River and a strip in Mexico adjoining the Boundary Line averaging 3 miles wide and running from the West Side Main crossing of the Boundary Line to about 4 miles east of Sharp's Heading and thence generally following the Alamo channel almost to the levee system along the river, the Alamo channel being carefully mapped and cross-sectioned. Much of this work was done in the heat of the summer, five complete surveying parties being on the work until after August 1st, when the force gradually lessened. A large part of the area was practically cleared land, but much of it was covered with a dense undergrowth, which made progress very slow, and, by cutting off the breeze, accentuated the severe climatic conditions. Nevertheless, the cost of this work was about 57½ cents per acre, or \$37 per sq. mile. This experience showed that, while the great summer heat there is quite disagreeable, it does not render engineering field work by any means impracticable, and indeed does not increase the cost more than 10 per cent. One agreeable feature of the very hot season is that the temperature is too great for flies, so that they practically disappear.

Cross-sections and current-meter observations were taken at various points in the Main Canal and in the important canals of the distribution systems of the various mutual water companies, to determine capacities, losses, etc.

When these data were compiled and put into form, estimates were made for the reconstruction and enlargement of the existing system and for extensions to cover a great deal of new territory. The estimate for this work was approximately \$900 000 with temporary structures, and including considerable improvements in the main Alamo channel from the river to the controlling works in the valley; and \$2 200 000 with permanent structures at essential points and replacing the Alamo channel with an entirely new twin main canal from a few miles below the concrete head-gate to the mesa ground east of Sharp's Heading. Whatever possibility there was of such fundamental reconstruction and extensions was dissipated by the severe financial stringency in November, 1907.

These designs included the construction of a head-gate on Mexican territory, and the total abandonment of the concrete head-gate, along with diversion, on American soil. The head-gate thus proposed was just behind the levee, about 3 miles below the Boundary Line, with a caisson foundation supporting extensive wing-walls and massive piers, between which there were to be large vertical gates, operated by gasoline motors.

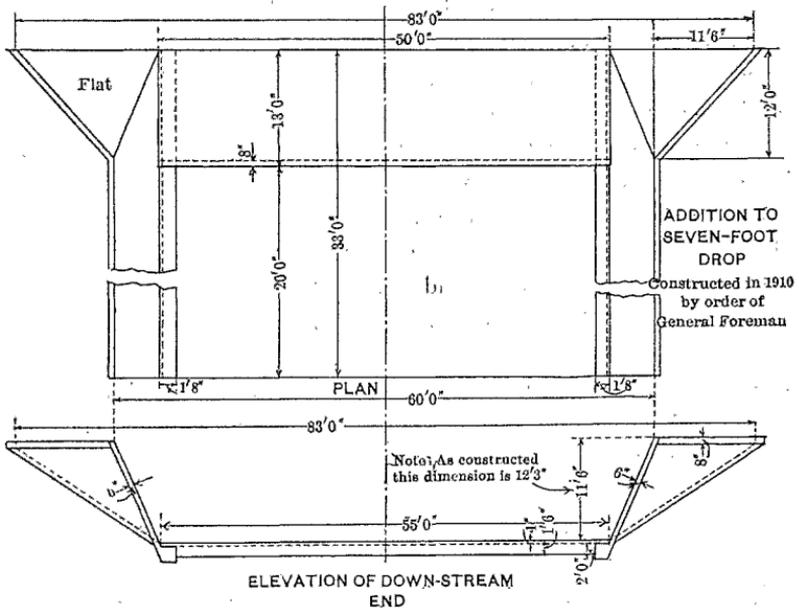
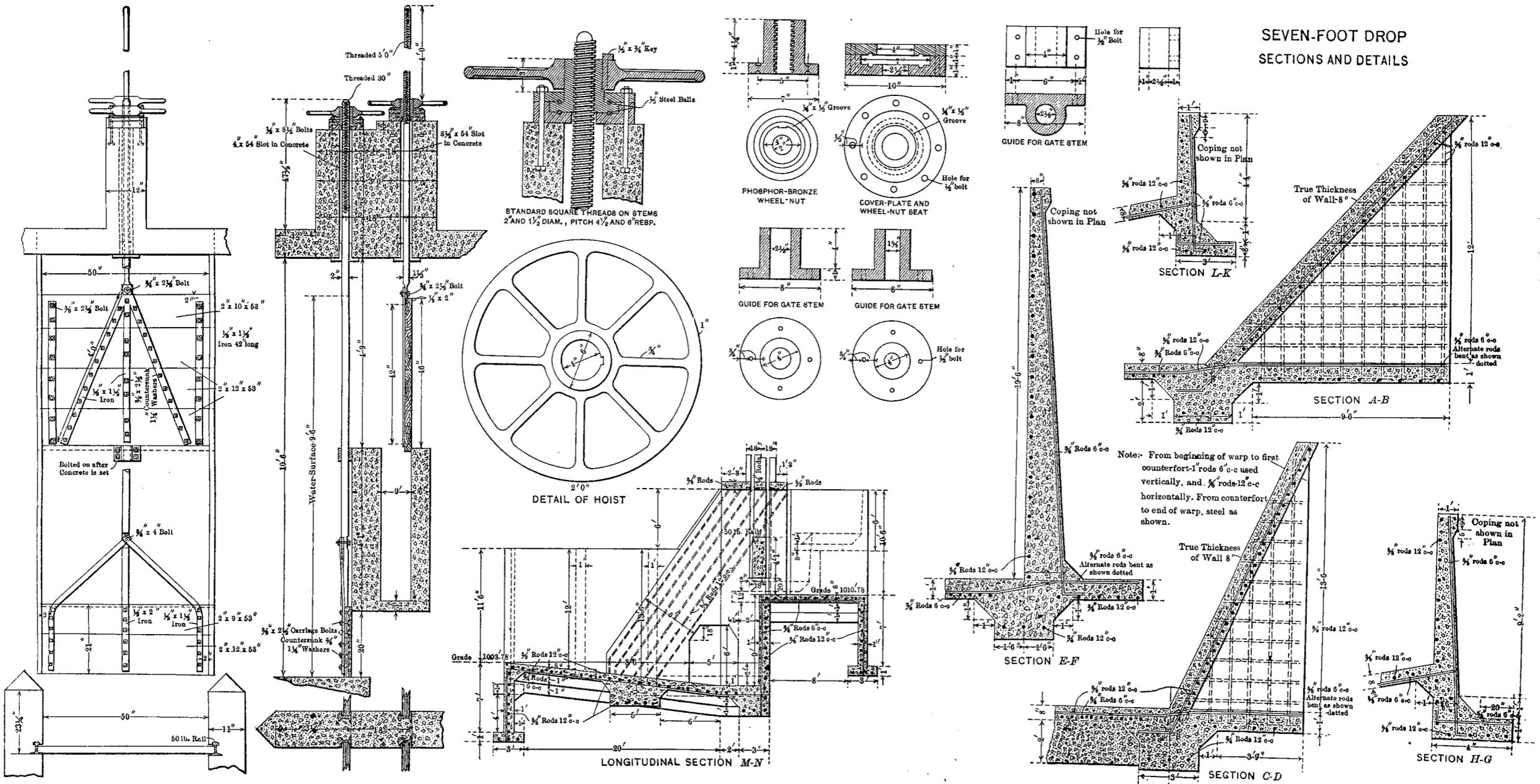


FIG. 63.

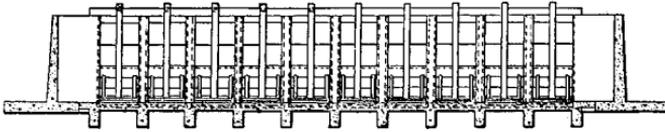
Of these designs the only ones constructed were the West Side Main, the Rose Levee and Waste-gate, including the Rositas Heading on the Alamo near Holtville, and the Seven-Foot Drop in the Central Main. The foundations in all cases were merely concrete footings without any sheet-piling, of which the Seven-Foot Drop (Plates LII and LIII, and Fig. 63), the Rositas Waste-gate (Fig. 64 and Plate LIV), and the Rositas Head-gate (Figs. 65 and 66) are quite typical.

The Rositas Heading and Waste-gate together cost \$55 250, and the Seven-Foot Drop, together with the little gates which constitute one structure, cost \$23 750. Concrete work, generally, has cost about three times as much as wooden structures; it has ranged from \$30 to \$35 per cu. yd. for the entire cost of completed structures.

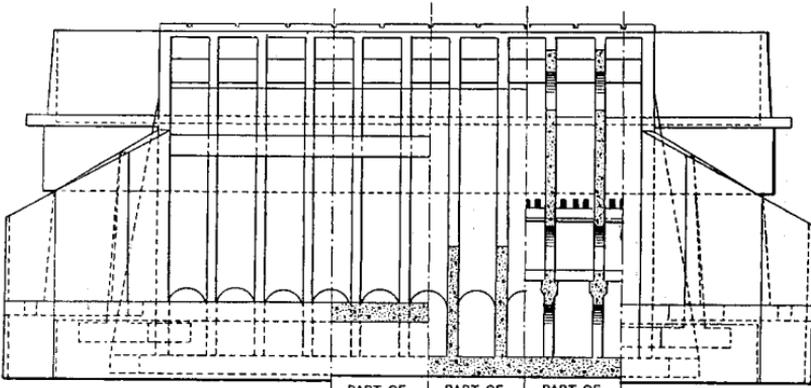
SEVEN-FOOT DROP
 SECTIONS AND DETAILS



ROSITAS WASTE-GATE

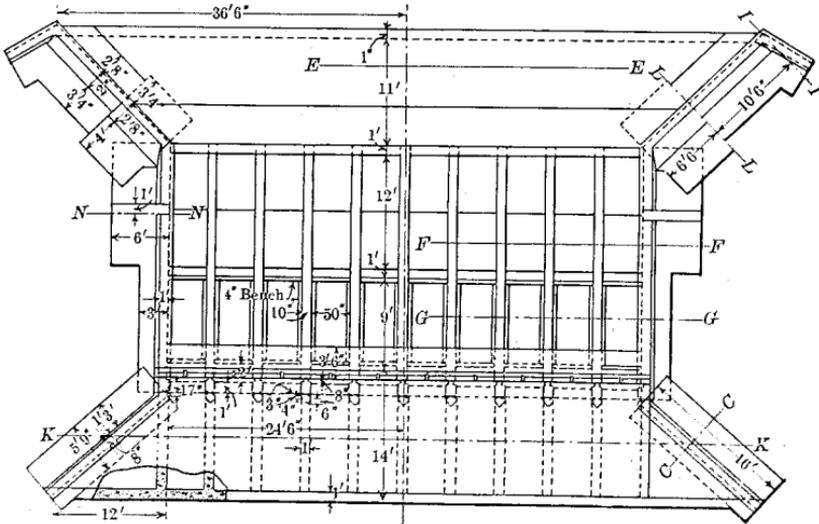


SECTION K K AND ELEVATION OF GATES



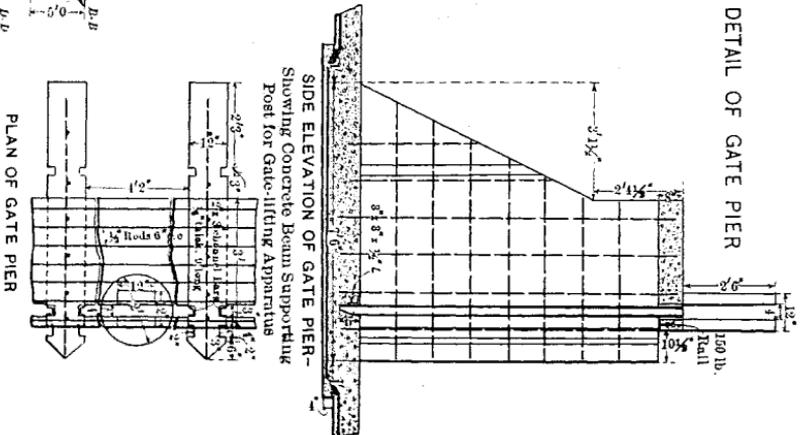
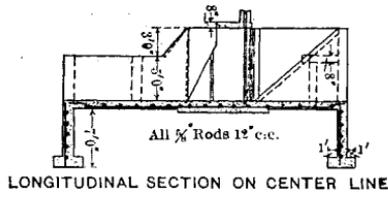
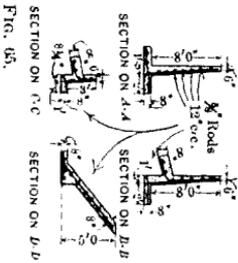
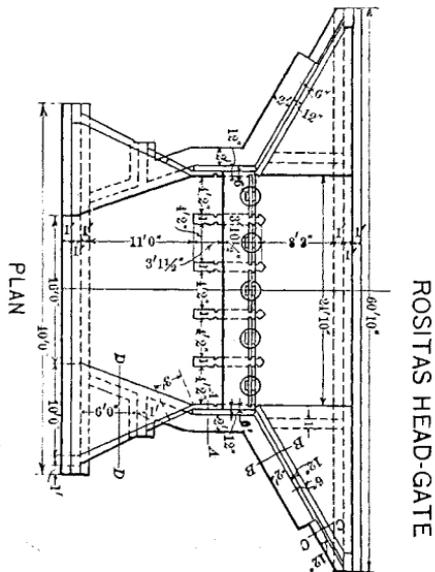
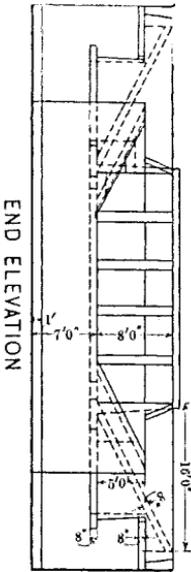
PART OF SECTION E E. PART OF SECTION F F. PART OF SECTION G G.

ELEVATION LOOKING UPSTREAM



PLAN

FIG. 64.



MAINTENANCE AND OPERATION.

Until such time as the promised arrangements for river control and levee maintenance by the Government should be fulfilled, the operations of the irrigation interests, under instructions from higher authorities, were made to include levee maintenance and extension as well as supplying water in wholesale to the mutual water companies. The business done by the corporations was in this way much more varied than that of most irrigation companies, although none of the land they owned was under cultivation.

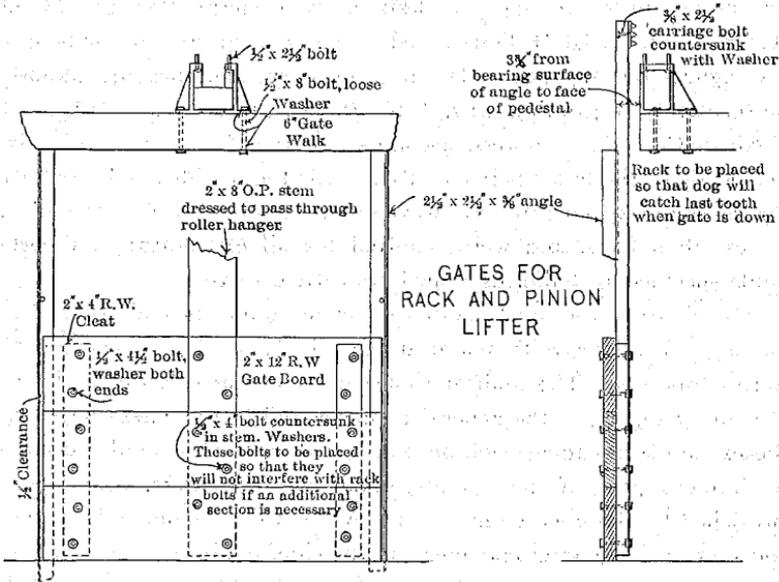


FIG. 66.

Because of the litigation which seemed inevitable, and indeed which had started ere this, it was deemed essential to have a complete and satisfactory system of accounts. Inquiries were directed to all possible sources of information, including the U. S. Reclamation Service, to discover a system of irrigation accounts similar in a general way to the system of railroad accounts generally adopted and for some time past made obligatory by the Interstate Commerce Commission. No such system was found. The U. S. Reclamation Service has a fairly satisfactory system of construction accounts, but its work, as yet, is almost exclusively construction.

The accounting system, therefore, was worked out, modeled closely after the classified railroad accounts. The account numbers of the Mexican Co. are the same as those of the C. D. Co., except that one thousand is added. Four years' experience with it has resulted in few changes, and in its present form it is extremely satisfactory. Lack of space forbids giving it in full, as there are 146 expenditure and 16 revenue accounts.

In order to ascertain the cost of particular portions of the work—whether new construction, betterments, or ordinary maintenance—special accounts are kept as desired, by General Manager's Orders (G. M. O.'s). A G. M. O. is asked to secure authority for, or to secure cost figures on, any particular piece of work, and they are numbered consecutively, beginning with 1 for the C. D. Co. and 1001 for the Mexican Co. The classified accounts and the G. M. O.'s are entirely independent, the latter being really a second and additional accounting for the same expenditure. G. M. O.'s were never asked for expenditures of less than \$300, and were required for all expenditures of certain kinds specified in bulletins issued from time to time.

Distribution was made both to account numbers and to G. M. O. numbers on all payrolls, material requisition blanks, vouchers paying contractors, etc. The auditor's office gathers these figures and makes a monthly report, to the general manager and to the chief engineer, of the expenditures under each account number, totaling under headings. A similar report, of the receipts, under account letters, with totals, is furnished to the general manager. A monthly statement is made up and sent to the general manager and the chief engineer concerning each G. M. O., giving a statement of original estimate, amount expended to date, and percentage completed. Whenever work covered by G. M. O.'s is materially changed, a new G. M. O. is gotten out accordingly.

With such accounts, occasional trips of inspection, to observe the physical condition of the system, will afford a very complete knowledge of the exact condition of the project at all times.

The relationship between the C. D. Co. and the various mutual water companies was at all times very satisfactory and cordial, until the former was thrown into the hands of a receiver, there being one exception, however, in Imperial Water Company No. 5. Differences autedating the beginning of the railroad management and in a large measure due to dissensions between former President A. H. Heber and

his Board of Directors, resulted in commencing litigation to compel Imperial Water Company No. 5 to pay up back water rentals. The attorneys of the latter company, in their cross complaint, attacked the validity of the mutual water company and water stock plan of a water right. The suit was before the United States Circuit Court, and in rendering the decision the judge expressed the opinion that the plan was illegal, and, practically speaking, the C. D. Co. was a public service corporation. This was but an opinion, because the State Courts of California have to decide this question finally, as it is a matter of the Constitution and Statutes of the State of California exclusively. The effect of this opinion, however, was to make the Southern Pacific Company feel that it would be unsafe to advance the large sums of money needed to reconstruct and extend the system on the expectation of being repaid ultimately through the sale of additional water stock to cover the new territory which would be brought under the canal. This suit, as much as any other factor, is responsible for the fact that practically nothing has been done on the betterment and extension work outlined. This litigation with No. 5, although begun in August, 1906, has not yet reached a definite conclusion.

When Imperial Water Company No. 1 was organized, the capital stock was placed at 100 000 shares, and the territory embraced within its limits was 135 000 acres. Of the excess land, a large part was found to be well worth reclamation, so that early in 1910 no No. 1 water stock was available. Imperial Water Company No. 1 was unwilling to increase the capital stock without obtaining from the C. D. Co. a contract increasing the quantity of water it would be entitled to demand and so retain the basis of 4 acre-ft. per annum per share of stock. It was impossible for the mutual water companies and the C. D. Co. to agree as to the proper division of the "water right" receipts for such 35 000 acres, so no relief was afforded to *bona fide* settlers who had their land ready and had to have water or lose their filings under the rulings of the U. S. Land Department. A trial suit was instituted, known as *Thayer vs. C. D. Co.*, which was decided in favor of the plaintiff on March 17th, 1911, by Judge George H. Hutton, of Los Angeles, sitting for Judge Cole in the Superior Court of Imperial County. Judge Hutton in brief decided that the C. D. Co. was a public service corporation; that the rate for supplying water was 50 cents per acre-ft.; that the C. D. Co. was in a position

to supply the plaintiff without detriment to the other water users; and ordered that it do so. This decision has been appealed to the State Supreme Court. If it is upheld, the mutual water company will not be a necessary factor in obtaining water from the C. D. Co. This decision has not affected the price of water stock in the valley very materially, because the various mutual water companies own the distribution systems, and the difficulties of getting water from the short mileage of the C. D. Co. main canals through other sources than the distribution systems of the mutual water companies are practically prohibitive. The decision, of course, absolutely precludes extension of the irrigated area any farther through such a water stock plan.

Seepage and Irrigation Losses.—It is very unfortunate that a clause in all the triparty contracts requires the actual seepage and evaporation from each mutual water company's distribution system to be reported after a period of 3 years, and that the percentage allowance thus determined should thereafter be made, to the end that the mutual water companies would pay for the quantity of water which could actually be delivered to the individual settlers. All the mutual water companies joined and selected an engineer, Mr. F. C. Scobey, to represent them in making seepage and evaporation determinations, and did quite a little experimenting and investigating. The engineers of the C. D. Co. also made numerous determinations under the direction of Mr. Herrmann, but for various reasons no experimentation was done jointly. The amount of work and expense involved greatly surprised the representatives of the mutual water companies, and proposals of a compromise were made, one thing helping to this being that such representatives agreed that it would be distinctly unsatisfactory to have different percentages agreed on for each of the mutual companies, as must obviously be the result. The C. D. Co. was thrown into the hands of a receiver just as these negotiations were reaching conclusion on the basis of 6% flat allowance. In the confusion following, the companies insisted on a 10% allowance, and this is the present status.

The results obtained by Mr. Scobey have never been given out, but the experiments by the engineers of the C. D. Co. showed a surprisingly small loss. It appears that the very fine silt deposited in the distribution systems of the various mutual companies forms a practically impervious coating on the sides and bottom, the measured

loss in many cases being as small as 0.25% per mile and increasing to a maximum of 1% per mile. From the available experimental data, computation of the losses from the distribution system of Imperial Water Company No. 1, comprising nearly 375 miles of canals, gives the total for seepage and evaporation throughout the year, under present operating conditions, as somewhat less than 7 per cent. The writer has no knowledge of so small a loss by seepage being reported by any authority heretofore.

The experience has been that the mutual water company plan of organization to distribute water, obtaining it from a larger company at wholesale, is highly satisfactory, and it is commended for careful consideration by those who are contemplating irrigation work, if the local laws will permit.

Canal Maintenance.—As far as the physical maintenance of the canal system is concerned, it may be said that the average life of the redwood structures, consisting of checks, drops, turn-outs, waste-gates, etc., is about 5 years for the smaller structures and 8 or 10 years for the larger ones. It must be remembered that water is used every day in the year, so that this experience has narrow application. The chief deterioration is caused by a sort of dry rot beginning about 1 ft. below the surface of the ground and extending down not more than $2\frac{1}{2}$ ft. It appears that deeper than that, regardless of the quantity of water present, the heat does not become great enough to cause trouble, and the upper layer of earth is nearly always so dry that the wood is not attacked. In the thin intermediate layer, which is both damp and hot, and perhaps where enough oxygen is available, dry rot appears very rapidly, and wood wet on one side and in contact with earth on the other has the earth side damaged to a depth of from $\frac{1}{4}$ to $\frac{3}{4}$ in., sometimes in 9 or 12 months. Redwood subjected to several kinds of treatment has been tried, but with little success. Oregon pine, for that portion of structures covered by earth in that region, rots very rapidly indeed.

The chief lesson taught by the maintenance of the canals—other than that the cost is unusually large because of tule growths and silt—is that inside berms must be avoided, and when possible all canals except the sub-laterals should have a double or twin cross-section. In the Imperial Valley the absolute minimum quantity of water is approximately 25% of the absolute maximum—a very unusual condition

of affairs. If the sections are identical, it is possible to use one canal for a long time, and have it never less than one-half full, and consequently the velocity of the water is never low enough to deposit the finer silt. This allows a sufficient time for cleaning one canal and then the other every year. When the demand increases beyond the capacity of one canal, both channels are more than half full. In this region, therefore, it is possible with the twin section to control the velocity between the excessive silt-depositing lower limit and the bank-erosion upper limit with absolute certainty. The additional construction expense of the canals for the twin section is much more than justified by the very greatly reduced maintenance charges thereafter.

Duty of Water.—As a basis for estimating the quantity of water required under the Yuma Project, investigations were made, under the direction of the University of Arizona Experiment Station, to determine the water required for various crops in the Yuma Valley. As a result of this work, it was decided that for the average 40-acre unit, 5.8 acre-ft. per annum, measured at the delivery box at one corner of the field, would be required. Such a figure is exceedingly interesting, but was not obtained under the usual operating conditions. Indeed, the satisfactory delivery of water has been made so recently and in such relatively small quantities in the Yuma Valley as not to justify any definite conclusions.

Water has been actually used in irrigation in Imperial Valley for more than 10 years, and although there seems to be no reason why the duty of water there should not be essentially the same as in the Yuma Valley, the quantity used in the former is only about half as much as indicated by the experimental work mentioned.

The crop census taken by the Zanjeros of Imperial Water Company No. 1 for that district during 1911 is as follows:

Alfalfa	44 262	acres
Barley	28 897	"
Corn	12 034	"
Cotton	6 263	"
Melons	2 153	"
Vineyards	1 352	"
Truck	1 092	"
Asparagus	192	"
Miscellaneous	3 327	"
Total	99 572	acres

To supply this acreage, the company bought from the C. D. Co. during the period 274 665 acre-ft. of water, or an average of almost exactly $2\frac{3}{4}$ acre-ft. per acre under cultivation. This is net, after deducting the 10% seepage and evaporation allowance given by the C. D. Co., as already explained. Of this net quantity, according to the water company's report, 92.3% was delivered and charged to the stockholders, making the average quantity of water used, measured at the farmers' boxes, 2,538 acre-ft.

The quantity of water used in irrigation depends on so very many different factors—quality of the land, nature of the crop, proper preparation and leveling of the land, and time of irrigation—that it is only by such general figures covering large areas that much tangible information for engineers is obtained. It must be remembered, however, that the water supplied is charged for on a quantity basis, which undoubtedly tends to minimize the quantity used, as well as the fact that the farmers know they can have all the water they want at any time they want it, every day in the year. On the other hand, water users—stockholders—are charged their *pro rata* of maintenance and operation expenses, regardless of whether or not they use any water, and also for a minimum of 1 acre-ft. per share of stock. Additional water is 50 cents per acre-ft.

The use of water is increasing in this district, and is in large measure due to the increasing acreage in alfalfa and cotton. The figures are:

1909	214 333	acre-ft., net.
1910	236 631	" " "
1911	274 665	" " "
1912 (Estimated).....	320 000	" " "

The figures for other districts are not available, but are probably similar.

LITIGATION.

The Salt Works Suit.—The New Liverpool Salt Company, whose property was inundated and destroyed on March 8th, 1905, began suit for damages to the extent of \$180 000 for land and salt deposits and \$30 000 for plant, changing the figures to \$325 000 and \$75 000, respectively, when the destruction became complete. In July, 1906, a compromise was suggested on the basis of \$50 000 cash, but the management of

the C. D. Co. declined to consider it. On January 10th, 1908, the case was decided, awarding the Salt Company \$456 746:23 damages and \$1 500 costs, and a permanent injunction was issued restraining the irrigation companies from diverting more water from the Colorado than would supply the substantial needs of the people residing in the valley. Later, the United States Supreme Court affirmed the decision.

Actions of the Southern Pacific Company.—When this adverse and excessive judgment had been rendered, it was seen that the United States Courts would hold the C. D. Co. liable for all damages caused by the diversion of the river, regardless of the fact that it had occurred in Mexico. All personal property and unsold water stock, therefore, was turned over to the Southern Pacific Company at fair prices, and future payments for water rentals were assigned to the Southern Pacific Company until the moneys loaned by it should have been repaid. At the same time, suit was brought in the United States Court for damages sustained in America, and suit was filed in the Mexican Courts for damages sustained in both Mexico and the United States, and all real property in the respective countries was attached. The suits in the United States are still pending. Judgment was rendered in the Mexican Courts for \$900 000, gold, against the Mexican Co., and enough property of that company was ordered to be sold to satisfy this judgment. Another Mexican corporation was formed by the Harriman interests, and permission to hold the concession of the original Mexican Co. was obtained from the Mexican authorities. At the sale, held on January 28th, 1911, this new Mexican Company bid in all the real and personal property of the Mexican Co., including the concessions from the Mexican Government, for the sum of \$325 000, gold, which was less than 40% of the judgment. Thus nothing now remains of the original Mexican Co. except the organization, with a \$575 000, gold, judgment against it, and additional suits aggregating nearly \$2 000 000 in the Mexican Courts, and absolutely no property.

The new Mexican Corporation, called the Lower California Land and Water Company, *Compañía de Terreños y Aguas de la Baja California, Sociedad Anonima*, owns practically all the parent irrigation company's holdings in Imperial Valley having any value, but has not yet taken possession. Shortly after the sale by Court decree, fraudulent dealing was alleged, and on November 18th, 1911, it was advertised that the Judge of the First Instance at Mexicali would hear any and all

complaints in the matter. No one appeared, and it seems probable that the validity of the sale must therefore be confirmed. In that event, the new company will be free of any contracts with the mutual water companies, the C. D. Co., or any one else, and is probably quite beyond the reach of the American Courts. This, however, means little to the water users living in either the United States or Mexico, as the Mexican Government has issued rules and regulations by which water must be sold under the Mexican concession, and these fix the price at 50 cents per acre-ft., and practically in no wise affect the conditions under which American users now receive water.

The C. D. Co., in that event, would be a mere shell; it owns only 65 miles of main canals which produce no revenue whatever, cost no little to maintain, and are hence liabilities instead of assets; it also owns its office, grounds, and buildings, all of which are under attachment, and its liabilities exceed \$2 000 000.

Appointment of Receiver.—On December 16th, 1909, the Title Insurance and Trust Company, trustees for the bond issue of the C. D. Co., applied to the Superior Court of Imperial County to declare the C. D. Co. insolvent and appoint a Receiver, which application was granted. The Southern Pacific Company has bought approximately \$325 000 worth of Receiver's certificates, which, together with the major portion of the water rentals received from the mutual water companies, has kept the property going. Application has been made to sell the property, but this has been delayed as long as possible by the attorneys representing the bondholders, the New Liverpool Salt Company, and the old stockholders of the C. D. Co. In a few months, however, it seems probable that this will be accomplished.

Formation of Imperial Irrigation District.—Because of the various difficulties and the serious litigation, the people of Imperial Valley, on July 14th, 1911, by a vote of 1 304 to 360, elected to form the Imperial Irrigation District. According to the present law of California, this district can condemn property, even of a public service corporation, and all taxable property within the district is assessable for its needs. It is authorized to incur a bond issue of 50% of the assessed valuation of the property of the district, and the five directors are elected by all voters in the district just as in the case of county and State officials. The assessed valuation of Imperial County this year is \$16 161 923; the value of its products is \$10 000 000.

It is intended to acquire all the property of the C. D. Co. and the main canals and works in Mexico, giving bonds of the Imperial Irrigation District in exchange therefor. It has not been decided definitely whether the mutual water companies are to be retained, or whether the district is to own and control the entire water system—probably the former will be done.

The present law of California, under which this district was formed, is extremely interesting to water supply and irrigation engineers. It is a considerably changed form of the Wright Irrigation Act, under which, some 20 years ago, a number of irrigation districts were created in California, all of which resulted disastrously. It is believed that in its present form the law is a practicable one, and experience with it will be awaited with much interest.

THE ABEJAS DIVERSION.

The excessive overbank flow during the summer flood of 1907 started cutting back fingers, as has already been stated. The flood of 1908 continued the work, and made it evident that the deep finger which first would have its grade receded to and through the bank of the Colorado, and thus again divert the entire river to the west, was one of the feeders of the Abejas, and that such diversion would occur about 20 miles below the International Boundary Line.

The situation was carefully watched, and the various interests affected were fully advised of developments. The United States Government had taken no tangible step to repay the moneys expended in closing the second break and in subsequent levee protection work, nor anything definite whatsoever with the Mexican Government looking toward a joint and satisfactory control of the situation. All interests, nevertheless, seemed to feel that the Southern Pacific Company would advance funds to protect the valley when a critical stage should be reached. The writer, in local charge of the situation for that company, had become fully convinced that the truest and best interests of all concerned would no longer be served by the railroad company standing in the breach, and recommended doing absolutely nothing further in protecting the valley than to maintain the existing levee system. In almost everything there comes a time to decline longer to carry the entire load. This recommendation was approved by the higher officials. When the summer flood of 1909 had passed, the

expected diversion was an accomplished fact, and as a result the entire low-water flow followed through the Abejas, spread out in a wide sheet without any defined channels, gathered into Volcano Lake and Hardy's Colorado and thence reached the Gulf.

The water in the river at the break dropped somewhat, and, as the river fell to its low-water stage, the water surface for a given discharge was found to be unusually low. The reasons for this have already been explained, but were not then fully understood. The demand for water in the valley increases greatly late in January, on account of the barley crop, and a serious water shortage seemed very probable.

Submerged Weir.—On urgent representations to the War Department, backed by the recommendation of the Reclamation Service engineers, permission was granted in March, 1910, to build a temporary obstruction in the river opposite the concrete head-gate, in order to raise the water a few feet and increase the flow in the canal. Work was started, but the river began rising and rendered it temporarily unnecessary. When the summer flood receded, in July, the situation was again critical, due to the large requirements in the valley, and work was resumed.

A trestle consisting of 4-pile piers, 15 ft. from center to center, was driven across the river at an angle of about 70 degrees. On this a railroad track was laid, and a little brush and considerable rock was dumped therefrom. Of course, there was no difficulty in developing a head of $2\frac{1}{2}$ ft. This weir or obstruction prevented any danger of water shortage in the valley, but, not being square across the river, it produced eddy currents, just below it on the Arizona side, which cut away the bank to some extent and necessitated considerable expense in bank protection work.

The permission of the Government was given for this construction, on the understanding that it was to be temporary, and would be removed before the next spring flood. In March, 1911, all the piling was blown off, not pulled.

Late in 1910, arrangements were made to obtain the large suction dredge, *Imperial*, and with it in service no further immediate difficulty in diverting sufficient water is anticipated. (See page 1283.)

A very important fact, however, was developed in the construction and attempted removal of this weir, namely, that the small quantity

of rock dumped from the trestles which was required to raise a head of $2\frac{1}{2}$ ft. at low-water stages—about 10 000 sec-ft.—was not undermined and did not settle except to a slight extent in a few places, with the summer floods of 1911 and 1912. These floods were ordinarily large, and, passing over it, had little effect in taking it away. This result was surprising, even to the proponents of rock fill methods of building weirs. The length of time it finally requires to eliminate all effects of this weir from the river flow at that point should be kept track of and reported to the Profession from time to time.

All Parties Frightened.—All the interests in jeopardy were now thoroughly frightened. It was finally realized that the Southern Pacific Company would no longer supply money for river control, and that the diversion was not only an accepted fact, but that the prophesied lowering of the river at the concrete head-gate had taken place. The fear had been that the bed of the river would be lowered at the Abejas break approximately from 5 to 8 ft. and that this lowering would rapidly run back up the river and have such an effect opposite the concrete head-gate as to prevent diverting enough water to supply the needs of the valley. This fear is now known to have been in large measure unfounded, as the permanent lowering of the water surface at the Abejas probably has not been more than 3 ft., and opposite the concrete head-gate not more than 2 ft., if indeed that much at either place.

Another fear was that the Colorado would now discharge directly into Volcano Lake, and during severe flood periods raise this body of water so high that it would flow northward and into the New River channel, thus cutting back a connection, permitting the river again to reach the Salton Sea, but by a course approximately 40 miles longer.

As the summer flood came on, the overflow covering the low lands on each side of the Abejas, especially in the vicinity of Campo Lino, was higher than any existing marks on trees, etc. To prevent this water from getting over the low divide to the north and thence to the Salton Basin, disconnected portions of the remaining gap in the levee line were partly built, the C. D. Co. through its Receiver paying the bills. While the work was in progress, the water, for long stretches, came within a few inches of the top of the fill being thrown up, and was held south of the divide only by strenuous efforts. Probably no

very serious results would have followed in any event, although the New River flume of the West Side Main might have been damaged.

The people of Imperial Valley were now thoroughly frightened, and urgent applications were rushed to President Taft, in which the civic and commercial bodies of California, especially Southern California, and the State officials joined. These applications pointed out the inability of American interests in jeopardy to handle a menace originating in Mexico, and the injustice they suffered.

CONGRESS APPROPRIATES \$1 000 000.

In response to these applications, President Taft sent a special message to Congress, and on the eve of adjournment the two branches of Congress joined in a resolution, approved June 25th, 1910, providing:

"That the sum of \$1 000 000, or so much thereof as shall be necessary, is hereby appropriated out of any money in the Treasury not otherwise appropriated, to be expended by the President, for the purpose of protecting the lands and property in the Imperial Valley and elsewhere along the Colorado River, within the limits of the United States, and the President is authorized to expend any portion of such money within the limit of the Republic of Mexico as he may deem proper, in accordance with such agreements, for the purpose, as he may make with the Republic of Mexico."

On June 8th, 1910, the acting Secretary of the Interior, Mr. Frank Pierce, addressed to the President a communication based on information and recommendations furnished by Mr. Hill, Supervising Engineer of the United States Reclamation Service, advising as follows:

"The ascertainment of what is necessary to be done for the purpose of accomplishing permanent avoidance of these recurring menaces to life and property on both sides of the International Boundary Line will require a thorough examination of physical conditions which, to be effective, should have the co-operation of both governments, and will consume considerable time. In the meantime, unless prompt relief is afforded, a water shortage, if not famine, is probable in the Imperial Valley within the next two months.

"In a country where the heat reaches an intensity of 120° and even higher, the great loss of property and the menace to both animal and human life which may result, should such a catastrophe occur, renders it imperative that prompt measures be taken toward averting the same. To that end, I respectfully recommend that you designate

an engineer having familiarity with problems involving river control to proceed immediately with an examination for the purpose of determining whether such emergency exists, and if so, to take the steps necessary to avoid the same."

On the recommendation of Gen. W. L. Marshall, Consulting Engineer to the Secretary of the Interior, John A. Ockerson, President, Am. Soc. C. E., and for many years Member of the Mississippi River Commission, was, on July 19th, 1910, appointed by President Taft. He at once went to Yuma, arriving there on July 30th, by which time Mr. F. L. Sellew, Engineer of the Yuma Project, on Mr. Ockerson's request, had made a survey covering the immediate vicinity of the C. D. Co.'s intake, and had prepared a plat which showed clearly that the bed of the river was above the bottom of the head-gates and that the deficiency of water in the canal was due mainly to the silting up of the intake above and the canal below the concrete head-gate.

There were two possibilities: one was to get dredging machinery into place as rapidly as possible and dredge out the canal; the other was to raise the water in the river by a submerged dam, the latter being temporarily necessary because of the time required to build dredges to do the necessary work. As explained, the weir was begun in the latter part of July and completed within a month, and the contract was not let for an efficient suction dredge until late in December, the delays in starting the latter being in part due to difficulty in arranging funds therefor, and in part due to a belief in some quarters that, with the submerged weir in place, a dredge was unnecessary.

Mr. Ockerson made an inspection of the Imperial Valley during the latter part of August, and about the middle of that month put out a surveying party which ran a stadia line along the Colorado River from about 6 miles below the Boundary Line to the Abejas break; thence down the dry bed of the Colorado for about 25 miles; down the Abejas River from the point of diversion about 5 miles; and made several cross-sections of the Abejas for the purpose of selecting the best site for a rock fill barrier dam—all of which required about 6 weeks.

On October 4th, Mr. Ockerson reported to the Secretary of the Interior that the Imperial Valley would never be safe from the menace of western diversions due to flood-waters until ample works were con-

structed to confine such flood-waters to narrow limits along the river proper; that there had been no appreciable lowering of the river bed on account of the Abejas break; that in extreme cases diversions to the west might depress the low-water plane opposite the concrete head-gate and render it difficult to supply water to the Imperial Valley with the present diverting works; that the maintenance of levees consists not only in keeping up the cross-section, freeing it from weeds, brush, and burrowing animals, but also in holding in check the tendency of the river to erode the banks and threaten to breach the levees; that a levee located 3 000 ft. from the westerly bends of the stream would probably remain intact for a long time; that if the C. D. Co. levee line had been carried down along the river instead of where it was built in 1907, it would have reached a point 6 miles below the Abejas break, and no break would have occurred there; that completing the upper levee would undoubtedly protect the Imperial Valley from floods for a short time, but constituted only a partial solution of the problem, and even that only temporarily; that, finally, the proper protection of lands in the Imperial Valley required that the Colorado River be restored to its former channel and an effective line of levees be built from a point on the existing levee system about 6 miles below the International Boundary Line and following along the west side of the stream to a distance of about 3 000 ft. from the westerly bends of the river, approximately 25 miles, where the flood height would be at an elevation below the ground line in the vicinity of Volcano Lake and any diversion of the water would not cause a tendency to flow north.

It was estimated that such a levee would require about 1 300 000 cu. yd. of earthwork and 450 acres of clearing and grubbing; and it was recommended that the top be 8 ft. wide, the slopes 3 to 1, and the berm between the toe of the slope and the edge be 40 ft. wide, and that borrow-pits be on the river side, with traverses 50 ft. wide at intervals of 400 ft.

In commenting on the situation early in September, 1910, Gen. Marshall recommended completing the northern line of levees, as originally designed by the writer, to prevent the water from getting north, and providing a suitable and practical intake for the canals of the C. D. Co. He also suggested that, if the present intake (concrete heading) be closed and the Imperial Canal be extended to the Laguna

Weir, the matter would be solved, as far as American interests were involved.

River Levee Plan Adopted.—A month later Mr. Ockerson went to Washington for a conference, the result being that the work suggested by him was ordered begun. On November 25th bids for the levee construction were opened in Yuma. According to the specifications, the contractor was to assume all risks of interruption of the work by floods, and as the season was by this time far advanced, the prices were deemed too high and endeavors were made to get the work done on force account.

At about the same time it was discovered that the Mexican Government—as would naturally be expected—could not consistently permit the United States Government, or any of its officials acting as such, to perform work on Mexican soil. For six years, the need for making satisfactory arrangements and agreements with the Mexican Government regarding the Colorado River and its control, and proper and equitable division of its waters, had been fully understood, but practically no progress had been made. That fact, however, makes it even more surprising that requests on the part of the United States should have been made to enter Mexican territory and do work therein. The difficulty was very easily overcome, of course, by operating through the medium of a Mexican corporation, as the Southern Pacific had done, and the C. M. Co., which, as has been explained, is a very large land company, was chosen. Consequently, nothing was done in the name of the United States, but the engineer in charge acted under power of attorney from the C. M. Co., there being a gentleman's agreement between the United States and the C. M. Co.

In this way, on December 12th, contracts were awarded for levee construction, the first 9 miles, aggregating 425 000 cu. yd., at from 19 to 22½ cents; the next 6 miles, aggregating 336 000 cu. yd., at 23 cents; and the remainder, aggregating 325 000 cu. yd., at 36 cents. These figures were afterward considerably increased, the total quantity being 1 277 984 cu. yd., and the total cost, including \$20 000 paid for duties, \$452 434. The work in the immediate vicinity of the Abejas break and the small quantity of grading on 4 or 5 miles of temporary track was done by the C. M. Co. on force account. President Lovett, of the railroad company, offered to supply, essentially at cost, all the organization, men, equipment, and supplies required for closing the break and for doing any other work that might be deemed necessary.

The Mexican Government had given assurances to the American Minister that duties on stock, material, and supplies would be remitted, which was considerably more than had been done when the railroad had the work in charge. The Government officials, however, were not satisfied with this, and thought that all material should be passed free—a matter very much more difficult to arrange under Mexican laws, as it would require Congressional action, and that country was already in the throes of a revolution. However, after a delay of 2 weeks in getting stock across the line, it was decided to arrange for the duties and depend on a refund later. The contractors began work early in January. At about the same time one pile-driver was put to work on a trestle across the Abejas, and by February 2d (river discharge, 11 000 sec.-ft.) the temporary track was completed to and over the trestle, and rock dumping began.

The method was that developed in closing the first and second breaks, and used later in closing the gap in the Laguna Weir, one trestle being deemed quite sufficient, as the maximum head was not expected to exceed 7 or 8 ft. At the Andrade quarry there were approximately 15 000 cu. yd. of rock ready to load with steam shovels, and the quarry was well developed, having a face about 900 ft. long and averaging 40 ft. high. Two 4-cu. yd. steam shovels were secured from the Southern Pacific Company, and a 2½-cu. yd. shovel of the Reclamation Service was brought down from the Laguna Weir. Work trains, men, and "battleships" were obtained from the railroad, as required, and rails and track material were furnished on a rental basis.

On February 7th, a sudden rise (maximum discharge, 23 000 sec.-ft.) caused a breach in the trestle; this was closed 10 days later. On March 7th another small rise in the river carried away seven bents, and 6 days later another rise (maximum discharge, 35 000 sec.-ft.) brought down a mass of drift and wrecked a considerable length of the bridge, caused the loss of a pile-driver and one steel "battleship," and drowned one man. On the 28th the pile-driving was resumed and the operations were continued without further mishap until May 15th, when work on the dam was shut down.

In making this closing, the rock fill was not kept at uniform height for the entire length of the trestle, the overpour for some of the time being confined to three places with a total length of from 260 to 275 ft. It is probable that this explains in large measure the breaking of the

trestles by floods and drift, after obtaining an effective rock mattress, such as is provided by dumping two or three cuts of "battleships" all along. In building the Clarke Dam, floods (maximum discharge, 32 000 sec.-ft.), with heavy drift, threw the trestle out of line in only one place after rock dumping began, and caused no other damage.

The number of cars unloaded in the Abejas closing work is given in Table 22.

TABLE 22.

Period.	" Battleships."	Flats.	Dealey.	Dinky.
January 17-31.....	88	....	....	12
February 1-10.....	314	....	....	....
" 11-20.....	350	5	....	....
" 21-28.....	616	....	....	34
March 1-10.....	181	....	....	....
" 11-20.....	108	....	....	108
" 21-31.....	207	....	....	108
April 1-10.....	747	48	....	20
" 11-20.....	781	40	8	....
" 21-30.....	581	70	37	....
May 1-2.....	41	3	....	8
Totals.....	3 996	161	49	182

The total quantities were: 139 860 cu. yd. of "battleship" rock, 193 cu. yd. of flatcar rock, 516 cu. yd. of Declez rock, and 1 092 cu. yd. of quarry rock in dinky cars, a total of 143 400 cu. yd. up to May 2d. The total quantity of rock used to May 15th, when work closed down, was about 180 000 cu. yd. The total cost of the dam is given as \$347 500.

About 140 000 cu. yd. of rock were used before the water was practically shut off in making this closing. The reasons for requiring such a large quantity probably are that relatively little flatcar rock of large size was used, the fact that the rock fill was not carried along at a uniform height for the entire length of the overpour, and the slow rate at which the rock was unloaded. The first methods of quarrying were not well adapted for giving the maximum output, consisting of operations along the top of the rock mass by the edge of the quarry face, but, later, horizontal tunnels were driven into the quarry face at intervals along the bottom and large charges of explosives were used, after which the output was much increased.

The levee work went along very rapidly, the contractors fortunately encountering no flood difficulties or delay, and on April 7th the last of the grading outfit left the work.

reach through the adobe soil under the construction, dug out and filled with good material under the axis of the levees. Except for a very few cases of logs and brush in the levee section, and inefficient muck-ditching reported to have been disclosed where the levees were broken, the dikes were very well constructed in accordance with the specifications. The levee was built to a grade of "5 ft. above the high-water marks of the 1909 summer flood, chiefly for the purpose of having excess material wherewith to remedy deterioration, rather than through any fear of overtopping from floods." No railroad track or gravel blanketing was put on the levees, because of the belief "that it would be better to extend the levees as far as practical, rather than dissipate available funds for mere convenience of maintenance."

A low levee was built along the south side of the break, extending from the dam a short distance up stream, to prevent water from getting into the levee borrow-pits until the grading outfits had finished work in the vicinity. As the water in the river was gradually raised, partly by increased discharge (total, 19 000 sec-ft.) and partly by increasing the height of the rock fill across the break, this low levee was, on April 21st, overtopped and almost at once about 1 000 sec-ft. of water started down the borrow-pit clearing, about 2 000 sec-ft. going into the old Colorado River channel. When the water hit the uncleared traverses it cut the berm and side-wiped the levee at almost every traverse for several miles. Work on the rock fill dam was stopped, and the men were set at work protecting the levee. Later in the day this was stopped, and work on the dam was resumed. The latter was facilitated materially by the waters breaking over into the borrow-pits, the elevations of the water surface above and below the dam being quickly changed from 79.6 and 71.6, respectively, to 78.6 and 71.0, the depth of overpour being reduced 1 ft. and the head on the structure 0.4 ft. By dumping rock and filling the holes where the confined overpour occurred, the situation there was soon in hand, and 8 days later (April 29th) the elevation of the lowest point of the dam was 80.6, or 1 ft. higher than the water surface up stream, where the water broke into the borrow-pits, and the flow over the structure was stopped.

By that date the levee to the south was cut entirely through in several places in the first 6 miles, and it was evident that the water

would soon merely detour around the dam and continue to follow the Abejas channel below. The river discharge then was 21 900 sec-ft., and about 4 000 sec-ft. were going down the old channel, the remainder running through the levee breaks and toward the west. On May 7th, the discharge of the river had increased to 32 800 sec-ft., of which perhaps 9 000 sec-ft. were running down the old channel of the Colorado, and the water varied in height from 4.3 to 6 ft. below the top of the levee in the 2 miles immediately north of the dam.

The rock fill was then up to the track all across, and the total percolation through it was reduced to about 120 sec-ft. The eddy currents below the dam, 9 days later, weakened the earth fill about 300 ft. from the north end of the dam, until the water broke through, and in a few hours the entire discharge of the river (except a little overbank flow) was going through it and down the Abejas. Soon the earth fill on the south was cut through, and thus the rock fill dam was made an island in the Abejas channel, which is the situation at present.

The final injury on the levee work prior to the summer flood was three breaks and several places side-wiped on the north levee, totaling about 16 000 cu. yd., and thirteen breaks, varying from a few hundred feet to more than 2 miles in length, and much side-wiping in the first 8 miles of the south levee, totaling about 200 000 cu. yd., or about 50% of the original earthwork in this stretch. The fact that such disaster was caused by so small a quantity of water reaching a maximum depth of only 4 ft. on the levee shows clearly the ease with which the material of the region is eroded.

The protective measures used were sand bags and brush placed to check erosion and the dynamiting of the traverses which, with the drift their vegetation caught, deflected the water to the levee section. The latter procedure had the bad effect of converting the borrow-pits into a continuous canal, but with severe eddy currents caused by the remains of the traverses. These endeavors had little effect; indeed, to hold long stretches of embankment against such action is practically impossible.

BOARD OF REVIEW.

On June 1st, Mr. Fisher, Secretary of the Interior, called a Board of Review consisting of Mr. F. H. Newell, Director of the U. S. Reclamation Service; Gen. W. L. Marshall, Consulting Engineer to the

Secretary of the Interior; J. B. Lippincott, M. Am. Soc. C. E., formerly a Supervising Engineer of the U. S. Reclamation Service and now an Assistant Engineer of the Los Angeles Aqueduct; Mr. C. E. Grunsky; Mr. J. A. Ockerson, Engineer in charge of the work; and Gen. Harrison Gray Otis, President of the C. M. Co., to report on the work done under the appropriation. All the members of the Board have examined the territory and understand the situation fully, although none of them except Mr. Ockerson has been on the ground since the Abejas diversion occurred.

On June 7th this Board made a report based on information as to the recent work done and results obtained, supplied by Mr. Ockerson, and answering specific questions submitted by Secretary Fisher. The full text of this report is as follows:

"1.—A breach in the west bank or levee of the Colorado River, if made at or within a mile south of the California boundary, or south of Mile 18, below Yuma Bridge, will result in water flowing directly into the drainage areas of the Alamo and New Rivers and thence into Salton Sea, which would be disastrous to property in the United States.

"2.—A breach in the river bank at any point between Miles 18 and 55, below Yuma Bridge, will result in spreading water over the Delta of the Colorado River, with a flow into New River *via* Volcano Lake, menacing Imperial Valley.

"3.—(a) The best practical method for the protection of land and property in the United States against a discharge directly into the Imperial Canal and thence through Imperial Valley into Salton Sea, is to protect and maintain the levees as at present located for a distance of at least 10 miles south of the California boundary and to hold the river by adequate bank revetment practically on its present alignment. (b) This levee, if extended to a point opposite the south boundary of Arizona, or about Mile 27, will also prevent a discharge directly into the Paredones.

"4.—(a) As a remedial or precautionary work to prevent damage which might result from a crevasse directly into the Imperial Canal or Alamo River, we have considered a secondary levee west of the river levees, across Imperial Canal, and large channels leading to the natural depressions, or diverting works, conducting the water southwesterly into channels leading into Volcano Lake, but it is believed that the cost of any such secondary defence could be better expended in maintaining the main line of defence at the river. (b) As a necessary defence against the northerly flow of any water reaching Volcano Lake, whatever be the treatment of the Lower Colorado River, there should be an embankment well protected against wave wash on its

south slope, constructed about on the line of the levees already built extending from high ground north of Volcano Lake to a connection with the levees already built by the California Development Company, southwesterly, toward this region from the Colorado River. The top of this embankment should at its western end be not less than 10 ft. higher than the rim land at Volcano Lake. This embankment is an essential requisite as a protection of Imperial Valley, against menace from the south, and should be constructed without delay.

"5.—(a) The maintenance of the works constructed in 1906 and 1907, closing the breaks of the Colorado into the Alamo, and the maintenance of these and of the river levees since constructed as far south as the head of the Abejas are essential requirements. Suitable arrangements for their repair and maintenance should be made with Mexico through the proper authorities. We do not consider the immediate closure of the break into the Abejas and the reconstruction of the levees below the break as essential to the protection of property in the United States. The ultimate treatment of this section of the Colorado River in co-operation with Mexico may well be determined by negotiations between the governments of the two countries. As a feature of the permanent solution of the river problem it is desirable that the Abejas break be closed, that the levee constructed in 1911 be repaired and maintained, and the Colorado River restored to its former course. (b) Provided the water of the Colorado is discharged into the Gulf of California through the Abejas into the Pescadero and Hardy Rivers, there is little probability of the cut back affecting the Laguna Dam. Such cut back will not injuriously affect the heading of the Imperial Canal or levees adjacent thereto, with a possible exception of requiring the lowering of the intake of the Imperial Canal a few feet. This is not a serious matter, and is one that should be dealt with by the California Development Company itself when necessary. The diversion by the California Development Company should be facilitated during low-water stages by dredging, or by lowering the sill of its intake, rather than by placing obstructions in the channel of the river below the intake.

"In view of the existing emergencies along the Colorado River, arrangements should be made with the government of Mexico to provide for the early creation of an International Colorado River Commission, embracing in its membership both American and Mexican engineers, invested with large powers and ample authority to examine into and to submit a basis for the adjustment of all questions relating to the conservation, use, and control of the waters of the Colorado River with a view to such governmental action as shall result in a complete, just, and final settlement of all such matters at issue between the two nations. We recommend that further work should be undertaken at once and in approximately the following order:

“(a) The levees north of Volcano Lake should be raised, strengthened, and extended.

“(b) The existing levees along the west bank of the Colorado River to the Abejas should be repaired and protected. For this purpose and to meet emergencies, there should be immediately available the sum of at least \$1 000 000. This sum provides only for the temporary maintenance of levees, and does not include the systematic revetment of the river banks.

“The conference ventures to suggest certain international questions which are involved and which will inevitably have to be met sooner or later:

“(a) The matter of the permanent protection of existing works on both sides of the international boundary line, the construction of further works, and the conditions under which the present and future projects may be carried out on Mexican soil, with the consent and co-operation of the government of Mexico for the benefit of both countries, to the end that the greatest practicable quantity of water of the Colorado River may be made available for irrigation by means of storage reservoirs and otherwise, and the least possible quantity be permitted to flow unused to the sea, and to what extent the cost of such maintenance should be chargeable to properties benefited and to what extent chargeable to either government.

“(b) That permanent agreements with the government of Mexico shall be entered into, having in view the just apportionment of the waters between the two countries, irrigation to be paramount to navigation.

“(c) The method by which either nation may acquire rights of way for canals, levees, and related works, each within the territory of the other, and the authority to maintain such works.

“(d) The modification of the boundary line between the United States and Mexico with a view to facilitating the solution of the entire Colorado River problem. An authoritative, just and final determination of this important question, now a matter of public discussion, will have the effect of removing existing doubts in the public mind and of settling the matter for the benefit of all concerned.

“The members of the conference desire to call attention to the fact that the plan and execution of the work accomplished during 1911 followed well-established principles of good engineering. That so large an amount was accomplished in such a brief space of time, under adverse circumstances, is worthy of the highest commendation. That the restoration of the Colorado River to its former channel was not realized is chargeable to the delay in the negotiations, which prevented prompt inauguration of the work and the prosecution during the low-water season, and also to the disturbed political situation and strike which demoralized labor conditions. The members of the conference,

in addition to the conclusions above reached, present also a statement of physical and related facts embodied in an abstract of the data available, and found largely in the reports of J. A. Ockerson and of C. E. Grunsky. Also in the printed hearings before a subcommittee of the Senate Committee on Claims, referring to Senate 4170, January 21, 1909."

When President Taft received the report, he sent a special message to Congress recommending the appropriation of another \$1 000 000 to continue the control work, but Congress failed to comply. It is desired to call particular attention to the last part of this report containing Suggestions *a*, *b*, *c*, and *d* regarding certain international questions involved, which sooner or later must be met. These suggestions contain the crux of the entire situation, and it is to be hoped that they will be expeditiously followed out. It is perhaps desirable to call attention to the wording of Suggestion *d* regarding modification of the Boundary Line between the United States and Mexico, the suggestion being implied that the matter be taken up more with a view of putting a quietus to the proposition, than with the idea of obtaining any territory from the Mexican Government.

SURVEYS BY THE NEW MEXICAN COMPANY.

As soon as the summer flood of 1911 began to recede, and the extent of the damage sustained by the new work was ascertained, the Harriman interests controlling the new Mexican Company deemed it wise to ascertain how effective the line of levees north of Volcano Lake would be in holding back the waters of a very large summer flood. Accordingly, three surveying parties were put out early in July under the immediate direction of Mr. Hind. The surveys were carried down the river to The Colony and as far west as Volcano Lake, much of the territory being covered quite thoroughly. The field work was completed during the latter part of September, and the data were assembled and mapped. Mr. Randolph analyzed these data and compiled a report which was forwarded to Mr. R. S. Lovett, Chairman of the Executive Board in New York City, recommending:

1st.—That the westerly portion of the Volcano Lake levee be raised and extended so as to occupy a plane 6 ft. above the then present crest; and

2d.—That an effective levee system, including a rock dam shutting off the Abejas diversion, be constructed along the river to a distance

of 16 miles below such dam; that the entire levee should be blanketed with gravel; and that a railway track be laid thereon in good condition for further operation when necessary.

Mr. Lovett, on December 13th, 1911, made a formal offer to President Taft, on behalf of the Southern Pacific Company, to return the Colorado River to its original channel and to maintain the levees necessary to keep it there for one year, providing the Southern Pacific Company be repaid for the work done in 1906-07 at President Roosevelt's request, in the sum of \$1 083 673.97, being the amount reported as proper under the circumstances by Mr. Grunsky in his statement to the Committee on Claims during 1908; and provided, further, that an additional appropriation of \$1 500 000 be placed at the disposal of the President of the United States with which to pay the actual cost of the work to be done and the cost of maintaining it for one year, the Southern Pacific Company to stand any excess of cost over and above such an amount; that the transportation charges of the Southern Pacific Company in connection with the work should be in accordance with the arrangements in effect during the work under Mr. Ockerson's direction; and providing, further, that should the Southern Pacific Company fail to return the Colorado River to its former channel and to retain the levee for one year thereafter, then in that event the Southern Pacific Company should receive no compensation or reimbursement for the work which it would do under that offer.

This proposition was referred to Gen. Marshall, Consulting Engineer for the Department of the Interior, who, under date of January 5th, 1912, reported in substance that the work proposed should not be done either by it or by any other agency on behalf of the United States at this time, nor until the entire subject of improving the Colorado River and utilizing its water should be investigated by an International Committee representing both the United States and Mexico. The following day, the Secretary of the Interior, W. L. Fisher, forwarded Gen. Marshall's report to President Taft and approved of its conclusions, stating that the suggestions constituted the most important recommendation of the Advisory Board of June 7th, 1911, and adding:

"I consider it of great importance that negotiations should be immediately opened and vigorously conducted with a view of arriving at a treaty with Mexico covering this subject."

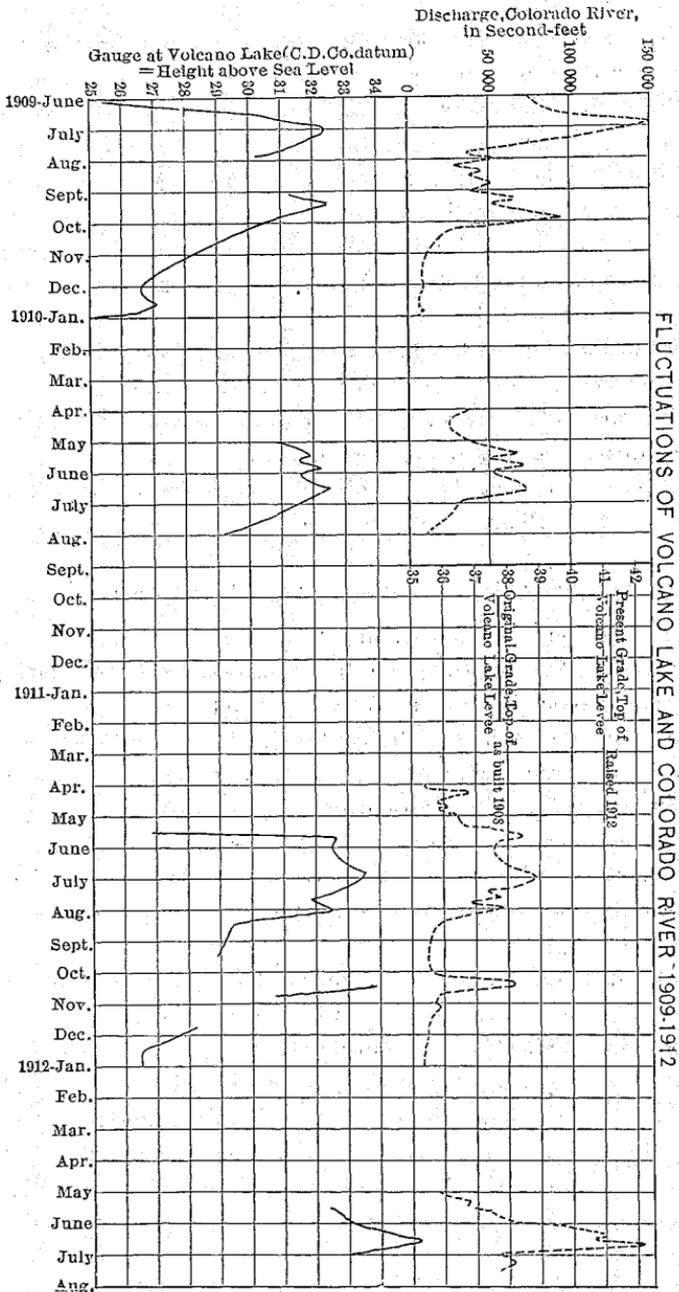


Fig. 60.

President Taft, in his message to Congress a few days later, placed the whole matter before Congress without recommendation.*

Perhaps the most important information obtained by these surveys is the fact that the average elevation of the bottom of Volcano Lake is 28 ft. while the general average prior to 1907 was 17.8 ft. above sea level. In other words, the bottom has been raised 10 ft. since the Colorado began to flow directly into the lake, during which time it has discharged into it approximately 30 000 000 acre-ft. of water. The streams below, draining to the Gulf, are now normally clear, showing that most of the silt content of the water reaching the lake is being dropped over its bottom, together with some material eroded from the new channels formed by the diverted river. On the other hand, very much suspended material carried by the waters is let down before reaching the lake. The conditions are extreme, yet they indicate the extreme silt deterioration which may be expected in reservoirs on the Gila, Salt, Verde, Colorado River below The Needles, and similar streams.

IMPROVEMENT OF VOLCANO LAKE LEVÉE AND REPAIR OF RIVER LEVEE.

Contracts were let on January 4th, 1912, for raising the Volcano Lake levee $3\frac{1}{2}$ ft. and widening the crown to 12 ft., 155 000 cu. yd. at 25 cents; repairing the recently constructed levee along the river north of the Abejas break, the contract calling for 15 000 cu. yd. at 22 cents; and paving with rock the south or water face of the Volcano Lake levee, approximately 70 000 cu. yd., for \$1.50 per cu. yd. This rock was obtained from the mountain sides at or near Cerro Prieto. The temporary railroad track from the C. D. Co. levee to the Abejas break was taken up, and the track material returned to the Southern Pacific Company.

Assistant Secretary of the Interior Thompson went to the City of Mexico to make arrangements whereby the Government might do this work in Mexico, but was unsuccessful. Until the United States concludes arrangements for working in conjunction with the Mexican Government, operations on Mexican soil will doubtless have to be handled in a roundabout way, particularly as long as there is fear of unfounded complaints that lawlessness interferes and delays the progress of such work as may be permitted. Mexico, however, author-

* See also House Document 204, 62d Congress, 2d Session.

ized the foregoing work to be done by the C. M. Co. through the engineer assigned by the United States to do the work, and a gentleman's agreement was reached between that company and the United States.

CONCLUSION.

Because of the various successful and unsuccessful work done in the region, the engineering features of irrigation and river control along the Lower Colorado are now understood, and engineering construction methods are thoroughly developed. The successful attempts in closing breaks along the river with rock fill barrier dams according to the method developed during the first and second closings have standardized this class of work. The Southern Pacific Company can easily, on very short notice, furnish all the equipment, men, and organization needed to do all the various classes of work involved, directly or indirectly, in controlling the river. The essential features of successful levee construction there have been made very clear. The maintenance and operation of the irrigation canals involve caring for excessive quantities of silt, and sufficient data regarding the silt problem in the Main Canal have not yet been obtained to decide on the most economical method of diversion.

The Colorado River Delta now presents no unusual, unsolved engineering difficulties; its problems are chiefly matters of statecraft, in both river control and irrigation. At the conclusion—in the near future—of existing litigation in American Imperial Valley, irrigation of the territory will be notably free from legal and managerial entanglements. This will be as soon as, and not until, reasonable treaty provisions between the two nations are arranged. Such a treaty is indispensable for the proper handling of river control work. Fortunately, both Governments profess not only willingness, but impatience, to adjust the matter.

DISCUSSION

Mr.
Le Conte.

L. J. LE CONTE, M. AM. SOC. C. E. (by letter).—This interesting paper furnishes valuable information relating to the troubles of the irrigation engineer and the irrigators. A record of the memorable struggles with flood-waters in the Colorado Delta in recent years will always be a source of valuable information.

The rich fertilizing qualities of the silty waters of the Colorado River are well known. The important point to keep in mind is the fact that the rich and desirable sediment always comes down with the first rising river waters, and the undesirable barren sandy silt during high water and the falling river stages. It follows, therefore, that the desirable silt is to be had largely from the rising river waters, and that suitable management and wise control of the scouring sluices and regulating gates at each end of the Laguna Weir are of the greatest importance in the maintenance of the entire canal system. In order to reduce silting troubles to a minimum, the mean velocity of flow throughout the entire canal system should be as nearly uniform as practicable.

For this purpose the formula given by Mr. R. G. Kennedy,* is very useful, namely:

$$\text{Velocity} = 0.84 d^{0.64},$$

hence, comparing one channel flow with another, we have practically the ratio:

$$v : v_1 :: \sqrt[3]{d^2} : \sqrt[3]{d_1^2}$$

but, after all, the main feature to keep constantly in mind is that the mean velocity varies as \sqrt{RS} , and that S is the slope of the surface of the water and not the slope of the bed of the canal. With the best of management, however, there will always be some silting up, but the silt ought to be largely of valuable character, and when dredged and deposited on the bank adjoining the county roads the farmers will eagerly cart it away for fertilizing purposes. The clean, barren, sandy silts which are so undesirable, should not be allowed to enter the head-works of the canal to any large extent. The cost of the Laguna Weir, \$434 per lin. ft., when compared with the cost of the Kistna Anicut, in India, \$104 per lin. ft., seems to be unreasonable, but such comparisons are always odious, especially when all circumstances are not known. The annual revenues from the Kistna system amount to \$1 500 000, and if the Laguna Weir system approximates this figure, in the course of events, all will be satisfied.

The author's remarks about a "rating curve" are commendable. No official record is so absolutely unreliable as the conventional rating curve for any given gauging station. It is worse than no record

* *Minutes of Proceedings, Inst. C. E., Vol. CXIX, p. 281.*

whatever, inasmuch as it is a worthless official record which will have to be officially disproved in Court before one can get authority to proceed. Experience everywhere on sedimentary rivers shows that all the cross-sections of a rising river are enormously increased in area by the scouring out effect of the down-rushing flood-waters laden only with lighter sediment. The heavy sandy sediments gradually crawl down river much more slowly than the rushing flood-waters, hence they do not show until the river begins to fall. It follows that all the cross-sections of a falling river diminish rapidly in area and return gradually to the usual low-water cross-section. These being the facts on every flood, how is it possible for any sane man to get up a rating curve which has any practical value whatever? This is particularly true in the case of a gauging station on the main river just above a large tributary stream.

Mr.
Le Conte.

When the tributary stream is in high flood, the water in the main river is not only high, but the current is often running up stream, which potent fact alone destroys completely the value of the rating curve.

The author's proposed plan of building a wide rock fill dam, without any concrete cross-walls whatever, seems to be plausible, in view of the valuable experience in closing the big breaks in the Colorado River banks leading down to the Salton Sea.

These rock fill dams have now stood the ravages of severe floods for the past 6 or 7 years, and are still intact and water-tight, for all practical purposes. The main object of the concrete cross-walls in the Indian dams is to shut off leakage through the broken-stone fill and hold the stones together. As the low-water flow of the Colorado River is small (6 000 cu. ft. per sec.), it becomes very important to hold all the water possible. If a successful, wide, water-tight dam can be made, as described, without them, all well and good. The writer is of the opinion that it is well worth trying, from a financial point of view, particularly at such a site as the Laguna Weir, where the slope per mile is only 1.2 ft.

In India, the anicuts are generally built where the slope per mile is 3.5 ft. and the river bed is pure sand of unlimited depth.

MORRIS KNOWLES, M. AM. SOC. C. E. (by letter).—This excellent and exhaustive paper is a most fascinating story of the ever-changing Colorado. The reader can almost picture himself on its banks, witnessing the frequent breaks, overlooking the vast overflows, and taking part in the repeated attempts at closure. The Engineering Profession can indeed feel gratified that it has members who will patiently chronicle events, analyze situations, and faithfully tell of failures.

Mr.
Knowles.

Much is related of irrigation needs, local causes and effects of floods, notable works built and projected for the former, the great emergency construction to overcome the latter, and studies and plans for future

Mr.
Knowles.

protection and control. Little has been said, however, of the possibilities of prevention, of great works that might be built to hold back the flood flows and let out at other times the increased quantities that would make for greater irrigation possibilities, increased navigation stages, if otherwise possible, more water for power, etc.

Within a short time, and brought to a focus by the work of the Pittsburgh Flood Commission, the country has realized that we can no longer be indifferent to the vast and universal country-wide problems of regulating the flow of our streams. Without going into details of the many correlated benefits to be obtained from storage of flood flows, the devastations of the Ohio, Missouri, and Mississippi Valleys, those of the Southern Appalachian regions, as well as those of the Pacific Coast and great Colorado, so vividly portrayed in this paper, have awakened people, all over this land, to the fact that here is an important problem to solve, in which the factors have some relation, wherever we go, and from the solving of which, much other good will come.

That this is also true of the Colorado Basin is evident from the author's remarks on pages 1206 and 1208 and from Table 2. It would be of still further interest, therefore, to know whether the storage of approximately 10 000 000 acre-ft. exhausts the possibilities on the Upper Colorado, and what effect such impounding at several selected points would have in decreasing the flood discharge and increasing the low-water flow. It is possible that it would not apparently diminish the interest and intensity of the problem of protection below Yuma, on account of the peculiar local characteristics, yet it is probable that the cost of such works would be less and safe results more certain.

If data are available to show the effects of such storage of flood peaks, as is illustrated by the Pittsburgh report, it is hoped that the author will present them in his closure. If not now obtained, perhaps this discussion may call attention to the need, and emphasize the fact that here is another place and a further reason for the Nation, by its Central Government, to take hold of its water problems as a great national question, and to study, plan, and treat each group of streams as a unit from source to mouth.

Mr.
Sellew.

FRANCIS L. SELLEW, M. AM. SOC. C. E. (by letter).—Turning the Colorado out of Salton Sea was not so much an engineering triumph as a triumph of engineers, of red-blooded fighters, who did not know when they were whipped, but realizing that the end justified the means, fought on to victory unmindful of its cost. All honor to them. The writer will go to the limit in expressing appreciation of results attained in the face of odds as great as any with which river engineers may expect to be confronted; but when the closing of this crevasse, which, from the nature of things, had to be accomplished by rough and ready

methods, is heralded as a solution of all engineering problems pertaining to the Lower Colorado, the writer's protest is immediately entered. Mr. Sellew.

Having been an innocent bystander while some of the work described was in progress, this paper has been read with much interest. The record of the operations incident to the return of the river to its former channel is extremely complete, although partly obscured by a mass of legal and financial entanglements which properly have no place in a purely engineering article.

Lack of time will confine the writer's discussion to an examination of some of the more important points. The data submitted in regard to the discharge of the stream and the degree of reservoir control possible vary materially from the writer's ideas on these subjects. It is also doubtful if the control attainable by reservoirs will greatly reduce bank caving, which is the real problem along this river. Although what follows is based on the best data in existence, it should be understood that, before definite conclusions can be drawn, much more detailed and extended examinations should be made.

FLOOD PREVENTION ON THE LOWER COLORADO.

It is apparent that if the flood discharge of the Colorado could be reduced materially, thereby bringing the fluctuations between low and high water within reasonable limits, the erosion of the bed and banks would be much reduced. There might still be a limited amount of bank protection required, but, if the control was such as to keep the river within banks, the cost of protective works would be greatly lessened. We have recently heard much about the control of streams by storage works; and, with reference to the Colorado, one advocate claims that storage near the head-waters will reduce flood levels so much that levees will be a thing of the past; that the flow of the stream may be entirely devoted to irrigation, thereby putting water on 5 000 000 acres of land; and also that immense quantities of electrical energy may be developed as the water is released from the places in which it is impounded. As the question of stream control by storage reservoirs has received much attention in most civilized portions of the earth, the writer has made a somewhat extended examination of the literature on that subject.

On page 406 of the "Report upon the Physics and Hydraulics of the Mississippi River," by Humphreys and Abbot, the following appears, in regard to the reservoir system:

"The plan, in theory, is admirable, and has long been a subject of discussion among European engineers. Artificial lakes for protection against floods were constructed as early as 1711 upon the upper Loire, and they have since been advocated, both for improving navigation and for restraining floods, by eminent writers, * * *"

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From page 407 of the same publication:

"Little consideration is necessary to make it apparent that this system is not applicable to restraining the floods of all rivers. Certain topographical conditions are essential to its success. The valley must be of such a character that dams of reasonable dimensions can be constructed, which shall keep back *the identical water which otherwise would make up the flood*. It is not sufficient for this purpose, as for improving navigation, that a large volume of water may be collected by the accumulations of months. The floods of great rivers are torrents, caused by rapidly melting snows and by widely extended and heavy rains. The greater part of this water does not drain from the remote mountain sides, and issue from the distant mountain gorges. It falls in the valley itself; and the nearer to the main river, the more sudden and disastrous will be its effects; partly from the more rapid accumulation in the main stream of the contributions of the tributaries, and partly from the absence of the natural reservoir furnished by the various channels, which must be filled before a freshet originating near the sources can reach the lower part of a river. To control such floods with certainty and economy by artificial reservoirs, it is, therefore, essential that certain important tributaries which drain relatively large portions of the basin shall debouch near their mouths from narrower gorges, where dams can be constructed at reasonable cost, and where artificial lakes can be formed without injury to other interests."

From page 408:

"In order to give a more definite character to these conclusions, they will be reduced to figures by aid of the data collected respecting the great June flood of 1858, by which the merits of all these different plans of protection are to be tested.

"To have protected 'the whole delta and the borders of every stream in it, primary or tributary' against this flood, not more than 1 050 000 cubic feet per second could have been allowed to enter the head of the alluvial region. Even this quantity would have submerged much of the lower country, had not the tributaries below the Ohio been so very low that their united contributions, joined to this amount, would only have been sufficient to maintain the river at full banks. The conditions of this flood were then the most favorable possible for the reservoir system.

"During the thirty-six days in 1858 from May 25 to June 29, inclusive, the total amount of water passing the latitude of Columbus exceeded by 648 172 800 000 cubic feet that which would have resulted from a discharge per second of 1 050 000 cubic feet. Reservoirs situated above the mouth of the Ohio, and sufficient to have kept back *in a single month* fully 600 000 000 000 cubic feet of water [14 000 000 acre-ft.] would, therefore, have been essential to the security of the delta, if this system had been depended upon for restraining this flood."

From a report on the examination of reservoir sites in Wyoming and Colorado, by Hiram M. Chittenden, M. Am. Soc. C. E., Captain (now General, Retired), Corps of Engineers, U. S. A. :*

* Annual Report, Chief of Engineers. U. S. Army, for 1898, Appendix PP, p. 2845.

"In no other portion of her works has nature left so much to be done by the engineer to supplement her deficiencies as in the modification of the natural flow of her streams, for in no other respect are her works so ill adapted to the uses of man. The ideal stream would be one in which the flow should be uniform from one year's end to the other, or, if not uniform, varying directly with the magnitude of the uses to which it is put.

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"It is not surprising, therefore, that one of the chief concerns of the engineer is the amelioration or prevention of the evils of this unfortunate arrangement of nature. Millions of dollars are annually expended to make up for the deficiency of water in seasons of drought, and like sums to prevent or alleviate the evils of excessive flow. Singularly enough, the measures generally adopted are put forward in disregard of one of the commonest rules of scientific practice. If an evil condition of things is to be corrected, the rational method of procedure is to remove the cause. In all river engineering, however, the measures adopted look only to the palliation of results, and leave the cause untouched. River channels are dredged out in low water and levees are built to protect from floods in high water. Scarcely anywhere is the effort made to prevent the occurrence of either high or low water. It would naturally follow that, if great evils result from the variable flow of streams, the primary and fundamental object of the engineer who is called upon to correct them would be to make this flow uniform. Whether or not this object is possible of realization (and if it is, by what means) is therefore one of the first questions which should be settled in any comprehensive project for the regulation of the flow of streams.

* * * * *

"* * * The only possible method by which uniformity of flow can be secured must therefore be by storing the surplus waters in seasons of flood and releasing them in seasons of drought.

"There is an additional motive for the use of reservoirs besides that of securing uniformity of flow. Over a large portion of the land area of the earth in civilized countries the climate of winter prevents any considerable use of the streams. Even if the flow were entirely uniform, that portion which takes place in the season of cold weather would mostly be lost. To derive any benefit from it, it must be stored and held over for the season of warm weather.

"These two purposes, viz., the attainment of uniformity of stream flow and the transfer of the winter supply to the summer months cover the entire argument for reservoir construction.

* * * * *

"At first thought it would seem that in storage reservoirs lies the whole solution of the river problem. To store the surplus in flood season and use it in season of drought ought apparently to strike at the root of the whole difficulty, and to render unnecessary those palliative measures which alone have hitherto received the sanction of the hydraulic engineer. Why so obvious a remedy has never yet been extensively applied will appear in the course of this report.

* * * * *

Mr.
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"It is the *cost*, not the physical difficulties, which stands in the way. It may be stated that as a general rule a sufficient amount of storage can be artificially created in the valley of any stream to rob its floods of their destructive character; but it is equally true that the benefits to be gained will not ordinarily justify the cost.*

* * * * *

"We now come to the specific question of reservoir construction in the arid region west of the one hundredth meridian, as exemplified by the reservoir sites examined in Wyoming and Colorado. Are there direct and primary motives which would justify reservoir construction in this country, apart from or in addition to those arising from their effect upon the regimen of the lower rivers? The answer must be that in no other part of the United States, nor anywhere else in the world, are there such potent and conclusive reasons, of a public as well as a private nature, for the construction of a comprehensive reservoir system as in the region here in question.†

* * * * *

"* * * in many sections the natural flow has been used as far as it is practicable to do so. The only resource left is to store that portion of the flow that runs away in nonirrigation seasons and the surplus in times of annual flood and sudden freshets and make these also available for use. Not until that is done can a stream be said to be really utilized to the fullest extent.

* * * * *

"While there are these clear and positive arguments in favor of the storage of the surplus flow of our Western streams, there are none of weight against it. It may be set down as a rule, to which there are very few exceptions, that every artificial body of water created in the West, by which the surplus water of its streams is held back, will be a positive benefit.

* * * * *

"The foregoing examination has led up to the following conclusions:

"First. A comprehensive reservoir system in the arid regions of the United States is absolutely essential to the future welfare of this portion of the national domain.

"Second. It is not possible to secure the best development of such a system except through the agency of the General Government.‡

* * * * *

"The total extent of a reservoir system in the arid regions which shall render available the entire flow of the streams will not exceed 1 161 600 000 000 cubic feet [approximately 27 000 000 acre-ft.]. If the construction of such a system were to consume a century in time, it would represent an annual storage of about 11 600 000 000 cubic feet, or 266 300 acre-feet. At \$5.37 per acre-foot this would cost \$1 430 031 per annum. This amount, distributed among the seventeen States and Territories of the arid region, gives an average annual expenditure in each of \$84 119. The annual value of the stored water

* *Loc. cit.*, p. 2860.

† *Loc. cit.*, p. 2864.

‡ *Loc. cit.*, p. 2872.

would return the original cost and maintenance in an average period of three years.”* Mr. Sellew

In a paper on “Reservoir Systems and Their Relations to Flood Protection,”† by C. O. Sherrill, Captain, Corps of Engineers, U. S. A., presented at a special meeting of the Louisiana Engineering Society on June 25th, 1912, the following appears:

“The most vital question of the moment for the people of the lower Mississippi Valley is how best to secure protection from disastrous floods, such as the one now passing, and in the proper solution of this question the sympathy and assistance of the entire country should be ready to aid. Every flood brings forth a multitude of plans, each purporting to be the only one capable of providing the necessary cure, and most of them are brought out as something entirely new, yet each one will, on examination, be found to have been carefully considered and thoroughly investigated years ago. One of these propositions, renewed recently with great energy, has been to control these floods by means of reservoirs located near the headwaters of the tributaries.

“In view of the fact that adequate reservoir systems for the control of floods in all streams would strike directly at the seat of the trouble, it seems remarkable that this method should not have been used long ago instead of the merely defensive method of elevation of overflow land or the erection of levees.

* * * * *

“* * * The question, therefore, is, Can this stream flow be made uniform; if so, how and at what cost? * * * I must answer that a reasonable degree of uniformity of flow can be secured by adequate systems of reservoirs properly located along streams where the topography is particularly adapted to such reservoirs; but as to the possibility of such control for the Mississippi below Cairo, or of the practicability of the scheme, if possible, it is hoped that the following remarks will be of some assistance in determining.”

This paper concludes:

“Taking the above brief summary of the facts into consideration, I must conclude that the control of the Mississippi floods by reservoirs is impracticable of accomplishment and that the next best thing must be relied upon, namely, the levee system with bank protection, which should be completed as rapidly as possible.”

The Pittsburgh Flood Commission, in a comprehensive and voluminous report covering a recent investigation, concluded that the maximum flood crests of the Ohio at Pittsburgh can be lowered approximately 8 ft. by the storage of about 1 000 000 acre-ft. of water, in seventeen reservoirs on the Allegheny and Monongahela, at a total cost of about \$20 000 000.

From the foregoing it appears that the desirability and practicability of reservoir construction depend on existing conditions in the drainage area of the stream under discussion; therefore, each stream

* *Loc. cit.*, p. 2878.

† *Journal. Association of Engineering Societies*, September, 1912.

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should be subject to careful analysis before definite recommendations can be made. As the Colorado receives almost its entire supply from melting snows at the head-waters, it would appear to be an ideal stream for reservoir control.

Existing Storage Works.—Before discussing the feasibility of reservoir control on the Colorado, attention is called to Tables 23 to 27, which show what has been accomplished by storage systems in various countries, with their extent and approximate cost.

Table 23 contains data on ten projects of the Reclamation Service having a total capacity of about 3 800 000 acre-ft., which have been constructed at an average cost of \$2.65 per acre-ft.

Table 24 shows other existing reservoirs in America with an aggregate storage of 2 383 500 acre-ft., built at a total cost of \$2 629 800, or an average of \$1.10 per acre-ft. In this list the storage at the head-waters of the Mississippi was by utilizing natural lakes, the outlets of which were controlled by low, inexpensive dams, the average cost being only 36 cents per acre-ft. If this system be excluded, it appears that the remainder amounts to only 283 500 acre-ft., which cost about \$6.65 per acre-ft. In this table there are also five sites in Wyoming and Colorado, suggested by Gen. Chittenden, aggregating 939 200 acre-ft., estimated to cost \$2 709 500, or an average of about \$2.90 per acre-ft. This table also shows 70 415 acre-ft. of storage in Europe and Australia, which have cost \$74 per acre-ft.

Table 25 contains data on ten works in France, having a total capacity 38 593 acre-ft. and costing \$3 518 900, or about \$91 per acre-ft. This table also shows that 38 400 acre-ft. of storage in Austria has cost \$232 per acre-ft., while in Canada reservoirs containing 3 800 000 acre-ft. are being created on numerous lakes on the Ottawa River at an estimated cost of 20 cents per acre-ft.; and further, that about 700 000 acre-ft. in South Africa have been built at an average cost of \$14 per acre-ft.

Table 26 gives a list of eleven projects in Germany, volume 488 111 acre-ft., cost \$22 449 874, or \$46 per acre-ft.; shows that Russia has 800 000 acre-ft. on the Volga (no records of cost); and that five systems in India, aggregating 775 250 acre-ft., cost \$6.77 per acre-ft. The storage of about 1 900 000 acre-ft. at the Assuan Dam, in Egypt, has cost about \$10 per acre-ft.*

The completed storage (Canada being excluded as under construction) is summed up in Table 27.

Although there are many storage dams for water supply and power in various parts of the world, they are of such relatively low capacity and high unit cost that they have no place in a discussion of this kind. The foregoing data are not submitted as complete, but include all the larger systems for river control, of which records are available

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TABLE 23.—RESERVOIRS IN THE UNITED STATES. BUILT BY THE RECLAMATION SERVICE.

Location.	Type of controlling works.	Storage, in acre-feet.	Cost.		Source of information.
			Total.	Per acre-foot.	
Arizona: Roosevelt Dam.....	Masonry.....	1 284 000	\$8 697 000	\$2.90	10th Annl. Rept., U. S. R. S.
California: East Fork.....	Concrete.....	45 600	239 000	5.25	" " "
Idaho: Deerhat.....	Earth.....	186 000	898 800	4.65	" " "
New Mexico: Carrisad.....	Earth and rock.....	47 000	220 700	4.70	" " "
Oregon: Cold Springs.....	Earth.....	50 000	442 600	8.85	" " "
Klamath.....	Rock fill.....	462 000*	130 000	0.28	" " "
South Dakota: Belle Fourche.....	Earth.....	209 700	1 123 900	5.40	" " "
Washington: Bumping Lake.....	Earth.....	34 000	410 700	12.10	" " "
Wyoming: Pathfinder.....	Masonry.....	1 023 000 +	1 098 000	1.05	" " "
Shoshone.....	Concrete.....	466 000	1 170 800	2.60	" " "
Totals		3 799 300	\$10 005 000	\$2.63	

* Lake storage.
+ Drainage area, 12 000 sq. miles.

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TABLE 24.—(Continued).

Location.	Type of controlling works.	Storage, in acre-feet.	Cost.		Source of information.
			Total.	Per acre-foot.	
MISCELLANEOUS RESERVOIRS.					
Spain:					
Villar.....	Masonry.....	13 050	\$ 890 000	\$29.80	Buckley.
Belgium:					
Gilleppe.....	Masonry.....	9 730	874 000	90.	"
Wales:					
Yrriwy.....	Masonry.....	44 680	3 334 000	75.	"
Australia:					
Boetalo.....	Concrete.....	2 945	573 300	195.	"
Totals.....		70 415	\$5 171 300	\$74.	

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TABLE 24.—VARIOUS RESERVOIRS.

Location.	Type of controlling works.	Storage, in acre-feet.	Cost.		Source of information.
			Total.	Per acre-foot.	
IN THE UNITED STATES.					
Mississippi Reservoir System.	Earth and Timber Dams....	2 100 000	\$ 750 000	\$0.36	Pittsburgh Flood Commission.
Texas:					
Reos River.....	Earth.....	82 640	170 000	2.06	Chief of Engineers, 1898, A. p. P. p. 2892.
Upper Reservoir.....	Earth.....	7 000	80 000	12.29	Chittenden Report.
Lower Reservoir.....	Earth.....	7 480	90 000	12.00	" " " " p. 2842
Colorado:					
Larimer and Weld.....	Earth.....	5 650	123 000	22.20	" " " " " " " "
Crahe la Poudre.....	Rock fill.....	8 500	110 000	31.44	" " " " " " " "
California:					
Escudido.....	Earth.....	114 755	959 800	8.97	" " " " " " " "
Cuyamaca.....	Masonry.....	22 500	264 000	11.70	" " " " " " " "
Sweetwater.....	Masonry.....	40 000	75 000	1.88	" " " " " " " "
Bear Valley.....					
Totals.....		2 383 505	\$2 629 800	\$1.10	
SUGGESTED RESERVOIRS—GEN. CHITTENDEN.					
Wyoming:					
Laramie.....	Masonry.....	414 000	\$1 418 000	\$3.42	Chittenden Report, p. 2842.
Sweetwater.....	Masonry.....	326 800	270 800	0.85	" " " " " " " "
Piney Creek.....	Masonry.....	85 400	214 600	2.52	" " " " " " " "
Colorado:					
South Platte.....	Masonry.....	67 200	540 000	8.04	" " " " " " " "
Loveland.....	Masonry.....	45 700	262 100	5.73	" " " " " " " "
Totals.....		839 200	\$2 709 500	\$2.90	

TABLE 25.—(Continued).

Location.	Type of controlling works.	Storage in acre-feet.	Cost.		Source of information.
			Total.	Per acre-foot.	
RESERVOIRS IN CANADA.					
Ottawa River.....	Three projects. Low concrete dams on numerous lakes.....	3 800 000	\$728 000	\$0.20	Pittsburgh Flood Commission.
RESERVOIRS IN SOUTH AFRICA.					
Cape Colony.....	Earth, six dams.....	55 422	\$1 700 000	\$30.80	Buckley.
	Concrete, five dams.....	44 274	2 800 000	63.20	"
Transvaal.....	Earth, one dam.....	35 000	684 000	7.20	"
	Concrete and weirs, four dams.....	505 000	4 646 000	9.20	"
Totals.....		639 696	\$9 830 000	\$14.00	

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Sellew.

Mr. Sellow.

TABLE 25.—RESERVOIRS IN FRANCE, AUSTRIA, CANADA AND SOUTH AFRICA.

Location.	Type of controlling works.	Storage in acre-feet.	Cost.		Source of information.
			Total.	Per acre-foot.	
RESERVOIRS IN FRANCE.					
Rhone River.....	Recommended as too expensive for reservoir control.				Pittsburgh Flood Commission.
Garonne River.....	Recommended for construction, but not built because of expense.				" " " "
Loire River.....	Reservoir control not applicable. Scarcity of sites.				" " " "
Seine River.....					" " " "
Furens Dam.....	Masonry, 184 ft.	1 300	\$318 000	\$244	" " " "
Ternay Dam.....	Masonry, 119 ft.	2 100	204 372	97	" " " "
Chuzon.....	Masonry.....	1 297	247 600	190	" " " "
Ban.....	Masonry.....	1 499	190 000	127	" " " "
Pas du Riol.....	Masonry.....	1 054	255 000	243	" " " "
Chartrain.....	Masonry.....	3 647	420 000	115	" " " "
Lake Ouedon.....	Earth.....	5 894	142 000	24	" " " "
Mouche.....	Masonry.....	7 011	1 008 657	143	" " " "
Liez.....	Earth.....	13 051	598 418	46	" " " "
Wassy.....	Earth.....	1 740	138 942	80	" " " "
Totals.....		98 538	\$9 518 989	\$97±	
RESERVOIRS IN AUSTRIA.					
Oder River.....	Six Reservoirs.....	5 100*	\$1 488 000	\$292	Pittsburgh Flood Commission.
Elbe and Tributaries.....	Four Projects proposed.....	13 000	2 067 000	159	" " " "
Wien River.....	Six Projects.....	10 000	3 661 000	183	" " " "
	One Project.....	1 300	1 630 000	1 292	" " " "
Totals.....		98 400	\$8 806 000	\$292±	

* Drainage area, 29 sq. miles.

TABLE 26.—RESERVOIRS IN GERMANY, RUSSIA, AND INDIA.

Location.	Type of controlling works.	Storage, in acre-feet.	Drainage area, in square miles.	Cost.		Source of information.
				Total.	Per acre-foot.	
RESERVOIRS IN GERMANY.						
Wupper River:						
Bever Valley.....	Masonry.....	2 700	9	\$348 200	\$127	Pittsburgh Flood Commission.
Linhese Valley.....	Masonry.....	2 100	4	258 800	121	"
Ruhr River:						
12 Reservoirs.....	Masonry.....	83 000	71	3 480 000	105	"
Ruhr River:						
Uffrt Reservoir.....	Masonry.....	87 000	145	1 000 000	27	"
Weiseritz River:						
Malter Reservoir.....	Masonry.....	7 000	40	883 000	126	"
Kleinhenburg Reservoir.....	Masonry.....	12 000	35	858 000	72	"
Weiser River.....	Masonry.....	184 000	552	4 500 000	27	"
Oder River:						
Glazter Neisse, Proposed.	Earth.....	82 500	906	3 840 000	47	"
Malapane Reservoir.....	Earth.....	72 000	408	2 880 000	40	"
Tributaries in Silesia.....	18 Reservoirs completed } or under construction.. }	75 000		4 817 000	68	"
Rammscheid.....	Masonry.....	811		91 154	112	"
Totals.....		488 111		\$22 448 874	\$46	Buckley.
RESERVOIRS IN RUSSIA.						
Volga Reservoirs.....	Low-damson numerous lakes.	800 000				Pittsburgh Flood Commission.
RESERVOIRS IN INDIA.						
Tansa.....	Masonry.....	52 670		\$988 000	\$18.76	Buckley.
Betwa.....	Masonry.....	36 800		180 000	4.85	"
Chamburambankum.....	Earth.....	63 780		312 000	4.89	"
Bombay:						
20 tanks.....	Earth.....	372 000	2 500±	2 090 100	5.62	"
4 tanks.....	Masonry.....	250 000	450	1 700 000	0.80	"
Totals.....		776 250		\$5 250 100	\$6.77	

Mr. Fellow.

to the writer; and it is believed that they cover the field quite thoroughly. Mr.
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It appears that the storage in the United States (which is about 50% greater than that of the rest of the world) as listed in these tables, has cost on the average only one-ninth as much per unit of volume, while the maximum cost, that of Austria, is about 116 times the average in America. The low cost of the storage created by the Reclamation Service, when compared with that of the rest of the world, is shown in a most remarkable manner.

TABLE 27.—SUMMARY OF COMPLETED RESERVOIRS.

	Acre-feet.	Cost.
FOREIGN.		
Egypt.....	1 900 000	\$19 750 000
France.....	88 598	3 518 000
Germany.....	488 111	22 498 000
Austria.....	88 400	8 896 000
Russia—no cost recorded.....	.....	.....
India.....	775 250	5 250 000
South Africa.....	699 696	9 680 000
Miscellaneous foreign.....	70 415	5 171 000
	4 010 465	\$74 913 000
$\frac{74\ 913\ 000}{4\ 010\ 465} = \$18.70 \text{ per acre-ft.}$		
UNITED STATES.		
Reclamation Service.....	8 799 800	\$10 005 000
Other systems.....	2 388 500	2 629 800
	6 182 800	\$12 684 800
$\frac{12\ 684\ 800}{6\ 182\ 800} = \text{say, } \$2.00 \text{ per acre-ft.}$		

Determining Factors.—The feasibility of controlling a stream by storage will depend largely on:

- (1) The cost, including the value of the area flooded, when compared with the benefits to be derived;
- (2) The quantity of storage required and whether sufficient volume is available.
- (3) The situation of such storage, whether it is placed so as to control properly the water-producing zone of the drainage area;
- (4) The character of the water to be impounded, whether it is clear or so charged with sediment that the silting will unduly shorten the life of the works.

Mr. Sellew. These factors, as applied to the Colorado, will be considered in the foregoing order.

The Cost.—From what has already been written, it appears that, where storage exists in the arid regions, its cost is reasonable. Assume that the cheapest sites have been taken up and that future storage will cost twice as much as that already created by the Reclamation Service (\$2.65 per acre-ft.), and we have \$5.30 per acre-ft. This is in close agreement with Gen. Chittenden, who, as previously stated, estimated \$5.35 for all storage needed in the Arid West. Of course, each site must be carefully examined, and detailed estimates must be prepared, which will no doubt vary considerably from the foregoing, but, from what has been stated, the figure given appears to be a fair and reasonable one to use in this discussion.

Volume of Storage Required.—An intelligent discussion of this phase of the matter would be greatly aided by continuous discharge measurements on the Colorado River at various points, and extending over a long period. Unfortunately, however, such measurements do not exist. The most complete records are those made at Yuma since November, 1902, by the Reclamation Service. These observations include current-meter measurements three times each week. Previous records of the flow at Yuma are based on such insufficient data—being a few scattered meter measurements from which a rating-curve was constructed—that they are of no value in this discussion. The wide variation in the quantity flowing for the same gauge height, due to the change in cross-section caused by scour, renders observations without a meter measurement practically worthless.

Table 28 shows the total discharge of the Colorado (excluding the Gila) by months, in acre-feet, the mean monthly discharge in second-feet, and also the total discharge in acre-feet per year from 1903 to 1912, inclusive. This table shows that the yearly discharge has varied from a minimum of 9 800 000 acre-ft. in 1904, to a maximum of 25 300 000 acre-ft. in 1909. The total monthly discharge has varied from a minimum of 182 500 acre-ft. in February, 1903, to a maximum of 6 397 000 acre-ft. in June, 1912.

In considering the uses of the stream for irrigation, it is proper to forecast as nearly as possible the lowest flow that is to be anticipated. In doing this, the writer has compiled Table 29, showing what may be called an "ideal minimum year", and also the monthly use of water for irrigation at Yuma. This table has been constructed by selecting from Table 28 the minimum January discharge, the minimum February discharge, etc., for all months included in the latter table. This gives a minimum year containing a total discharge of 8 315 500 acre-ft., and these discharges are shown in monthly totals on the diagram, Fig. 70.

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For the present, the duty of water in this vicinity is assumed as $5\frac{1}{2}$ acre-ft., its use being distributed throughout the year as shown in Table 29. It is hoped, and indeed expected, that this use of water will be reduced considerably as larger areas are put under cultivation and the settlers become more skilled in the application of water, but

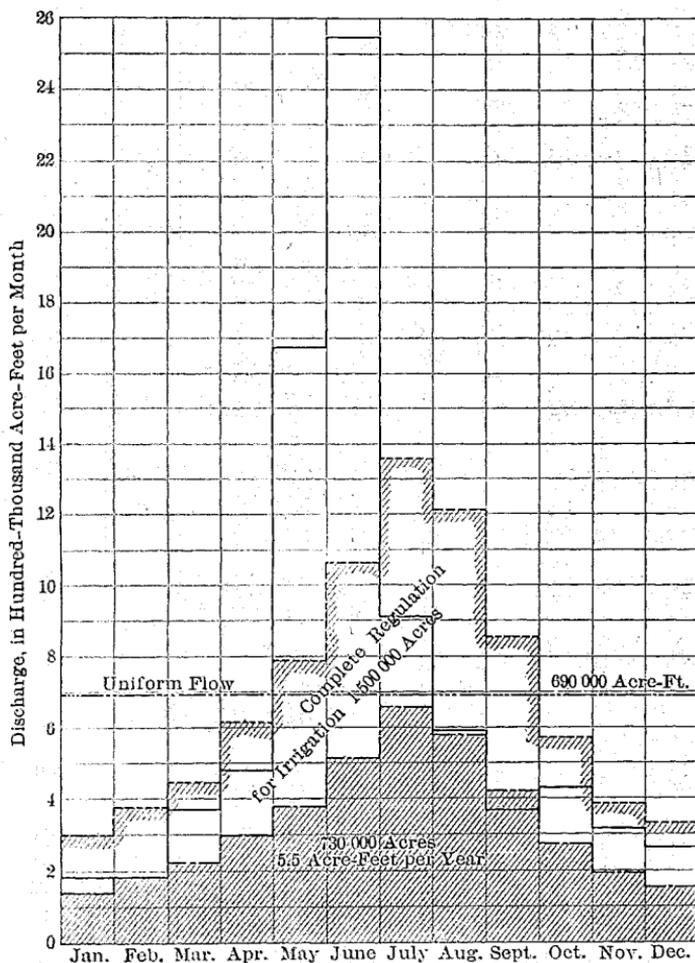


FIG. 70.

for the present this appears to be the best distribution for calculations, in view of the fact that the use now is considerably in excess of $5\frac{1}{2}$ acre-ft. On Fig. 70 is also platted the use which can be made of the stream for irrigation without any regulation whatever. This was ascertained in the following manner: The use of water in February

being about 0.25 acre-ft. and the lowest run-off in that month being 182 500 acre-ft., it was found that this quantity was sufficient for the watering of 730 000 acres. This was assumed as the limiting month. If greater areas were placed under cultivation, there would be a shortage in that month at a time when the new crops are usually going in. Taking this 730 000 acres as a basis, and plating the monthly duty in the ratio shown in Table 29, it appears that the volume of water used will be that shown by the shaded area in Fig. 70. This arrangement may create a slight shortage in September, but the use in that month is so near the minimum run-off that the danger is considered of slight importance and is neglected.

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TABLE 29.—MINIMUM MONTHLY DISCHARGE OF COLORADO RIVER AND DISCHARGE IN RATIO OF MONTHLY DUTY.

Month.	Minimum discharge, in acre-feet.	Monthly duty.	Percentage of total yearly duty.	Monthly discharge for year in ratio of duty.
January.....	185 407	0.20	3.6	302 801
February.....	182 581	0.25	4.5	378 000
March.....	387 702	0.30	5.4	453 500
April.....	479 663	0.41	7.4	619 801
May.....	1 670 000	0.52	9.4	786 100
June.....	2 550 000	0.70	12.8	1 058 100
July.....	904 476	0.90	16.4	1 360 700
August.....	591 480	0.80	14.6	1 209 500
September.....	366 948	0.56	10.3	846 701
October.....	429 428	0.38	6.9	574 500
November.....	321 271	0.26	4.7	398 150
December.....	266 598	0.22	4.0	382 651
Totals.....	8 315 504	5.50	100.0	8 315 504

It is well to remark that the continuous irrigation of 730 000 acres depends on the diversion of the entire river, and is substantially all that can be accomplished, unless the stream is regulated, even should the duty of water be increased, for it is seen that the use of water at the extremes of the year is as low as can be anticipated, and although a saving may be made in the summer months, it will allow an increase in the cultivated area only during those months, because the crops which can be grown continuously for twelve months in the year are limited by the small quantity of water available during low flow.

There is drawn on Fig. 70 a line showing the uniform flow throughout the year, which would be at the rate of 690 000 acre-ft. per month. The establishment of such uniformity in discharge would be of value in controlling the floods and also for power purposes, but it is extremely wasteful toward the irrigation interests, because this line is practically coincident with the maximum use of water in July for 730 000 acres. The reinforcement of the low flow by this method would not allow an increase in the area under crop in the summer. It would cover more ground, however, during the winter.

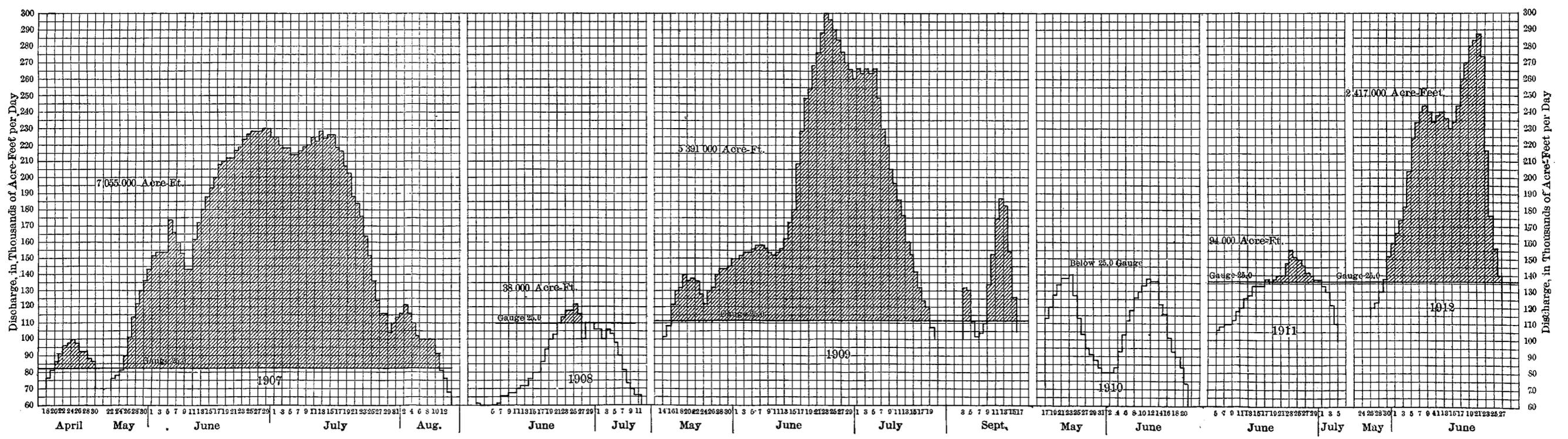
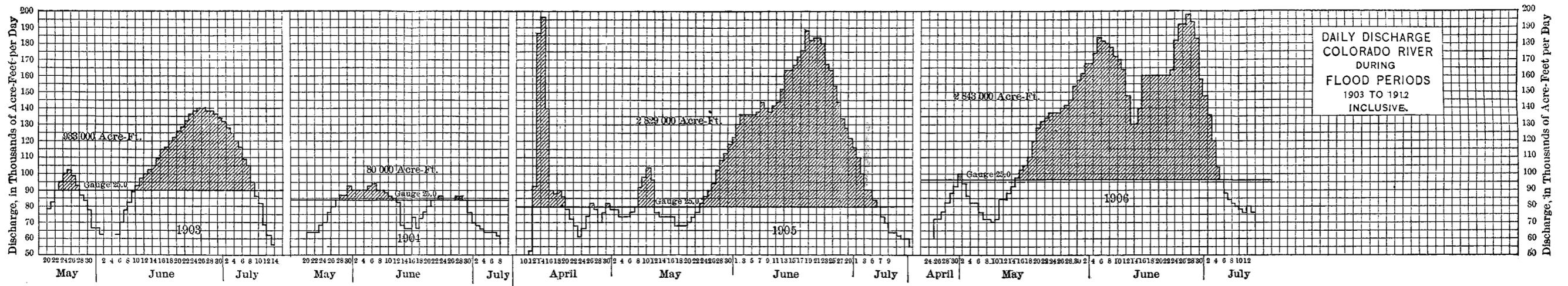
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Table 29 also shows the percentages of irrigating water required per month, and on this basis the discharge of the low-water year of 8 315 500 acre-ft. has been distributed. This assumes complete regulation of the river, entirely in the interests of irrigation, and the distribution throughout the year is shown by the shaded line. Under such regulation, 1 500 000 acres (which agrees with the author's estimate) could be irrigated. This is the area that could be served with the flow of the Colorado past Yuma as observed during the years under discussion. The lower Gila is so erratic in its discharge that it is not a very dependable supply, for which reason it is omitted. To the foregoing should be added any area existing in the upper reaches already under cultivation and which it is assumed has received its supply. To regulate the river as indicated would require a storage capacity of about 2 400 000 acre-ft., which, at \$5.30 per acre-ft., would cost \$12 720 000. Such regulation in low-water years would also have a very beneficial effect on the flood discharge. The maximum monthly volume would be about 1 400 000 acre-ft., equivalent to approximately 50 000 acre-ft. per day, or 25 000 sec-ft. The effect of this discharge on the bed and banks would be but slight, as compared with what goes on at the present time, and would keep the lower river well within its banks.

Although this amount of storage would make the river an ideal one for irrigation during periods of ordinary low flow, it would have little beneficial effect on floods in the maximum years, as will be seen from an inspection of the diagrams on Plate LV. Here the daily discharge in acre-feet during the flood periods is shown for the years 1903 to 1912, inclusive.

When the river at Yuma rises above 125 on the local gauge, overflow occurs at various points within the limits of the Yuma Project, and levees become a necessity. If the control of the stream by storage is to regulate the discharge in such a way that levees will not be required, the volume passing when the gauge is above 125 must be stored. On the diagrams referred to, a horizontal line has been drawn representing 125 on the Yuma gauge, and the volumes of discharge above this gauge height in various years are clearly marked. They were:

In 1903	933 000	acre-ft.
1904	80 000	" "
1905	2 829 000	" "
1906	2 842 000	" "
1907	7 055 000	" "
1908	38 000	" "
1909	5 391 000	" "
1910 (the gauge did not rise above 125)		
1911	94 000	" "



And in the season just passed. 2 417 000 acre-ft.

A total of 21 680 000 acre-ft., or an average of 2 168 000 " " "

for the ten-year period.

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If storage is to be created for the maximum of these quantities, 7 055 000 acre-ft.—and this is necessary if all overflow is to be prohibited along the lower river—the cost of storage, if sufficient sites existed, would be \$37 391 500, estimated at \$5.30 per acre-ft. Should this be considered an excessive provision to make, and it were thought better to take what damage would come from a flood of this kind (which might be of infrequent occurrence), and storage were provided for the next largest year, which is 1909, 5 391 000 acre-ft. would be required, which would cost, on the same basis, \$28 572 300. This would give a protection that would have been ample during the last 10 years, with one exception. If we take the average of the excess discharge at Yuma above the 125 gauge for the last 10 years, we get 2 168 000 acre-ft., which is about that required to regulate the low flow in the interests of irrigation. The cost of creating this amount of storage at \$5.30 would be \$11 490 400. With such control of the river, however, overflow would have occurred in 5 years during the last 10.

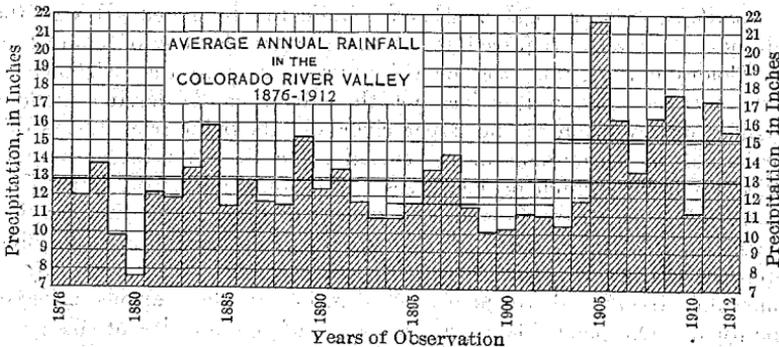


FIG. 71.

Attention is directed to Table 3, which is an exhibit of the annual discharge of the river from 1894 to 1911, inclusive, a period of 18 years. The first 9 years have an average discharge of 7 220 000 acre-ft., and the last 9 years show an average of 17 556 000 acre-ft., indicating a most remarkable, sudden, and continued increase in run-off. Such an increase might be possible with a small drainage, but, with a tributary area of more than 250 000 sq. miles, the variation appears to be altogether too much. To aid in the examination of this question, various publications of the Weather Bureau have been used in the preparation of Fig. 71. For the northern part of the water-shed, no continuous observations within the drainage area appeared to be available, there-

Mr. Sellew. fore Denver, Salt Lake City, and Cheyenne were used. These stations are probably indicative of conditions within the area under consideration. For the central and southern portions, the records of Prescott, Tucson, Yuma, Phoenix, and Flagstaff were taken. The average precipitation for the entire period is 12.92 in., shown by the heavy line. That for the period 1894 to 1902 is 11.73 in., and for 1903 to 1912 is 15.20 in. These latter amounts are indicated by the shorter and lighter lines. Thus it appears that although the run-off in the latter half of the period covered by Table 3 is about 2.4 times that of the first half, the increase in precipitation was only 1.3 times. Furthermore, it appears that the sudden increase in precipitation did not occur until 2 years after the change indicated by the table. There is no doubt that there is considerable difference in the run-off of the two periods, but it is not nearly as great as Table 3 indicates. The explanation is clear: In November, 1902, careful and systematic gaugings of the stream were inaugurated at Yuma by the Reclamation Service, and the data since collected are dependable. The data prior to that time are based on a rating-curve constructed from so few observations that the results are worthless. The first half of Table 3 should not have been presented.

Available Storage Sites.—Having indicated in a general way the volumes of storage required to attain various degrees of control of the Colorado at Yuma, the next inquiry relates to the existence of such storage. The writer has not the advantage of having made a personal examination of the upper river and its tributaries, hence this portion of the discussion must be limited to the data found in published reports to which he has access. The only authentic data found are contained in the various annual reports of the Reclamation Service, to which reference is made for more complete information. The first reference is to the Second Annual Report, page 123, "Investigations on Colorado River", where mention is made of the various schemes examined. On page 132 data are given of a dam site at Williams River, where 1 300 000 acre-ft. of storage may be created. The statement is made that investigations of a site at Bulls Head were abandoned because of poor foundation. A 100-ft. dam at this point would provide storage for 845 000 acre-ft. The lower end of Pyramid Canyon was examined. Surface conditions appeared to be favorable for a high dam, but no suitable foundation was found. If it were possible to build dams at these points, the scheme would be impractical because the reservoirs would soon be filled by the deposition of sediment, which will appear from data given later. Reference is made to this difficulty in the Second Annual Report, page 155, where we may read:

"In connection with this question of the study of reservoirs which silt up, it seems most necessary that a thorough investigation be made of the reservoir possibilities upon the head-waters of the Colorado,

above the points where the streams carrying large quantities of silt enter, so that permanent reservoirs may be established in anticipation of the time when all the irrigable lands along the Colorado will be under ditch." Mr. Sellow.

Thus the Second Annual Report shows no available storage sites for the permanent control of the river.

The Third Annual Report, page 70, has the following:

"Colorado River Storage Projects.—As it has been thought necessary to store water in the Rocky Mountain region for the regulation of the flow of the Colorado River, with a view to the reclamation of about 600 000 acres of land along the lower Colorado in Arizona and California, certain reservoir sites have been withdrawn in western Colorado, two of these being on Grand River, in Grand County, and two on Yampa River, in Routt County. Preliminary examinations have been made of all these sites, and some of them have been surveyed."

On page 217, the Kremmling site is credited with a capacity of 1 500 000 acre-ft. At Grand Lake about 23 000 acres are reported as withdrawn, but no capacity is given. Two sites on the Yampa were located and 100 000 acres withdrawn, but no capacity is given, as the data were not complete.

In the Fourth Annual Report, page 121, it is stated that at the Kremmling site more than 1 000 000 acre-ft. may be stored by a dam 180 ft. high, and that a 230-ft. dam would impound 2 200 000 acre-ft.

On page 124 reference is made to further examinations on Grand River above the Kremmling site, where it is stated that: "Few reservoir and dam sites worthy of investigation were encountered during the reconnaissance."

Reference is made to:

Windy Gap site—capacity.....	100 000	acre-ft.
Lehman site—capacity.....	24 000	" "
Grand Lake—capacity.....	140 000	" "
	264 000	acre-ft.

The first site is crossed by a railroad; would require a large dam; and 75% of the area flooded would be ranches already under cultivation. The second site would cover valuable land under cultivation, and is of slight consequence in size. Regarding Grand Lake, the report says, on page 127:

"Considered as a site for storing irrigation water for use along the lower Grand and Colorado rivers, Grand Lake, as will be readily seen from the foregoing, would be of little value."

It appears, then, that this report shows no storage sites of value except the Kremmling, with a possible capacity of 2 200 000 acre-ft.

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The Fifth Annual Report states, on page 114, that the field work in connection with reservoir sites on the Colorado was brought to a close late in 1905, and no additional examinations have been made since those described in the Fourth Annual Report. The Sixth Annual Report gives no additional information regarding this matter. On page 57 of the Seventh Annual Report reference is made to investigations for storage reservoirs along the Green River and its tributaries, from which the following is obtained:

Flaming Gorge site—capacity.....	350 000	acre-ft.
Island Park site—capacity.....	150 000	“ “
Browns Park site—capacity.....	2 500 000	“ “
	<hr/>	
	3 000 000	acre-ft.

No additional information is contained in the Eighth, Ninth, or Tenth Annual Reports.

Taking from the foregoing those sites which appear to be available for storage on the tributaries of the Colorado, we have:

	Capacity in acre-feet.
Grand River: Kremmling site.....	2 200 000
Green River: Flaming Gorge site.....	350 000
Island Park site.....	150 000
Browns Park site.....	2 500 000
	<hr/>
Total.....	5 200 000

Railroad interests have secured control of the Kremmling site, therefore its future development may prevent the creation of reservoirs of any magnitude. Such a result would remove the only known reservoir capable of controlling the Grand River, and would reduce the known available storage for uses on the Lower Colorado to 3 000 000 acre-ft., all confined to the Green. This is but little in excess of that required for minimum-year control in the interests of irrigation, and furnishes little relief in the years of maximum flow, when, as previously shown, 7 000 000 acre-ft. must be stored in order to prevent overflow, unless dependence is placed on levees. The foregoing data are not sufficient to determine with accuracy the feasibility of reservoir control on the Colorado River. Before conclusions can be properly drawn, investigation should show the total available storage, its geographical distribution, and whether it is placed so that it will control the run-off from the various parts of the catchment area. Should sufficient storage exist to save the surplus of the maximum years for use in years of low flow, the irrigable area along the Colorado could be increased correspondingly.

The Quantity of Silt.—As previously stated, reservoirs created on the lower portion of the stream would very soon fill with deposits, as

the Lower Colorado is a notorious silt carrier. Professor R. H. Forbes* Mr. Sellew. says, regarding Colorado silt:

"Beginning with January, the regular low winter water averages about 62 parts of sediment in 100 000 parts of water during January, February, and March. These sediments are probably chiefly the result of erosion upon the upper river channel, rather than surface sweepings into the drainage. During April, as the river rises with the melting snows of its highest water-shed, and its erosive power increases, the sediment rises to an average of 112 parts; during the highest waters of May and June, to an average of 374 parts; decreasing with the lowering waters of July and August to an average of 122 parts. The summer rain-storms of September, October, and November, partly within Arizona, bring the silt to its maximum (2 072 parts, Oct. 8-13), after which the quantity sinks to the normal amount for winter waters, averaging 151 parts in 100 000 during the two months ending Jan. 24, 1901.

"* * * The average acre-foot of Colorado river water for the year of observation carried 7 291 pounds of silt, varying from 1 182 to 56 410 pounds as shown by 6-day composite samples.

"On the basis of the profile constructed from available data for the volume of flow of the Colorado, and of the year's silt determinations made in this laboratory, it is estimated, conservatively, that the river during 1900 brought down about 61 000 000 tons of sedimentary material, which, condensed to the form of solid rock, is enough to cover 26.4 square miles one foot deep; or, to make 53 square miles of dry alluvial soil one foot deep; or, to make about 164 square miles of recently settled, submerged mud one foot deep, reckoning the whole amount of mud for the year to average 6.2 times the bulk of the solid sediment."

From these extracts it appears that in 1900 the volume of sediment varied from 0.062% in January, February, and March, to 0.374% in May and June, and that following desert rains it was as high as 2.07 per cent. An area of 164 sq. miles of mud 1 ft. deep equals 105 000 acre-ft. Since May, 1909, the Reclamation Service has observed the quantity of sediment passing Yuma, the results being as shown in Table 30.

TABLE 30.—QUANTITY OF SEDIMENT IN COLORADO RIVER.

Year.	Total discharge, in acre-feet.	Number of silt observations.	Average percentage of silt, by weight.	Acre-feet of submerged mud annually.
1909.....	25 967 577	8	0.65	321 010
1910.....	14 832 692	23	0.50	156 660
1911.....	17 839 245	52	1.15	391 115
1912.....	18 357 686	64	0.756	265 734
Total..	1 114 519

*Bulletin No. 44, Arizona Experiment Station, pp. 198 and 200.

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The observations of 1909, although few in number, covered the period from May 26th to October 7th, and should give a fair average. Those of 1910 extended from April 19th to December 31st. In 1911 they extended from January 11th to December 28th, and in 1912 from January 4th to November 30th, the discharge being estimated to December 31st. As shown in Table 30, the total quantity of sediment passing Yuma during the last 4 years, when measured as submerged mud, has exceeded 1 000 000 acre-ft. This proves conclusively that reservoirs for the permanent control of this stream must be placed on the head-waters where clear water exists.

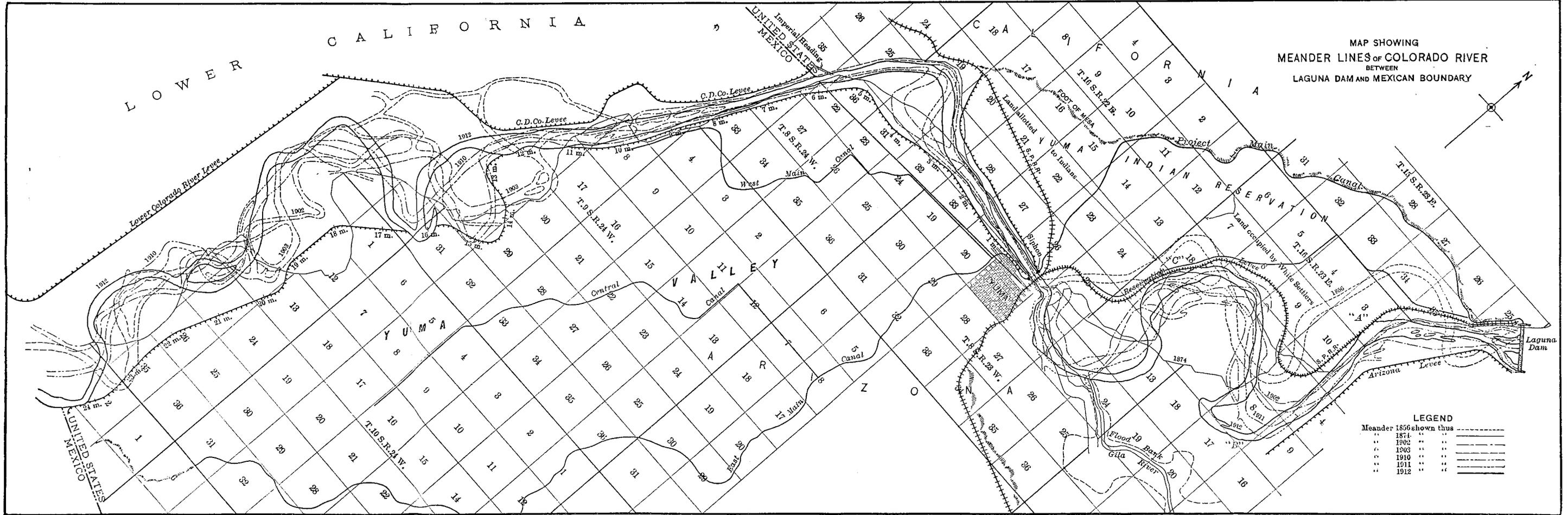
The author shows in Table 2 an approximate storage of about 10 000 000 acre-ft., and although he qualifies the table by stating that it is "theoretically possible" and would have to be reduced for "commercially feasible developments," the table is so at variance with facts as to be misleading in its present form, and likely to lead uninformed persons to erroneous conclusions. Storage on the Gila is out of the question, as this stream carries more silt during its flowing season than the Colorado. Little Colorado, Bill Williams Fork, and San Juan must be eliminated for the same reason. The Kremmling site is in the hands of interests foreign to irrigation or storage development. The only site of value contained in Table 2 is Browns Park on the Green, which has a capacity of about 2 200 000 acre-ft., as previously indicated. This analysis reduces the author's "theoretically possible" 10 150 000 acre-ft. to 2 200,000; reservoirs which will silt up in a few years or are controlled so that they cannot be developed, are not in the "possible" class.

There are some statements which the writer cannot reconcile with the facts as they have come under his notice. The area of the Yuma Project is some 130 000 acres, instead of 90 000. Table 4, showing mean monthly discharge from 1894 to 1911, is valueless, for the results from 1894 to 1903 are based on erroneous data, as previously shown.

RISE OF BED.

The data in regard to the rise of bed at Yuma are based on observations made largely by the Reclamation Service, but are not considered by the writer as sufficiently definite to justify the conclusions. Although the advance of the delta into the Gulf will tend to raise gauge heights at points above, certainly many more observations are necessary before definite relations can be established between the rise on the Yuma gauge and the memory of a steamboat captain.

There is at least one other cause for variation in gauge height at different points on the stream, which is entirely dissociated from any advance into the Gulf. There are two points on the lower river in this vicinity which may be regarded as definitely fixed. They are Laguna Dam and the conglomerate hills at Yuma between which the river



MAP SHOWING
 MEANDER LINES OF COLORADO RIVER
 BETWEEN
 LAGUNA DAM AND MEXICAN BOUNDARY

LEGEND
 Meander 1856 shown thus -----
 " 1874 " " -----
 " 1902 " " -----
 " 1903 " " -----
 " 1910 " " -----
 " 1911 " " -----
 " 1912 " " -----

passes. The floods of 1909 and 1912 carried substantially the same quantities at their crests, 150 000 sec-ft., but the difference in the elevation of water surfaces between the Yuma gauge and Laguna Dam was 4 ft. greater in 1912 than in 1909. The casual observer might think that this indicated a rise in the bed of the stream. It is found, however, that the slope per mile was substantially the same, being 1 ft. in 1909 and 1.04 ft. in 1912. The rise is not due to any silting up of the channel, but is plainly caused by the meanders of the river. The records show that the distance from Laguna Dam to Yuma has varied as follows:

In 1856	13	miles.
1895	11 $\frac{3}{4}$	"
1902	14	"
1909	13 $\frac{3}{4}$	"
1911	15 $\frac{1}{4}$	"
1912	17	"

Some of these various meanders are indicated on Plate LVI. The river in 1912 between the points mentioned was 3 $\frac{1}{4}$ miles longer than in 1909, and this accounts for practically all the increased difference of elevation in the water at the two points. The same phenomenon is true on the lower river, and, assuming a given elevation at the Mexican boundary, the increase in length of the stream due to meanders will give an increased height on the Yuma gauge, whether the river is advancing into the Gulf or not.

The author's description of the works of the Yuma Project and remarks relative thereto, indicate unfamiliarity with the subject. A very excellent account of the work at Laguna Dam may be obtained from articles* by the Resident Engineer, Edwin D. Vincent, M. Am. Soc. C. E. The Colorado Siphon has been described by the writer.† These cover the main features of the work. Levees and canals are so common, and those at Yuma present no unusual conditions, that description appears to be superfluous.

The author's statement, that a rock fill such as was used for closing the crevasses which he discusses could have been used in place of Laguna Dam, is open to serious doubt. What he built has been used as a levee, which purpose it answers admirably. How it would act as an overflow weir, carrying 150 000 sec-ft., even if covered with concrete, is problematical. In addition to a concrete top, crest and foot-walls appear to be necessary to prevent the top from being undermined, and, if these are provided, the resulting structure will not differ materially from Laguna Dam either in design or cost.

* *Engineering News*, February 27th, 1908, and June 10th, 1909.

† *Engineering News*, August 29th, 1912.

LEVEES.

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The statement that the flood of December 7th, 1906, caused levee failures on the Yuma Project due to the absence of muck-ditches, is not correct. In October, 1906, the writer took charge of the Yuma Project, and his first act was to order muck-ditches under all new levees. The slight damage done here by the flood of December 7th, was caused by burrowing animals and the overtopping of work which was incomplete.

Regarding the advantages and disadvantages of land-side and river-side borrow-pits, the writer has fully expressed himself,* so that it is not necessary to comment further. Particularly is this so when the author states that he "realized that this was not in accordance with the usual practice." Based on a personal examination made a few hours after the break of December 5th, 1906, the writer hazards the opinion that the damage caused by a head of 15 in. against the levee was due primarily to the presence of land-side borrow-pits, although small quantities of water came under the levee itself in many places due to the absence of a muck-ditch and the improper grubbing of the foundation.

Regarding the loan of a grading camp by the Reclamation Service, which outfit the author declares did work at excessive cost, the following is submitted:

Immediately following the break, in December, 1906, the writer discussed with Mr. Cory the feasibility of assembling a sufficient force to construct levees required before the coming of the annual freshet. At that time it was not known how much levee work would be done, as the surveys were incomplete. Consequently, no contracts were let, and the size of the outfit which could be immediately available was not known. Because of various interests at stake, the writer suggested that, to assist in overcoming the difficulty, one camp of Government stock then operating on the Arizona levees be transferred for the use of the California Development Company. Mr. Cory welcomed this suggestion; authority was secured from the Department; and the camp was immediately transferred. It was supposed when the transfer was made that the camp was to work for the California Development Company and not for a contractor. However, shortly after the move was made, the superintendent of the camp informed the writer that he was working under the direction of a contractor, and it was next to impossible for him to obtain the proper supplies to keep his camp up to efficiency. A visit to the camp showed the facts to be substantially as stated, and a personal appeal was made to Mr. Cory to remedy the matter. This was remedied, in a measure, but conditions continued to be such that, as soon as it was evident that the camp was

* *Engineering News*, February 15th and April 11th, 1912.

not necessary to secure the completion of the levees in advance of the annual flood, the men and equipment were brought back to the United States. Mr. Sellew.

The camp that was loaned the C. D. Co. had been at work for considerable time prior, for the Reclamation Service, and continued to be thus employed for several years thereafter. It was one of the most efficient camps which the Service has had on levee construction. There have been completed on the Yuma Project about 50 miles of levee, aggregating more than 2,600,000 cu. yd. of excavation, the accomplishment of which compares most favorably in every way with any levee work which has come under the writer's notice. Criticism of Government work seems to be a general pastime of people who are not responsible for it, and certainly if a contractor desired to place a Government camp in an unfavorable light, Mr. Cory granted him a most excellent opportunity to do so.

Under the head of "Criticism of Levee Work Done" the author shows that after a Consulting Board from the Reclamation Service had advised on the methods of levee construction, their recommendations were ignored and a second Board was necessary before the recommendation as to the location of borrow-pits was complied with. The author states that the use of the checker-board system of borrow-pits increased the cost of the work about $6\frac{3}{4}$ cents per cu. yd. Experience on the Yuma Project has shown that an increase of 2 cents per cu. yd. is ample to cover this kind of borrow-pit, and the writer believes that the protection thus afforded fully justifies the additional expense.

INTERNATIONAL NEGOTIATIONS.

International agreements are necessary to a comprehensive plan for the control of the Lower Colorado. Such agreements must be preceded by diplomatic action, and while such negotiations may be in progress, discussion of this phase of the matter appears to be inopportune.

THE ABEJAS DIVERSION.

The author is correct in the statement that this diversion has had little effect on river levels at the entrance of the Imperial Canal. The observations show that it has had no effect whatever. The writer has little first-hand knowledge of the work at the Abejas, carried out under the direction of John A. Ockerson, Past-President, Am. Soc. C. E., so does not feel qualified to discuss it. He wishes to state, however, that the delay in starting the work, due to causes over which Mr. Ockerson had no control, which exposed the operations to the menace of the flashy winter floods, had much to do with the progress. It is believed that the Ockerson plan to levee the river to the range of tidal influence is the correct one; until this is done and the levees are made

Mr. Sellew. secure against the attack of the current, the Lower Colorado cannot be regarded as under control.

THE REAL PROBLEM.

The author concludes:

"Because of the various successful and unsuccessful work done in the region, the engineering features of irrigation and river control along the Lower Colorado are now understood, and engineering construction methods are thoroughly developed.

* * * * *

"The Colorado River Delta now presents no unusual, unsolved engineering difficulties; its problems are chiefly matters of statecraft, in both river control and irrigation."

After more than 6 years of service, during which time about 45 miles of the lower river has been in his charge, the writer wishes to state that, in his judgment, the real problem of this river is not generally understood. This problem, for the solution of which the author offers no aid, is bank protection. Construction methods for its accomplishment are not developed, and it cannot be attained by statecraft, however high the talent engaged. Relief from this menace will come only from hard work and a liberal expenditure of money on the immediate banks. When levees are undermined while the stream is below bank-full stage, it is clear that many years must elapse before a river of this magnitude will be controlled by reservoirs in such a way that caving banks will be eliminated. A plan by which these banks may be made stable will now be outlined, but, before proceeding with it, a short sketch of the flood of 1912 may be of interest.

LOWER COLORADO FLOOD OF 1912.

The annual freshet of 1912 first made its appearance on the Yuma gauge on March 12th, the reading then being 117.8 ft. and the discharge 12 800 sec-ft. It continued to rise until June 22d, when the gauge was 129.1 and the discharge was nearly 150 000 sec-ft. During this rise the erosive action of the current was causing radical changes in the bed and banks of the stream, as may be seen by Fig. 72, showing conditions at the gauging station. It is there seen that at low water the width of the river was 420 ft., its average depth about 3½ ft., maximum depth 8 ft., and the area of the flowing prism 1 420 sq. ft. At the crest these dimensions had become, width 600 ft., average depth 35 ft., maximum depth 53 ft., area 20 740 sq. ft., the discharge having increased 43 times and the area about 15 times. This increase in area, of 19 320 sq. ft., is made up of 7 440 sq. ft. caused by the rise on the gauge and 11 880 sq. ft. (60%) which was the increase in section due to scour. These modifications in cross-section were probably maximum at the gauging station, where the width of the stream is restricted; but

similar changes, although less in magnitude, are characteristic of the lower river. Mr. Sellow.

During the rise, extensive meanderings were in progress at various points, the first attack which required defense being between 10½ and 12 miles below Yuma, on the Arizona side, where the levee had been cut out by the river in 1909. During 1909 and 1910 efforts were made to hold this portion of the bank with fascines and other light brush protections, but such work was soon carried out, and resort was then had to permeable dikes of piles and brush. About seventeen permeable dikes have been built, beginning in May, 1911. Some of these dikes are shown on Figs. 73 and 74. At this point the Steamer *Searchlight*, with a pile-driver barge, worked throughout the flood of 1912, building dikes and defending the bank between them with

VARIOUS CROSS-SECTIONS OF COLORADO RIVER
AT YUMA, ARIZONA, DURING 1912.

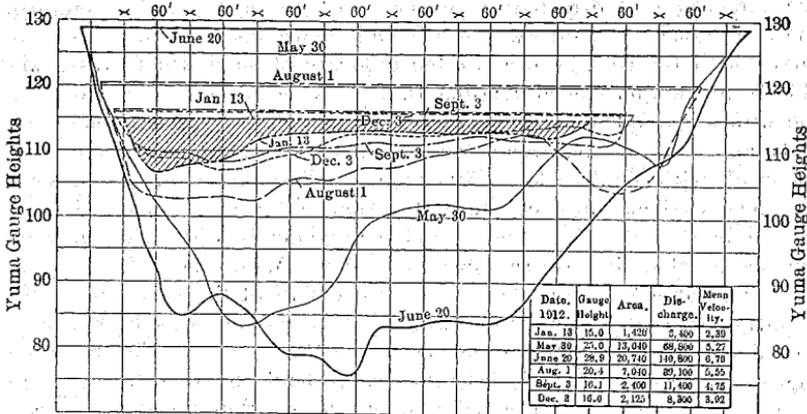


FIG. 72.

fascines. A temporary levee also was thrown up when the river threatened overflow. The efforts here were successful, the dikes holding well and preventing further recession of the bank line, and the temporary levee removed all danger from overflow.

The first attack on the Reservation levee was at the point, C, on Plate LVI. At the beginning of the rise, the bank at this point was some 800 ft. from the levee, but on June 15th bank caving set in, and on June 17th, when the river was within 150 ft., defensive operations were commenced. As all our floating plant was engaged below Yuma, the fight here had to be made from the shore. When the stream went overbank the bottoms were flooded to within 150 ft. of the levee, making defensive operations impractical until the caving reached this point. Fascine mats weighted with sand sacks were hung over the face of

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the bank, but, as the water was more than 30 ft. deep, such defenses would not reach the bottom, and, although our work delayed the advance of the stream, it was slowly undermined, demonstrating that a strong revetment would be necessary to hold the river in check. Conditions along the front at this point are shown on Fig. 75. Fortunately, the Reservation levee furnishes the location for the Potholes Branch of the Southern Pacific Railroad, therefore, rock, which was the only material that would save the day, could be delivered at the site of the works and dumped directly into place. Rocks weighing from 1 to 6 tons were ordered from the Declez granite quarries some 200 miles west of Yuma on the main line of the Southern Pacific. The railroad expedited the shipment, and within 36 hours after the order was placed the first train load, consisting of fifteen cars, was being thrown into the river. At this time the river had cut to the toe of the levee slope, the water there being 32 ft. in depth, therefore the rocks as rolled from the cars could be directed to the point where they would accomplish the most good. Considerable brush and thousands of sand sacks were mixed with the rock, also a limited quantity of spoil which was available from the quarries at Laguna Dam. As the flood came up to crest, the attack extended for a length of about 900 ft. Several bad sand boils appeared at the inner toe. Fig. 76 shows one of these boils "hooped" with sand sacks. This menace became so serious in some instances that at one time the destruction of the levee appeared to be only a matter of a few hours, and arrangements were made to confine the overflow in case the levee went out. About 500 ft. to the rear of, and parallel to, the levee is one of the canals of the Reservation distribution system. The outer bank of this channel was hastily connected with the levee above and below the threatened portion by sand-bag dams (Figs. 77 and 78), the canal bank between these dams being raised to about 1 ft. above the river level. Sand bags were necessary as the ground, because of the seepage, was under several inches of water, and stock could not be worked upon it. These dams and the canal bank would have confined the overflow to this area had the levee gone out. It was also intended to flood this enclosed area to a depth of 2 ft. or more to check the sand boils, water for this purpose being supplied from the canals, but the boils were checked by a liberal use of sacks along the front before such action was necessary. Figs. 79 and 80 show the character of the rock used for protection, and Fig. 81 is a view of the Steamer *Searchlight* engaged in dragging the larger rock from the cars with her steam capstan, the boat having been temporarily transferred for this purpose from the work below.

The flood crested at about 1 A. M. on June 23d, and then fell rapidly. By June 25th there was no further danger of overflow, but dumping the spoil, in order to blanket the outer slope and reinforce the levee, continued until August 18th.



FIG. 73.—PERMEABLE DIKES.



FIG. 74.—PERMEABLE DIKES.

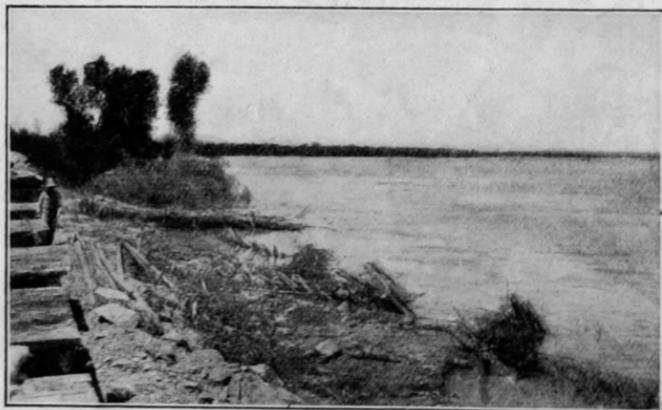


FIG. 75.—CONDITIONS ALONG THE FRONT.

While this attack was in progress, another was initiated by the river at the point, *A*, on Plate LVI. Here the caving banks came to the levee toe with a water depth of 30 ft., and the defense was practically a repetition of the one just described. Mr. Sellow.

On June 25th, the river having fallen below the overflow line, shipments of Declz rock were stopped; a steam shovel was placed in commission at Laguna Dam, and a work train and crew were obtained from the Southern Pacific Company, which, with assistance from our dinky engines, continued to dump rock and spoil at the points, *A* and *C*, until August 18th, when 18 000 cu. yd., including 1 300 cu. yd. of Declz rock, had been placed. On this date the threatened levees were safe from further attack, and the work was stopped. At the present time the river lies against the rock slope of the levee at *A* for 1 500 ft. and at *C* for 1 000 ft. Should these conditions remain until the next flood, further rock revetment will probably be necessary immediately above and below each of these points, therefore steam shovels, cars, and engines are being placed in condition to do this work if required.

While the attack on the Reservation levees was going on, rapid bank caving was also in progress on the Arizona side below Yuma. The work at the 12-mile post has already been briefly described. At the 16-mile post the river was 600 ft. from the levee on May 25th. On June 1st it had moved out to 1 300 ft. On June 10th it had returned to within 500 ft., on June 20th about 300 ft., and on June 25th it cut through the levee. When the caving had approached within 300 ft. of the levee, provisions were made to protect the work. There was no floating plant available for this protection, and, had there been, no effective use of it would have been possible, as the depth of water and velocity of the current made the construction of spur dikes impracticable. As there was no railroad on the levee, rock could not be obtained, as the roads to the nearest quarry, 12 miles away, were impassable for heavy loads. The only defense that could be offered was to protect the bank by fascine mats, there being plenty of suitable willow brush near at hand. The force employed, consisting mainly of Cocopah Indians, was rather indifferent labor, but by diligent efforts the rate of caving was delayed so much that, when it reached the levee on June 25th, the river had fallen below the natural bank level and no overflow occurred.

Shortly after the cutting out of the levee the river swung away for several hundred feet, and later came back for a portion of this distance, the present position of the river being shown by the meander line on Plate LVI.

About July 1st, the river being well within its banks, the patrol which had been maintained during the flood was removed. On this date no serious cutting appeared at any point between Yuma and the International Boundary Line, on the American side of the stream.

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On August 10th it was found that the river had cut through the levee at the 24-mile point, but the bank here being above the river level, no overflow had occurred. On June 20th, or a few days prior to the crest of the flood, the bank at this point was 1 300 ft. away from the river, and there appeared to have been no material change on July 1st, when the patrol was taken off; thus it appears that the caving here must have been extremely rapid.

All work of bank protection was continuous, day and night, while the danger of overflow existed. During this period the temperature in the day averaged 106° and at night about 73 degrees. Because of the extreme heat, the work was very hard on the men, and at times our efforts were greatly hampered by lack of labor. All the Indians in the vicinity were pressed into service. Wages were temporarily increased to attract idle men in the Town of Yuma, and on the Reservation the settlers whose lands were threatened turned out practically to a man and fought valiantly in the defense of their homes.

FUTURE BANK PROTECTION.

The work of bank protection should be directed:

- (1) Toward holding existing levees and regaining lost ground, in order that work which has been destroyed may be rebuilt near its original position, thus maintaining as nearly as possible the irrigable area;
- (2) To cause the river to occupy a position about midway between the levees in order to prevent, if possible, the erosion of one season from reaching the embankments; or the river slopes of the levee should be made impregnable to river attack.

It is also desirable, in order to prevent meandering—which, as shown previously, may result in a rise in plane—to confine the stream to the shortest route consistent with a fall of about 1 ft. per mile.

Regarding the recovery of lost ground, the writer is aware that the building of levees on their old locations has not been generally practiced. The following, relating to the Mississippi, is from *Occasional Papers No. 41*, Engineer School, U. S. A., page 278:

Location.—The two objects of levees, protection of land and concentration of flood discharge, will be most efficiently obtained by building the levees as close as possible to the river bank, and, as owing to the general slope of the bottom land, the banks are usually higher than the land farther back, their location close to the river satisfies generally the two conditions of maximum usefulness and minimum cost, and if the river were straight and its banks stable no better location could be sought; but the river is not straight and the banks cave rapidly, and a location close to the river therefore has some disadvantages. On some of the long points of the river a levee following the bank will have, compared with a line across the point, a length



FIG. 76.—SAND "BOILS" HOOPED WITH SAND SACKS.

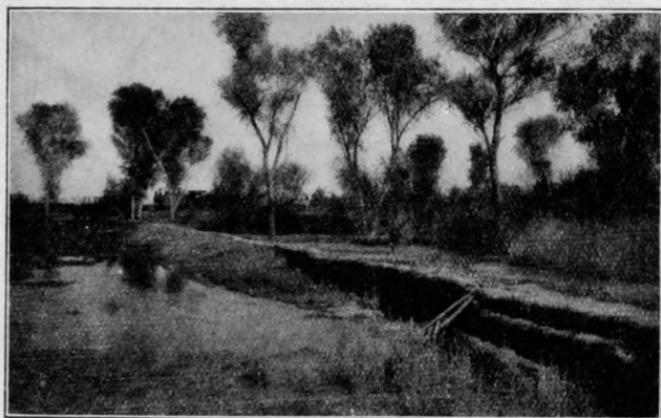


FIG. 77.—SAND-BAG DAM.

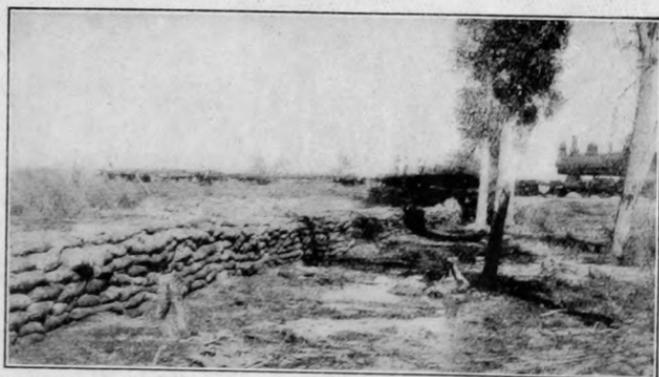


FIG. 78.—SAND-BAG DAM.

not justified by the small additional amount of land protected. In a rapidly caving bend a levee close to the river bank must in a short time be destroyed. Complications are also frequently introduced by the existence of the old river lakes caused by cut-offs. The short and direct line would pass between the lake and the river, but such a location requires usually a high and large levee and involves danger from the nature of the soil recently deposited in the old river bed and the probable existence of permeable sub-strata liable to be washed out by hydraulic pressure during floods. On the other hand, the line around the lake, though safe, is apt to be of extreme length.

"The question of levee location is, therefore, not a simple matter and should receive careful consideration, but such consideration has, unfortunately, not been always given to it. Most of the existing levees have grown up gradually by the incorporation in the main system and successive enlargement of old levees built by private parties for their own protection, and the location of these old levees, having been made without any reference to a general system, is, of course, in many cases, faulty. Even where the levee has been built entirely anew the location has been most usually fixed by the local boards, who are, of course, subject to local influences, and many levees have thus been located too close to a caving bank, in order to include special farms.

"But even when a new levee is to be located with reference only to its general use, the question is not an easy one. If the banks of the river cave with any regularity, the cost of a new levee and its life in any location could be balanced against the value of the additional protection obtained by this location. But the caving does not go on with any sort of regularity; some places that may not have caved for years will suddenly begin to cave rapidly, and at other places where caving has long been going on the caving will sometimes somewhat suddenly cease. In placing levees near caving banks, therefore, a careful study must be made of the locality and of the river for some miles above, and, in general, it is considered a good location for the levee if this study indicates a probable life of about twenty years."

Although 20 years was formerly considered economic practice on the Mississippi, recent developments have modified it, as shown by the following:*

"It is the judgment of the Commission that these revetment works and some others which will be imperative within a short time are required for the preservation of the levee system. Without them a permanently completed system will be impossible. The increasing height and cost of the levees and the rapid development of the country protected by them greatly augment the disaster of crevasses. A break in an embankment 5 or 6 feet high resulting in the thin overflow of a sparsely populated country is a small calamity compared with a break in a levee 20 feet high, discharging over a thickly populated country threaded with railroads and filled with towns and factories. Owing to the increased height now necessary to control the floods the expense of replacing an undermined levee by a new line going far around a lake or impassable swamp is enormous. The point of development

* Report of Mississippi River Commission, Appendix PPP—Chief of Engineers, 1908, p. 2655.

Mr. Sellow. has come at which the only economical way to maintain the levees is to hold the banks against caving—not everywhere, but in all places where the special conditions exist which have just been described. This is a distinct stage of the work only recently reached.”

The area protected by the Colorado levees will be occupied by farms of rather small area, and consequently a comparatively large population will be dependent on them. Intensive farming will be practiced, and the preparation of the land will be expensive, therefore it appears that overflow should be prevented by all possible safeguards. The integrity of the levee system will depend principally on bank protection. There are two general methods by which this may be accomplished: (1) to give the bank a revetment which will protect it against erosion; (2) to keep the main current away from the banks, so that erosion cannot occur.

Revetment may be continuous throughout the river, or salient points which are strongly attacked may be treated first, the work being extended as occasion demands. The most extensive revetment in the United States, if not in the world, is to be found along the Mississippi River and its tributaries, where the General and State Governments and local levee boards have engaged in protective works for many years. The standard revetment consists of a woven brush mat or fascine mattress protecting the bed of the stream for a short distance from the shore and the side of the channel below low water. Above low water, where brush deteriorates rapidly, the bank is graded to a uniform slope and paved with rock. Such work is very expensive.

The magnitude of bank protection and river control on a large stream is seen in a “Report by a Special Board of Engineers on a Survey of the Mississippi from St. Louis to its Mouth,”* with a view to obtaining a channel 14 ft. deep and of suitable width. On page 52 it is stated that up to the date of the report, 1909, there had been expended by the General Government on the Mississippi from the mouth of the Missouri to the head of the Passes more than \$88 000 000. In addition, there had been some millions spent by the riparian States and local levee boards.

Reference is again made to *Occasional Papers No. 41*, Engineer School, U. S. A., being “A Résumé of Operations in the First and Second Districts of the Mississippi Improvement, 1882-1901.” This material, which covers the work done by the National Government under the direction of the Army Engineers, has been compiled in detail by E. Eveleth Winslow, Major, Corps of Engineers:

(From page 45): “It is now considered settled that in a plan for the permanent improvement of the channel by the contraction of its low-water width, the work of bank protection should precede the permeable dikes and other structures of that class, and that the latter

* Doc. 50, 61st Congress, 1st Session.

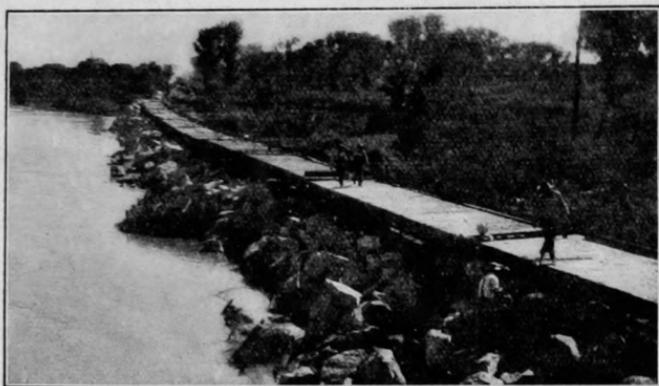


FIG. 79.—SIZE OF ROCK USED FOR PROTECTION.

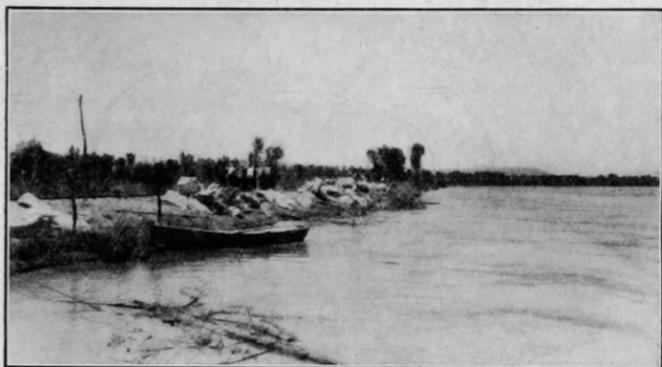


FIG. 80.—LEVEE PROTECTED BY ROCK.



FIG. 81.—STEAMER "SEARCHLIGHT" DRAGGING LARGE ROCKS FROM CARS.

may be regarded as supplementary in functions and as necessary only in a minority of cases." Mr. Sellow.

(From page 47): "It was recognized from the beginning of the Commission's work that the construction of works of bank protection and channel contraction in detached reaches would be subject to influences more or less unfavorable from changes in unprotected bends above. In commencing work in the detached reaches of Plum Point and Lake Province, the Commission was not oblivious of this fact, but was influenced by the other considerations which seemed to overbalance this disadvantage, and it has not since seen good reason to doubt the wisdom of that decision. But the experience gained in those reaches emphasized the fact that it is highly important in any project for general and permanent bank protection to leave no unprotected reaches above the work done from changes in which new conditions may be produced in improved parts of the river. And it is considered by the Commission that in undertaking a complete and permanent system of bank protection the work ought to begin at the upper end of the river at or near Cairo and be carried thence down-stream with substantial continuity. * * *

"It is considered that the annual cost of maintenance of completed work could not be estimated at less than ten per cent of the original expenditure."

(From page 233): "The object of bank revetment is to protect the banks of the river from destruction by the currents. The active agency in this bank destruction is erosion, and bank revetment must therefore prevent this erosion. Perhaps the easiest and most obvious method of doing this is by laying over the exposed surface of the erodable bank a non-erodable covering, and this is the method adopted. This non-erodable covering must, of course, be fairly durable, must have sufficient strength to withstand any strain put upon it, and must be free from interstices through which scour might take place.

"Owing to the fluctuations in the river, the different parts of the bank are subjected to different conditions. Below the low-water line the bank is always wet; above that line sometimes wet and sometimes dry, and this difference in conditions allows, if it does not require, that the portion of the bank above and below low water be treated differently.

"Above low water the bank can be seen and the non-erodable covering can be laid with ease, and it has been found that here a properly laid stone pavement forms an efficient protection. The individual stones of this paving must, of course, be so large that they cannot be moved by the current, and it was found by experience that stones of this size are not of themselves sufficient, as through their interstices scour could take place when the bank was sandy and the current strong. This has been prevented by first covering the bank with a layer of spalls or crushed rock of such thickness and closeness as to prevent scour through them and to hold this down with a layer of larger stone. Such protection, when carefully laid, has been proven to be all that is required for the upper bank.

"Below low water the conditions are different. As it is impossible to construct the non-erodable covering actually in place, the next

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best thing is done, constructing it on the surface of the water above where it is to lie, and when constructed sinking it. In this way the continuity of the covering can be assured, and it can be placed exactly where it is needed. As has been stated, this covering must not contain interstices through which scour can take place, for in such a case not only would the purpose of the covering not be fulfilled, but by such scour its own eventual destruction would be assured.

"The covering actually used has been a mattress of brush and the only kind that has been found to prevent scour in very rapid currents is the fascine mattress. In moderate currents another type of mattress might do, but as changes in current conditions are always likely to happen the fascine mattress only should be used."

(From page 256): "In the early work brush was used as a covering for the upper bank, but, subject as it was here to alternate submergence in the water and exposure to the atmosphere, it decayed rapidly and possessed little strength after about two seasons, and it was this rapid decay of the brush permitting it to be easily broken up and exposing the bank to erosion, that led to its disuse and the substitution for it of an all-stone covering."

(From page 260): "It is probably safe to estimate that a fascine mat built of small brush will be effective for at least twenty-five years and that when a good proportion of large brush is used its life will be considerably extended."

Applying these principles at Yuma, revetment should begin at Laguna Dam and proceed continuously down stream, leaving no unprotected caving banks above completed work.

The portion of the revetment lying above low water should be constructed by grading the bank to about a 3 to 1 slope and paving it with rock. This is necessary, as any brush work laid on this portion of the bank, being subject to alternate periods of submergence and exposure to the air, will deteriorate in about two seasons and be of little use in holding the bank. Below the low-water mark, the sides of the channel and the bottom for 50 ft. from shore should be protected by a fascine mattress. Assuming that the gauge oscillation along the stream is about 12 ft., a slope of 3 to 1 for this height would give an exposed bank of about 38 ft., and, with a stone paving 2 ft. thick, would require 76 cu. ft., or, say, 3 cu. yd. of rock per lin. ft. of bank. By using the quarries at Laguna Dam and Pilot Knob, delivering the stone into barges, and then towing the material into place for use, a fair estimate for the material in place on the bank will be about \$2 per cu. yd., or \$6 per lin. ft. of bank. In addition, assume that brush mattress will cost about \$4 per lin. ft., making a total for revetment of \$10 per lin. ft. of bank, or \$50 000 per mile. The distance from Laguna to the Mexican boundary is about 45 miles, and probably at least two-thirds of this distance, or 30 miles, will require continuous revetment. At a cost of \$50 000 per mile of bank

or \$100 000 per mile of river, 30 miles of revetment would cost about \$3 000 000. Mr.
Sellew.

The foregoing quotations from the Mississippi reports state that the annual maintenance of bank revetment should not be taken at less than 10% of the original cost, which means that expenditures for this purpose must be duplicated each 10 years.

S. Waters Fox, M. Am. Soc. C. E., an assistant engineer in charge of some of the Missouri River improvements, states* that 45 miles of the alluvial portion of that stream had been improved at a cost of \$2 500 000, or about \$56 000 per mile. The division of this cost was stated by him as follows:

Actual construction.....	67 per cent.
Care of, repairs, and moving plant.....	22 " "
Administration	9 " "
Other items.....	2 " "
	100 per cent.

It is thus seen that, in this particular case, the cost of maintenance was more than double that assumed for the Colorado. Another thing to be considered in the matter of bank protection is the source of the material to be used. The supply of rock in the quarries at Laguna Dam and at Pilot Knob is abundant, but the same cannot be said regarding the brush, which for the best results, should be young, live willow. In *Occasional Papers No. 41*, Engineer School, U. S. A., previously referred to, the following appears on page 46, in an extract from reports of the Mississippi River Commission:

"Another fact now definitely settled is that in the construction of mattresses of the type now employed on a large scale, the supply of material becomes an element of the problem presenting serious difficulty. The area of willow-producing bar necessary to supply material for a mile of fascine mattress 300 feet wide is practically five times as great as that required for an equal length of mattress built in the early years of the work. The quantity of small willow growth used in this form of mattress is so great that the estimate of the yearly supply available along the whole length of the river from Cairo to Vicksburg is not more than sufficient for the making of 15 miles per annum of bank revetment."

The writer is not aware how the growth of willow along the Colorado compares with that along the Mississippi between Cairo and Vicksburg, but will assume for the present that the quantities are about equal. The assumption will also be made that the quantity required for the Colorado will not be more than one-third as much as that on the Mississippi; therefore, if 600 miles of river provide for 15 miles of revetment on the Mississippi, it would provide for 45 miles

* *Transactions, Am. Soc. C. E.*, Vol. LIV., p. 280.

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on the Colorado. If 600 miles of river will furnish material for 45 miles of revetment, then 45 miles of river between Laguna Dam and the International Boundary would provide for about $3\frac{1}{2}$ miles of such work annually. In the 30 miles of stream to which it is suggested the revetment be applied there would be 60 miles of revetted bank, and at $3\frac{1}{2}$ miles per year it would require 17 years to build this revetment with the ordinary growth. This makes no allowance for the annual repairs, which are estimated at 10 per cent. It would also be impracticable, even with the material available, to construct this revetment immediately, not only on account of the constructive difficulties of doing so much work in a short space of time, for the control of the stream by revetting its banks and contracting its channel must necessarily be slow because the changes which these works bring about cannot occur immediately. On this point the writer quotes from *Occasional Papers* previously mentioned, page 41:

(From the Mississippi River Commission's report for 1889): "This work is still incomplete, although its feasibility and value have, it is thought, been fairly demonstrated. It is, however, well understood now that it is likely to prove a slower process than was at first supposed, for the work cannot be hurried. It must be gradual and progressive."

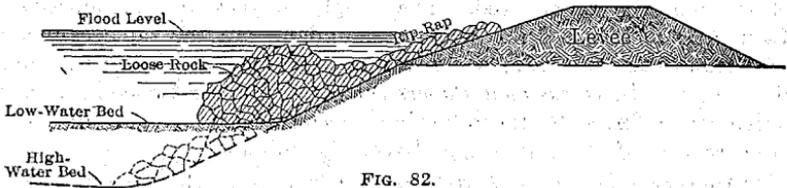


FIG. 82.

Seventeen years is entirely too long a period over which to stretch this work, as the protection of the Government's investment and the welfare of the settlers demand that the control of the river be almost immediate.

The radical difference between the high-water and the low-water channels of the Colorado furnish another obstacle to the foregoing form of bank protection. An examination of the diagram (Fig. 72) shows, that while protection of the upper bank by the rip-rap could be readily accomplished, it would be impossible to place the fascine mattress in the proper position. At low water, when conditions are favorable for mattress work, the channel is so silted up that a mattress sunk in position would not even approximate the place it should occupy to protect the flood channel from erosion. At high water, when the channel is scoured out and the bank to be protected is exposed, the depth of water and the velocity of the current are too great to accomplish work of this class successfully.

From the foregoing it appears that mattress revetment below low water, combined with rock revetment above, should not be applied along the Lower Colorado, for the following reasons: Mr. Sellow.

- (1) The high first cost and excessive cost of maintenance (10%);
- (2) The time required (17 years) for the natural growth to produce the willows necessary for this form of protection;
- (3) The impossibility of placing the mattress in its proper position, due to the silted condition of the stream at those seasons when depth and velocity are favorable for such work; and
- (4) That in great floods a concentrated attack might destroy a portion of the mattress at a time when its repair or the protection of the bank thus exposed would be impossible.

Rock Revetment.—Another method of protecting the bank would be to make the revetment entirely of rock. At low water the exposed slope would be graded, properly rip-rapped, and at the foot of this slope a large quantity of loose rock would be placed (Fig. 82). As the high-water channel was created by the scour of the current, this loose rock would be undermined and gradually slide into position, making a revetment along the bank thus exposed which would be practically a permanent protection. In approximating the cost of such work, let it be assumed that the average depth along the levee during high water will be about 20 ft. It is known that at exposed points where severe cutting has been in progress it has been as much as 32 ft., but, for a general average depth to which revetment should extend, 20 ft. appears to be safe. Suppose that the rock will stand at a slope of 2 to 1; then the length of the revetted slope in contact with the water will be 45 ft., and, if the revetment is 2 ft. thick, the area of the section will be 90 ft. Assuming that, owing to wasteful methods by which this is applied, one-half is lost, then the sectional area of rock per linear foot which has to be placed along the levee is 135 sq. ft., or 5 cu. yd., or 25 000 cu. yd. per mile of bank, equal to 50 000 cu. yd. per mile of river. For 30 miles this would mean the placing of about 1 500 000 cu. yd. of material.

Should such a course be adopted, quarries would be opened on each side of the river at Laguna Dam, which, by connecting railroads, would supply the levees within economic reach. Another quarry at Indian Hill, opposite Yuma, would serve for the portions above and below for proper distances, while quarries at Pilot Knob would control the remainder on the California side. From this latter point, a temporary trestle, which appears to be the best arrangement, would connect with the Yuma Valley levee, on the Arizona side of the Colorado. Later, if it was decided to extend similar treatment to the Gila levees, the Arizona quarry at Laguna Dam would control the levee on the north side of the stream, and the south levee could be reached from

Mr. Penitentiary Hill. Considering now only the embankments along the Colorado, it appears that the suggested treatment will require a railroad over their entire length, which is about 60 miles. These levees are already in existence, and the cost of equipping them with track (52-lb. rails) is estimated as follows:

Cost per mile of railroad on existing levee:	
Steel, 52-lb. = 90 tons, at \$30.....	\$2 700
Fastenings	600
Ties, 2 600, at \$1.25.....	3 250
Track laying.....	400
Train service.....	125
	<hr/>
(Say, \$7 000 per mile).....	\$7 075

There is a railroad on the Reservation levee between Yuma and Laguna Dam, and deducting this length of 13 miles from the 60 miles required leaves 47 miles to be built. At \$7 000 per mile this cost would be \$329 000, to which may be added about \$10 000 for the Pilot Knob trestle, giving a total for railroad construction of, say, \$340 000. The average length of haul from these quarries will approximate 15 miles, and it should be done for not more than 1½ cents per ton-mile. The 1 500 000 cu. yd. will equal about 3 000 000 tons, and with an average haul of 15 miles, gives 45 000 000 ton-miles, which at 1½ cents equals \$675 000. Using large steam shovels, quarries with long and high faces, mined with small tunnels in which heavy charges are used, it would appear that the material could be placed on the cars at an outside price of 30 cents per cu. yd.; to this should be added, say, 25 cents per cu. yd. for spreading and placing the rock on the slope, giving 55 cents per cu. yd. as the cost above that of hauling. At 55 cents, 1 500 000 cu. yd. would cost \$825 000, which, added to the expense of hauling, makes a total charge of \$1 500 000, which is increased to \$1 840 000 when the cost of building the railroad is included. Adding 10% for contingencies and repairs gives a round sum of \$2 000 000 for protecting 30 miles of river, or about \$66 000 per mile, equivalent to \$33 000 per mile of bank.

Although these estimates must be considered as approximations, it appears that permanent rock revetment can be had for not more than one in which mattresses are used, and probably for less. The permanence of the rock, its slight maintenance cost, the ample quantity available, and the fact that it can be placed as well during attack at high water as at low, makes it the best and most economic protection for the banks of the river between Laguna Dam and the Mexican boundary. Once the tracks were on the levee, exposed points could be quickly protected, and the remainder of the work could proceed as desired.

By Deflecting Currents.—Bank protection by deflecting the currents away from the shore so that erosion cannot occur may be done by spur-dikes or by opening channels across sand-bars which are the cause of the impingement. The deflection of currents by brush dikes has been tried in many localities and with varying degrees of success. They are subject to destruction by the natural course of deterioration, by deep scour which occurs around their outer ends, and by the undercutting of eddies below them which they have created. They have been tried sufficiently along the Lower Colorado under the writer's direction to demonstrate that at best they are only a temporary expedient. If built of cottonwood piling, which grows along the banks of the stream, their life would not exceed $2\frac{1}{2}$ or 3 years as the maximum; probably the average is not more than 2 years. Constructed of fir piling, they could be depended on for 6 or 7 years. If, at the end of that time, the new banks which had been created by silting between them were not protected by revetment, it is probable that the dikes would need renewal, in order to hold the work. One other disadvantage of spur-dikes is that the proper location for them is demonstrated only by the varying attack of the river, and, when this attack comes on, the water is generally so deep and the currents so swift that the dikes cannot be built. It is then necessary to defend them as best one can until lower water, and perhaps, on the falling stage, the river changes its point of attack; so that dikes are needed in other places. In the writer's judgment, protection by spurs should be used only in an emergency; they have no place in any permanent form of bank protection on this river.

Mr.
Sellew.

Dredging.—There remains the method of diverting the current by opening up channels across sand-bars. Wherever the banks have been attacked, the impingement has been caused directly by the formation of deposits on the opposite side of the stream. As these deposits build out toward the opposite bank, the flowing prism of the river is narrowed, the concentration of the water increases the velocity, the channel is correspondingly deepened, and, as a result, there is deep water and high velocity against a caving bank. Under such conditions, if it were possible to open up a channel of sufficient dimensions across this bar, and if the current could be induced to follow this new channel, the attack on the bank would be immediately relieved. In some instances, where the encroaching bar is short and other conditions are favorable, channels have been opened up and relief secured by a liberal use of dynamite. Such a method is impracticable in most cases along the river. It is seldom that a condition occurs that can be relieved by explosives.

The following is taken from *Occasional Papers No. 41*, page 44:

"The experience with the revetment work previously done had shown it to be inadequate for the purpose, and rapid changes of type

Mr.
Sellow.

were not made until there was developed the standard of the present day: A fascine subaqueous mattress with upper bank paving of stone. But as the revetment work had gradually been increased in strength, it had also increased in cost, until in the new standard type the cost had reached about \$30 per linear foot of bank, or approximately \$150 000 per mile.

"As the large cost of a systematic improvement of the whole river became evident, the Commission was led to investigate means for temporarily improving navigation during the low-water season. The principal obstructions met with are the sand bars built up during high stages, through which the river slowly cuts a channel as the flood recedes. If this process could be assisted and hastened, navigation would be improved thereby, and to this end experiments were made with dredges. These experiments, started in 1894, were successful and as a result the Commission was led to reconsider the whole subject of the river improvement, and as a result of this study the Commission decided to adopt a new plan for future operations, namely, to depend for the relief of the immediate needs of navigation upon dredging, and to restrict the improvement by bank revetment to special localities, where local interests or necessities demanded it."

(From page 46): "From all these facts together it became apparent several years ago—not all at once, but gradually, as facts accumulated and the deduction of experience was unfolded—that it was not possible by any or all of the methods which had been employed to accomplish such permanent improvement of the river from Cairo down as was necessary to meet the urgent demands of commerce within any reasonable time to come. It was this disagreeable but unavoidable conclusion from the work of preceding years, together with the recent and wonderful development of the hydraulic dredge, that led the Commission to undertake the experiments of dredging the bars of the river with the view to the temporary improvement of its low-water channel which has been detailed in recent reports of the Commission and to which more extended reference is made elsewhere in this report. Those experiments have proceeded favorably so far as to hold out a reasonable probability of entire success."

A suction dredge of large capacity and light draft which could be maneuvered in the Colorado during flood stages would be of value in opening channels across sand-bars. During low water the dredge could be used in creating a channel about midway between the levees at those points where attack from caving banks was imminent. The excavated material could be deposited in the vicinity of the levee through pipes carried on pontoons, thereby building the banks and making their alignment more regular.

It might appear at first thought that the quantity of material to be moved would require a dredge of unheard-of proportions, and that the expense would be prohibitive, but such work appears to be well within the range of the hydraulic dredges as developed for work on the Mississippi River, the largest of which have a capacity of 2 000 cu. yd. per hour. About one-third of their time is lost in tie-ups for

repairs during high water, maneuvering for position on bars, and in change of position, so that throughout the year the dredge would operate not more than 240 days, or 5 760 hours. Such operation of the dredge would result in removing about 11 000 000 cu. yd. of material. Mr. Sellew.

Assuming a low-water discharge of 4 500 sec-ft., passing Yuma with a velocity of 3 ft. per sec., the area of the flowing prism would be 1 500 sq. ft. If this was excavated, with a depth of 5 ft. and a width of 300 ft., the 45 miles of such channel between Laguna Dam and the Sonora line would contain about 12 400 000 cu. yd. It is clear that no such quantity of excavation will ever be required along the lower river in any one season, therefore the dredge under discussion has ample capacity. The questions to be examined are: (1) its cost; (2) whether it can be designed of dimensions which will allow it to navigate the shallow and tortuous channels of the Colorado; and (3) whether it can be operated during floods for opening channels across the bars.

Referring to Document 50, 61st Congress, page 55, where is shown a memorandum of a project for maintaining by hydraulic dredging alone a navigable channel, 14 ft. deep and 500 ft. wide, between St. Louis and the mouth of the Ohio River: The estimates provide for 20 dredges, each with a capacity of 2 000 cu. yd. per hour, to cost, with all attendant floating plant, tools, auxiliaries, etc., \$6 000 000, or \$300 000 per dredge. The annual maintenance is stated as \$100 000 per dredge. In estimating the cost of a dredge, its life is here assumed as 20 years, and a sinking fund is provided for its renewal at the end of that time.

Estimated Annual Cost of Dredges.

Interest at 3% on \$300 000.....	\$9 000
Annual maintenance.....	100 000
Sinking fund.....	11 166

\$120 166

The maintenance of the channel by dredging would require continuous work, year after year, no permanent results being obtained. In about 16 years the sum of the annual maintenance would equal the estimated cost of the rock revetment, and the maintenance, capitalized at 3%, gives an amount double that for which it appears a safe and permanent bank protection may be obtained. Whether or not a dredge can be built to satisfy the local conditions cannot be stated from the data at hand, but as such operations will cost double those necessary for permanent bank protection, further examination in this direction appears to be needless.

Mr.
Sellew.

CONCLUSIONS.

The purpose of this discussion is to indicate in a general way the present conditions along the Lower Colorado, and to point out, from an analysis of the data here assembled, the future course which will probably be productive of the best results. It appears:

(1) That in their present state, the levees are at the mercy of the meanders of the stream, except throughout those portions where a railroad occupies the levee top;

(2) That checking the meanders of the stream by permeable dikes during low water and brush defences during high water are simply emergency works which accomplish no permanent good;

(3) That owing to the large amount of scour during freshets and the fill-back on the falling stage, bank protection by means of willow mattresses as constructed in other places is impractical, if not impossible;

(4) That bank revetment, permanent in character and reasonable in cost, when compared with other methods, can be readily and quickly accomplished with rock placed from railroad trains operated on the levee tops and connecting with existing quarries which are within a reasonable distance;

(5) That further investigation is needed before it can be predicted, with any degree of accuracy, what effect the possible storage of flood water on the upper reaches will have on the flood discharge and the meandering tendency of the lower river;

(6) That it is doubtful if the amount of control obtained in this manner will eliminate the necessity of bank protection, and, even if such control could be obtained, a number of years must elapse before it can be made effective;

(7) In the meantime, existing works will continue to be menaced, therefore protective measures of greater or lesser magnitude must continue. In view of this fact, and the probability that some caving banks will always exist, the money spent for their protection should be for permanent revetment.

Nothing in the foregoing should be construed as opposing in any degree the creation of storage works at the head-waters of the Colorado. All feasible sites should be carefully examined, their probable influence estimated, and a well-determined construction plan matured. Such preliminary action is necessary before the advantages to come from the complete development of this river can be realized.

The destiny of this stream should be controlled by engineers rather than by statesmen, as the author suggests.

Mr.
Mead.

ELWOOD MEAD, M. AM. SOC. C. E. (by letter).—The author's able review of the irrigation development in the Imperial Valley and the measures taken to control the Colorado River, describes the most

unique achievement in American engineering since Eads deepened the mouth of the Mississippi. The Society is indebted to Mr. Cory for having given such a complete history. Mr.
Mead.

If the gap in the Colorado had not been closed, Imperial and a score of other towns would have been buried deep under the waters of an inland sea; the grain fields and orchards of thousands of farmers, and representing the savings of lifetimes, would have been blotted out; one-twelfth of the irrigated area of California would have disappeared; the Laguna Dam would to-day have probably been only a memory; and the greatest change in the earth's geography which has taken place within recorded time would have been an established fact.

Only those who heard the turbulent torrent that roared through the break in the bank of the Colorado and saw the forest-covered lands along the new channel melt and disappear in its depths, could understand the appalling nature of the disaster which impended and the tremendous odds which had to be faced to restore the river to its original channel.

In this attempt an expenditure of more than \$1 000 000 had to be risked, with the chances on the side of failure. The courage with which Mr. Randolph and Mr. Cory assumed their trying responsibility, and the generalship which they showed in handling their immense equipment, are not made clear in Mr. Cory's paper. Only those who knew the conditions faced can fully appreciate the superb merit of their achievement.

The chief value of this paper, however, is not found in its description of the engineering methods used, but in the social and political conditions, attending irrigation development in the West, which it reveals. This history shows that, so far as this enterprise was concerned, there was an utter lack of public direction and supervision, or either State or National aid; and, as these are fundamental features of irrigation development, it is that portion of the paper which the writer proposes to discuss.

If it is the duty of the Government to conserve the public resources and to give any regard to the general welfare of the people developing them, this should be shown by the enactment of intelligent land and water laws and adequate administrative control of streams, as this is the only means of ensuring the full development of these resources and the right conditions of life in the arid West. This part of the country embraces two-fifths of the Nation's area. It was almost worthless without irrigation, it is immensely valuable now, but the change has been accompanied by a waste of effort, a loss of money, and the infliction of hardships and injustice which could have been easily prevented if the State and National law-makers had done their duty.

Mr.
Mead.

When Western settlement reached the arid region, Congress should have provided for the diversion of rivers under public control, and in accordance with a general plan. This would have secured the irrigation of the best land, prevented the duplication of canals, or the building of canals where there was no water to fill them. It should either have built the large and costly irrigation works as Government projects, or safeguarded the private investments in these works, by making land and water security for the cost. Instead of this, there has never been any satisfactory title to water, and the public land has almost invariably passed into a control hostile to or independent of the irrigation works. Instead of adequate security, there was never, prior to the passage of the Carey Act and the Wyoming State law accepting this Act, any security for the money spent in irrigation works to water public lands, and at least three-fourths of these enterprises were financial disasters.

If all important irrigation works had been built by the Government, money could have been obtained at one-fourth the interest charge the majority of private projects had to pay, and without the ruinous discounts on loans which the flotation of these enterprises entailed. Low interest rates would have made much lower water charges possible and thus removed from American irrigation its most serious handicap.

If there had been any attempt to frame a land law suited to requirements in the arid region, it would have at once been manifest that the homestead should have been reduced in acreage instead of increased, because it requires more labor to cultivate 80 irrigated acres than it does 160 acres watered by rain, and the returns are larger. Instead of reducing the homestead and restricting settlement to homesteads, however, the Desert and Land Act was passed, which gave 640 acres to the individual, conferring title without residence, without cultivation, and too often with the mere pretence of watering. The Desert Land Act was promoted by the rich range stock owner. It was the worst handicap irrigation ever had, and, instead of aiding the deserving settler, it took away his best opportunities. Instead of public control of streams, men fought for their possessions with shotguns and shovels along the banks, or with more costly weapons in the Courts, where litigation, instead of settling issues, as a rule, created new fields for controversy. The water-right litigation of the arid States has not only been a continuing source of ill-feeling, injustice, waste, and loss, but its existence is a reflection on the capacity of the law-makers who are responsible for it. An understanding of these matters is necessary rightly to interpret what occurred in the Imperial Valley.

The irrigation and settlement of the desert of Southern California should never have been left to private enterprise. This was a case calling for direct Governmental control and responsibility. The desert

was below sea level. It was worthless to the State, dangerous to travelers, and ugly to look upon. It was known that the Colorado River was a stream subject to torrential floods, and that the banks were alluvial; and it required only the slightest consideration to realize the danger which would menace settlers if they were allowed to make homes in this valley without the diversion works being made safe beyond question. The benefits which would come from irrigation and settlement made it a matter of direct concern to every resident of California, gave the project a National importance, and justified its construction as a public work.

Mr.
Mead.

If, however, the State did not build the works, it was its duty to supervise them and protect the private enterprise which did. Before investors were allowed to risk their capital or settlers risk their lives and comfort, some public authority should have seen to it that the land was fit to cultivate, and that there was a legal title to water; and there should have been an inspection of engineering plans and an investigation of financial arrangements.

Instead of this, an irresponsible company without capital employs an engineer, whom it fails to pay. A right to 10 000 cu. ft. per sec. of a navigable international stream is established by the engineer posting a notice in an uninhabited jungle of weeds and brush. Of course, this was a farce, but it was the manner of establishing water titles prescribed by the law of California. That the title was worthless was shown later, but the early investors did not know this, they trusted the State to uphold and defend its statutes, and were betrayed. Any one who reviews this record must be amazed at the exhibit of imperfect laws and the incompetence or indifference of the public authorities. The surveys of public lands were shown to have been fraudulent, which was bad enough, but the delay of six years in correcting them was infinitely worse. The examination of the soil should have been made before settlement instead of afterward, and should never have been made except by experts having practical knowledge of irrigation. Instead of a proper land law, much of the land was acquired by non-resident speculators.

When the water title was attacked by the Interior Department, it was the duty of the State to defend its authority to grant titles and to protect this struggling project and the unfortunate settlers. For this protection, however, they had to look to a foreign country, and one wonders what would have been the result if Mexico had been as indifferent as the United States. This attack on the water title by the United States seems to have been morally wrong even if legally defensible.

Finally, when it was known that the river was beyond control, and the most appalling calamity that ever menaced the State of California was impending, it should not have been left to a bankrupt company and impoverished settlers to cope unaided with this disaster.

Mr. Mead. It was the duty of the State or Nation to take charge, and provide the money and men needed to restore the river to its former channel. Apparently, no one in authority was interested, the State Government only considered the matter long enough to write a letter to the President, and the President, having Congress on his hands, shifted the responsibility to the head of a railroad company; and it was not until this railroad company took charge that we have the first refreshing example of generosity and public spirit. Nothing could have been finer than the action of Mr. Harriman. The loan of \$250 000 when his time and resources were overtaxed by the earthquake at San Francisco, providing more than \$1 000 000 for the last hazardous attempt to save the valley, furnishes an inspiring contrast to the supine indifference and irresponsibility shown by both the State and Federal authorities.

The Imperial Valley produced last year crops worth \$10 000 000. The most desolate part of California has become attractive, productive, and profitable; but, when one contemplates the hardship, anxiety, and suffering of settlers, and the waste and loss to the investors in the enterprise, one cannot help feeling that the conditions which imposed such burdens on development ought to be removed.

The National and State benefits which have resulted ought to have brought both wealth and public recognition to the pioneers of the enterprise; instead, its engineer and organizer was in the end cast on the scrap heap, his life work wasted; and a large percentage of the pioneer settlers, after untold hardships, had to give up and leave. Many of those now in the valley have had to pay high prices for their land as the result of early acquirement by speculators. The Southern Pacific Company, although requested by the President of the United States to save this valley from destruction, has not been paid for doing so. The speculators in the company, who were astute enough to get two dollars for one, have in many instances become rich; the lawyers who have had charge of the unending litigation have reaped a fruitful harvest; but those who worked for the real success of the enterprise, the men who risked their own comfort and that of their families to create homes, have paid penalties which are entirely unnecessary where irrigation development is carried out under a proper system of public control.

Mr. Cory's paper needs to be read in connection with that recently submitted by Mr. Lewis,* the State Engineer of Oregon; both papers show the need for a change in the public conception of the duties and responsibilities of the Government in conserving and developing public resources, and a general appreciation of the need of more effective laws for safeguarding investments and making the settlement of arid lands easier, cheaper, and safer than this has been in the past.

* *Transactions, Am. Soc. C. E., Vol. LXXVI, p. 637.*

W. W. FOLLETT, M. AM. SOC. C. E. (by letter).—Mr. Cory's paper is valuable and interesting for several reasons. It gives in chronological order the history of irrigation in the Imperial Valley, culminating in the terrible battles with the gigantic and treacherous Colorado; it records the impressions and beliefs, after sober second thought, of one who was there in responsible charge during the months and years of greatest stress, and, above all, it is especially pleasing to the writer because the author takes occasion to show how uncalled for was the hysteria which accused Mr. Rockwood of having made a criminal blunder in opening the cut through which the river made the crevasse.*

Mr.
Follett.

In March, 1903, the writer made a trip down the Colorado River by rowboat, starting at Yuma and going to a place known locally as "Mike's Landing," which was about 80 or 90 miles by river below Yuma and near the head of tide-water. The return trip was made by wagon, through the delta lands west of the river, along the west bank of Volcano Lake, and to Calexico.

On this trip, which was made on a Yuma gauge of 18.3, or about 1.5 ft. above low water for that season, it was noted that the height of the river banks varied from 5 to 8 ft. above the surface of the water. The maximum flood of 1902 was 24.5 on the Yuma gauge, and, judging from the high-water marks on the trees, filled the river a trifle more than bank-full, whether the banks were 5 or 8 ft. high. Apparently, so much water escaped as soon as the banks were topped that the rise ceased. After passing a point about where the crevasse of 1905 afterward occurred, where the width of the channel was 800 ft. or more, the latter narrowed, as water was spilled over the banks, until it was only 410 ft. between the overflow banks at Mike's Landing. These apparently did not overflow deeply—although at that time there had not been for many years such enormous discharges as have come during the last 8 or 9 years.

On leaving the landing, the wagon road led directly away from the river for about 10 miles and then veered to the northward, toward Volcano Lake. The high-water marks showed that there was a rapid fall in the ground as the river was left behind. Of course, these marks were not level, but fell away from the river, as drift showed that the current had been in that direction. The fall mentioned by the author—from 5 to 8 ft. in the first 3 000 ft.—was found, being nearer the latter figure. After that, the fall was more gradual.

In going north it was noted that each flood-water channel crossed was running on a ridge similar to, but much smaller than, that on which the main river ran.

As a result of that trip, the writer was impressed with the idea that the Colorado was nearing an epochal change in its course across its delta. It is well known that an alluvial stream builds up its banks

* *Transactions, Am. Soc. C. E.*, Vol. LXII, p. 24.

Mr.
Follett.

and beds across its delta until it lies on a ridge; and that finally the time comes when the river breaks away from this ridge, takes a new course to the sea across the lower portion of the delta, and proceeds to build another ridge. When the stream reaches this condition of instability it is impossible, except at great expense, to keep it on the high ground. The writer had no idea, however, that the river would break into the Imperial Valley, but believed that the ridge north of Volcano Lake and the embankment along the canal of the California Development Company, would prevent such a diversion.

Subsequent events have confirmed this idea, and the writer is now of the opinion that any money which may be spent in attempting to close the Abejas Crevasse will be wasted, because, even if it is closed and held, the river will break out again somewhere else.

The author has shown quite clearly* that no serious grade recession has resulted from the Abejas Crevasse. As the river has been running through this opening for 4 years, during which time there have come the two largest floods ever known, it is fair to assume that no further grade recession will occur, but that a new delta is forming, pointing toward Volcano Lake, and that the tendency henceforward will be for the bed of the river to rise. Therefore, no danger to the water supply of the California Development Company nor to Laguna Dam is to be expected. It is best, therefore, to recognize this as an epochal change, allow the river to take its own course to the Gulf, and protect the Imperial Valley by raising and strengthening periodically the levee which lies north of Volcano Lake and extends back to the river. For the valley this will be a sure protection, which the closing of the Abejas Crevasse would not afford for any length of time.

Attention is called to the narrow gorge between levees, which begins opposite Andrade and extends for 2 miles down stream. The levees average about 1 500 ft. apart, with a width of river channel of 1 000 ft.; that is, the average berm on each side between the river and the levee is only 250 ft., and, in some places, it is probably narrower. This condition is shown on Plate L.

If, during some flood, the current of the river should be deflected so as to strike the right bank, and scouring began, it is the writer's belief that the levee and canal bank would be eaten away like sugar, and the river would be diverted into the canal and down the Alamo, again reaching the Salton Sea.

To prevent this diversion, a safety gate can be built about 2 miles below the Hind Dam (see Plate L). At this point, the Rockwood Crevasse channel touches the sand hills on the north, and a cross-levee could be built from the gate to the main levee on the south. As there is much fall, a drop would probably be needed. In this might be

* Pages 1214-1215, and Fig. 3.

placed gates, if thought best, which could be used for sluicing sand from the canal above. Mr.
Follett.

The writer was on the ground several times prior to the closure of the crevasse by the Hind Dam, and was strongly impressed with the danger of the river "side-wiping" the canal in this narrow stretch. If it starts to shift, the efforts of man to stop it will seem puny in comparison with the immense destructive force of the current. It is stated that, in the Edinger Dam, piles, 64 ft. long, were driven more than 50 ft. into the bed of the river, and that, when the flood struck them, they scoured out and floated away; they were not broken, but came out bodily. Attention is called to the author's statement (page 1214) that, in 1907 and again in 1909, it was found that for an increase of 10 ft. in the gauge height at Yuma there was a lowering of the bed of about 30 ft. This was where the river was flowing in a straight and unimpeded channel. It is not possible to say how deep it would scour in a sharp bend. It would be deep enough, however, to undermine and destroy the levee, regardless of any rip-rapping which might be on its face, or any rock which might be hastily dumped into the river. It is the writer's belief that this is a serious menace to the Imperial Valley. The fact that the river channel is now practically straight for about 4 miles is almost proof positive—bearing in mind the idiosyncrasies of an alluvial stream—that it will not remain in that condition very long. Whichever way the bend may start, the current will soon be attacking both sides, as it will rebound from one bank to the other.

R. H. FORBES, Esq.* (by letter).—To those who know the Colorado River, and who in a measure realize its eccentric and unmanageable character, Mr. Cory's account of control work in the Delta is rendered doubly interesting by that which the reader may find between the lines. For, in proportion as the work was difficult, original in methods adopted, and spectacular in its accomplishment, Mr. Cory's account is unassuming, matter of fact, and quietly scientific. Of the errors made by various agencies that in some way touched the reclamation of the Delta, he is most uncritical. Mr.
Forbes.

An observer of events along the Colorado from 1905 to 1912 could not but be impressed by the efficiency of the Southern Pacific Railroad organization, with its ready and varied resources, its personnel, and its *esprit de corps*, in dealing with the situation. Not the least factors in a successful outcome were the democratic and friendly relations that existed between Mr. Epes Randolph, Mr. Cory, and others of the management, and the motley crew of Americans, Mexicans, and Indians whose confidence and loyal support they commanded to a remarkable degree.

Of the colossal and urgent nature of the task, the adverse weather

* Director, Agricultural Experiment Station, Univ. of Arizona, Tucson, Ariz.

Mr.
Forbes.

conditions, the experimental character of the work, the conflicting advice received from influential sources, the diplomatic complications with Mexico, and the financial entanglements incident to the undertaking, Mr. Cory's own account is sufficient evidence.

In Dr. William P. Blake's account of the region, written shortly before his death, he relates the discovery in 1853 of San Gorgoño Pass, through which the Southern Pacific Railroad was built about twenty-five years later, and describes the descent of his party into the old lake bed, below the level of the sea.

He also outlines the topography and geology of the region, describing the lacustrine deposits, the fossils, the salt beds, the mud volcanoes, and to some extent the vegetation of the basin. He points out the manner in which the sediments of the Colorado, the tides, and rising land levels finally cut off a portion of the ancient Gulf of California, and describes the old lake Cahuilla thus formed, with its beach lines and its fluctuations in level as the river flowed to one or the other side of its delta. He even relates the Indian traditions of the former existence of this lake.

Most interesting, however, are Dr. Blake's quotations from his reports to the War Department in 1855, in which he points out the fertility of the soil, and the possibility of irrigating the region by a canal from the Colorado. He even states the danger of overflow through such a canal and the refilling of the ancient lake. The following words, quoted from the old report, have prophetic value:

"From the preceding facts [relating to soils and vegetation] it becomes evident that the alluvial soil of the Desert is capable of sustaining a vigorous vegetation." * * * "If a supply of water could be obtained for irrigation, it is probable that the greater part of the Desert could be made to yield crops of almost any kind. During the seasons of high water, or the overflows of the Colorado, there would be little difficulty in irrigating large areas in the vicinity of New River and the lagoons. By deepening the channel of New River, or cutting a canal so low that the water of the Colorado would enter at all seasons of the year, a constant supply could be furnished to the interior portions of the Desert. It is, indeed, a serious question whether a canal would not cause the overflow of a vast surface and refill, to a certain extent, the dry valley of the Ancient Lake."

Nothing is wanting here but a suggestion for the control of the river, as detailed in Mr. Cory's paper.

It is remarkable that a man in his early twenties, inexperienced in irrigation, and traveling for the first time through desert country, should have estimated so accurately the possibilities and liabilities of Salton Basin, fifty years before the development of the region. It seems that, until recently, Professor Blake's was not only the first, but the clearest, general conception of conditions in the Delta. Others

have promoted the irrigation of the Basin, and some have realized the possibility of a break-away; but, until 1905, additions to knowledge of the region were mostly supplementary to Professor Blake's descriptions. Mr.
Forbes.

If one may look for useful suggestions in this connection, attention may be called to the necessity for a co-ordinated study, by the proper agencies, of our great physical problems, such as the utilization of a great river, and the proper control at all times of operations affecting the final solution of such a problem. The "pork-barrel" method of handling river improvements from the governmental side, is admittedly desultory and wasteful; and it is to be feared that scientific agencies engaged in the study of these same problems, as a rule, are not well co-ordinated. It may be that the Colorado has drawn attention to these facts, with corresponding advantages to come. The Newlands River Regulation Bill, now before Congress, will make possible a comprehensive study and development of the Colorado River as a whole, for storage, power, and irrigation; and the Carnegie Institution, on the purely scientific side, is soon to publish a collection of scientific papers relating to the Delta region, among which will appear Professor Blake's complete paper.

R. S. BUCK, M. Am. Soc. C. E. (by letter).—The writer has read Mr. Cory's paper, as well as several of the discussions thereon, with great interest, but is forced to a view radically different from that of Mr. Sellew regarding the propriety or advisability of incorporating in such an engineering paper so much collateral matter of legal, financial, and (he might have added) political character. Mr.
Buck.

Mr. Sellew says:

"The record of the operations incident to the return of the river to its former channel is extremely complete, although partly obscured by a mass of legal and financial entanglements which properly have no place in a purely engineering article."

Though it may have necessarily taken a longer time in the relating than the casual reader, in quest of purely technical knowledge, may have desired, one of the principal features of interest and value to the writer in Mr. Cory's paper is the graphic portrayal of the desperate odds which engineering talent and effort are often forced to meet, as a result of long-range financial management, clogging legal complications, and the blind, selfish play of the political game.

Engineering work is now controlled by forces far beyond the laws of physics, and, if he would occupy a position to which his technical talents properly entitle him, the engineer must learn something of these forces.

Mr. Buck. In the writer's opinion, Mr. Cory is to be commended rather than criticized for devoting so much attention to the conditions in question, for he has certainly thrown light on some dark places, and has shown how vital it is for engineers to consider, in their planning, the laws and habits of men and money, as well as the laws of Nature.

The Lower Colorado is not merely a problem of yesterday, presenting a vague general moral. It is a vital problem of to-day and to-morrow and of years to come. It will probably take a place alongside the Lower Mississippi River as another engineering problem, dragging out a long, weary, and costly existence as a result of Government incompetence and political selfishness.

Of course, Mr. Cory's paper can affect but little the thus far meager results of mighty efforts to control the Colorado, but it should have a marked effect on future efforts, if a reasonable amount of intelligence is to direct these efforts.

If Mr. Sellew's apparent views were shared by the Publication Committee, we would have no papers such as those on water laws and valuation of public utilities. The importance of these and similar collateral subjects, the writer feels, is growing to be more and more appreciated from the engineering point of view.

Mr. Robson. F. T. ROBSON, Assoc. M. AM. Soc. C. E. (by letter).—Under the heading, "Salton Sea", the author makes two statements which are quite noteworthy, and not to have been expected. The first is that the land uncovered as the sea recedes is being cultivated with entire success, and presumably with no preliminary treatment to remove soil alkalinity. This is the more significant because, before the formation of the sea, this land had an alkalinity so great that it was condemned by the soil surveys of the United States Department of Agriculture, mentioned elsewhere by the author. The soil alkalinity of this part of the desert is in general greater than throughout the portion first cultivated and for which the Imperial Area Soil Survey was made. Since then it has been covered for from 1 to 6 years by water which, according to Tables 20 and 21, was in 1907 more than one-tenth as high in soluble solids as ocean water (and generally similar in the proportion of the various elements), and is undoubtedly growing constantly stronger because of the submerged salt beds. Nevertheless, independent inquiry confirms the statement as to the successful cultivation of the land which is being exposed.

The other interesting and surprising statement is that the gross evaporation from the sea is only 6 ft. per annum. The writer has also taken the trouble to check this figure—and has found that it should be only 67 in.—and in doing so he has collected some information bearing on this point which it is thought will be of interest.

The opportunity offered at the Salton Sea for careful determination of gross evaporation from large areas of water surface, and the relation of this evaporation to that from small pans and evaporators, was recognized by the officials of the United States Weather Bureau, and from October, 1907, to the end of 1910, a large amount of work was done there.

Special studies of evaporation loss from the surfaces of lakes and reservoirs were begun by the Weather Bureau, under the direction of Professors Bigelow and Marvin, at Reno, Nev., about August 1st,

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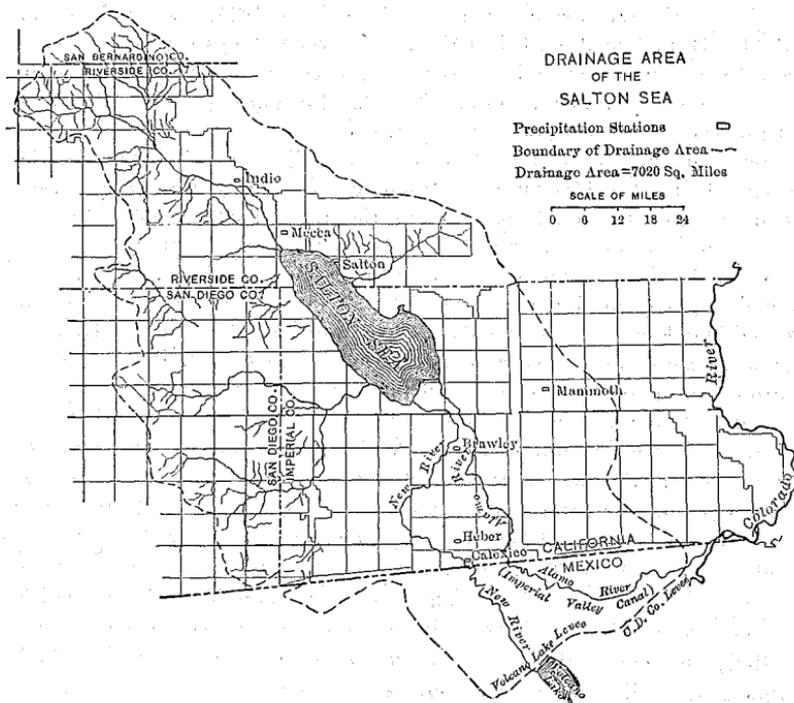


FIG. 83.

1907, the main headquarters being transferred to the Salton Basin near Salton in the following October. Observations were also made simultaneously at the near-by points, Indio, Mecca, Mammoth, and Brawley, and at the following distant points: Phoenix, Ariz.; Eagle and Carlsbad, N. Mex., these being at low elevations in these States; Mitchell, Nebr.; Howell, Wyo.; Rupert and Boise, Idaho; Hermiston and Klamath Falls, Ore.; North Yakima, Wash.; Fallon, Nev.; Lake Tahoe, Cal.; on the Rocky Mountain Plateau up to an elevation of

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Robson.

6 000 ft.; Birmingham, Ala.; Cincinnati, Ohio; Tupper Lake, N. Y.; and Lockport, Ill., in the districts east of the Mississippi River. Most of the western points selected were stations of the U. S. Reclamation Service, and at most of them evaporation observations were taken at 2, 6, and 10 A. M. and at 2, 6, and 10 P. M., though in a few cases observations were taken only at 6 A. M. and 2 P. M., which were found to be about the time of minimum and maximum evaporation, respectively, and from which, it has been shown, very accurate results can be obtained by taking the mean values.

The final bulletin on the data collected and the conclusions derived therefrom, though promised to be issued in 1911, has not yet appeared. It is hoped that it will not be much longer delayed. However, Professor Bigelow has given a summary of results and deductions in a preliminary report.* This preliminary statement does not contain the observed data, which, however, are abstracted by Professor Bigelow in the "Abstract of Data, No. 4", issued by the Weather Bureau, being "A Provisional Statement Regarding the Total Evaporation by Months at 23 Stations in the United States, 1909-10".

The preliminary experiments at Reno indicated that a large body of water loses only about seven-tenths as much as a small pan set in a dry place outside its vapor sheet. The further experiments indicated the loss to be near 65%, in the opinion of Professor Bigelow; and the results at the Salton Sea, properly corrected, in the writer's opinion, indicate the proper coefficient to be still lower, namely 60 per cent. This relation, from the practical point of view, is the most important fact brought out in the work at these various stations, particularly in that at Salton. At this point four towers were built: No. 1 about 1 500 ft. from the water's edge, No. 2 near the Southern Pacific trestle over Salton Creek about 500 ft. from the shore, No. 3 $\frac{3}{4}$ mile west, in 40 ft. of water, and No. 4, which is 120 ft. high, $1\frac{1}{2}$ miles west, in 55 ft. of water (depths in 1909). These towers, though made as stiff as possible, were found to have a slight vibratory motion, even in quiet weather, and hence the water in the evaporation pans required to be damped in oscillation by submerged partitions.

The important results, as given by Professor Bigelow in the preliminary report referred to, are:

1.—That the wind velocity was so different at various heights, 0, 10, 20, 30, and 40 ft. above the ground—amounting often to 30% less at the ground than 10 ft. above—that every evaporation pan must be supplied with its own anemometer wherever evaporation observations are made, whether on land or on large bodies of water.

2.—That pans of different sizes evaporate at different rates, and

* *Monthly Weather Review*, February and July, 1910, pp. 307 and 1133, "Studies on the Phenomena of the Evaporation of Water over Lakes and Reservoirs."

these rates were found to vary approximately as the expression, $0.023 (1.23)^n$, where n has the following values: Mr.
Robson.

$n = 0$ for large open-water surfaces,

$n = 1$ for 6-ft. pans,

$n = 2$ for 4-ft. pans,

$n = 3$ for 2-ft. pans,

$n = 4$ for ordinary dry air.

This variation seems to be due to the banking up of the vapor on the leeward side under the action of the wind, and because the small pan clears much more completely of vapor, and evaporation takes place into a mixture of air of different contents according to the size of the pans and the force of the wind.

3.—The formula finally suggested by Professor Bigelow is (c. g. s. units):

$$E_d = C_2 \frac{e_s}{e_a} \frac{de}{ds} (1 + 0.070 W),$$

where E_d = Evaporation in 24 hours (one day), in centimeters;

C_2 = Coefficient, found to be 0.138 $(1.23)^n$;

e_s = Saturation vapor pressure at temperature of the water surface, designated by s ;

e_a = Saturation vapor pressure at temperature of the dew point in the air near the water;

e = General symbol representing vapor pressure;

E = General symbol representing depth of evaporation;

$\frac{e_s}{e_a}$ = Expression for the gradient (use Crelle's tables);

$\frac{de}{ds}$ = Expression representing the change of vapor pressure with temperature, s , taken. This quantity is merely the tabular difference in ordinary vapor pressure tables at the temperature under consideration (use Manual Table V).

W = Wind velocity, in kilometers per hour.

It is proposed to substitute this formula for that now in general use, which was proposed by Dalton in 1803 and may be written as follows (same notation):

$$\frac{dE}{dt} = C (e_s - e_a) (1 + aw),$$

where t = time, and C and a supposed by constant terms,

or $E_d = 0.036 (1.23)^n (e_s - e_d) (1 + 0.070 W)$ using the values of the constants deduced from these experiments at Salton.

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Robson.

4.—That water in pans of the same size evaporates at the same rates at 4 000 ft. elevation as at sea level, and hence the formula does not contain any barometer pressure term.

5.—The recommended formula has no annual period in the C_2 coefficient; the diurnal period is very small.

6.—A pan of very fresh water was allowed to evaporate alongside a pan filled with brackish Salton Sea water, which was gradually concentrated by adding water from the sea from November to May without emptying the old water. The brackish water evaporated a little slower than the fresh water, to the amount of 2% in April and May.

7.—The actual fall of the Salton Sea level from June 1st, 1909, to June 1st, 1910, was 51 in., and Professor Bigelow estimated that the rise was 12 in. due to inflow from the Alamo and New Rivers, and there were 6 in. of accretions from annual precipitation, making a total gross evaporation of 69.0 in. This total checked with results computed by formula from observed data necessary.

8.—Practically, it was the conclusion that engineers would necessarily have to adopt a standard pan and reduce the observed readings to the open-water surface, as explained above. Thus, the evaporation from a 4-ft. standard pan, when corrected for temperature and wind, and multiplied by 0.66, is very close to what observation suggests. If a water thermometer on a small raft in the lake measures s_0 , and e_s and e_d are determined by using a sling psychrometer, through t and t_s , and the wind velocity by an anemometer as near the water surface as possible is W , then $C = 0.138$ for a 24-hour interval. In the formula, the mean values taken at readings made about 6 A. M. and 2 P. M. should be used.

The writer has checked the estimates of Professor Bigelow as to the inflow from the Alamo and New Rivers, and the increase due to the rainfall and run-off from the water-shed, from all the available data (of which considerably more exist now than when Professor Bigelow did his work). It is known that there are no springs or underground sources of supply discharging into the basin, because, until very recent years, the sea contained no water, and salt beds in the bottom were regularly mined. The rainfall is very light, consequently the run-off is small. From the time when the Colorado River was finally re-diverted (the middle of February, 1907) to date is 6 years, and it seemed to the writer that the results should be checked to obtain an average for this entire period, rather than for the year from June 1st, 1909, to June 1st, 1910, which was taken by Professor Bigelow.

In determining the inflow, it is possible to utilize the sea itself as a large measuring tank in which to measure the combined rainfall on the water surface and the run-off from the drainage area due to rainfall—proper correction being made for the regular inflow from the

Alamo and New Rivers—by using the daily gauge heights or elevations of the water surface.

Mr.
Robson.

As a first step in obtaining the average evaporation for the entire 6-year period, the difference in elevation of the water surface on April 1st, 1907, and April 1st, 1913, was found to be 26.10 ft.

If, then, (1) the total precipitation on the sea itself, plus (2) the total run-off into the sea, plus (3) the total discharge of the Alamo and New Rivers into the sea for the same period, be added to this 26.10 ft., the result will be the total loss due to evaporation—percolation being considered as of no consequence.

a.—The writer prepared a table of the rainfall for each month of each year, as observed at Brawley, Calexico, Heber, Imperial, Mammoth, Mecca, and Salton, all these points being within the drainage area and fairly well distributed. It was then assumed that the total rainfall at all these stations, divided by the number of stations, would give a fair average of the precipitation on the sea itself. The total thus found for the 6-year period was 16.59 in. or 1.38 ft.

b.—A table was then made showing the decrease in elevation of the water surface for each month of the period, and the decrease for each month was compared with that for the corresponding month of the other years. It was found that the decrease in one month compared very closely with that for a corresponding month in another year, except in cases of unusual rains or other known causes. Eliminating these months, a total was then made of those remaining, and the result was divided by the number of months comprising the sum. The average thus found was assumed to be the normal average decrease for that month. Sufficient amounts, corrected for excessive rainfalls on the sea itself, were added to bring the eliminated months up to the average, and these additions were considered as the run-off or inflow due to precipitation. This total was 15.00 in., or 1.25 ft., for the 6-year period. The results obtained by this method were checked by examination of the daily precipitation records for these various Weather Bureau Stations. In such desert country, where the rainfall is scant, that which does occur is frequently in intense storms or in local cloudbursts. Monthly records, therefore, are of little value as indicating the probable run-off, and each storm at each observation station must be considered, instead of the monthly totals. Only two or three heavy precipitations extending over the entire water-shed occurred during the 6 years, the heavy rainfalls usually being rather local in character and in the nature of cloudbursts. The total number of such heavy precipitations throughout the period at all these stations, however, was surprisingly small, and the daily gauge heights of the sea surface for several days was carefully examined in connection with each of these heavy rains. In this way a very good check was obtained on the foregoing method of deter-

Mr. Robson. mining the total inflow into the basin from its water-shed—exclusive of the New and Alamo Rivers.

c.—The discharge of the Alamo and New Rivers has been observed, and a rating curve has been applied only for a period from June, 1909, to October, 1910. Based on the records published in Water Supply Paper No. 300, and from information kindly given to the writer by Mr. Cory from his personal records, the following rises in the elevation of the lake surface have been determined, and are believed to be very close to the truth.

To January 1st, 1908.....	0.62 ft.
From January 1st, 1908, to January 1st, 1909..	0.65 "
" " " 1909 " " " 1910..	0.68 "
" " " 1910 " " " 1911..	0.71 "
" " " 1911 " " " 1912..	0.75 "
" " " 1912 " " " 1913..	0.78 "
Total	4.19 ft.

To sum up, then, the evaporation has been as follows:

Loss in elevation of lake, as shown by gauge heights....	26.10 ft.
(1) Total rainfall on lake surface.....	1.38 "
(2) Total run-off from rainfall.....	1.25 "
(3) Total discharge from Alamo and New Rivers.....	4.19 "
Total evaporation, April 1st, 1907, to April 1st, 1913....	32.92 ft.
or a yearly average of.....	5.58 ft.
or	67.02 in.

as compared with 69.0 in., the total gross evaporation found and estimated by Professor Bigelow for the 1-year period, June 1st, 1909, to June 1st, 1910.

Table 31, containing observed data at Salton Sea, is taken from "Abstract of Data, No. 4," by Professor Bigelow, referred to previously. The figures for Nos. 1, 2, 3, and 4, for March, April, May, and June, were interpolated from curves plotted from records of previous years, and found by experience to give close results.

At the stations outside of the vapor sheet, at which observations were taken, for a 6-ft. pan on the ground, the total evaporation observed was:

Indio	119.33 in.
Mecca	107.81 "
Brawley	103.55 "
Mammoth	125.53 "
Total	456.22 in.
Average	114.055 "

Mr.
Robson.

The total evaporation, as determined by the writer, was 67.02 in. Hence the coefficient to be used in converting the observations from a 6-ft. pan on the ground outside the vapor sheet, and in a desert country, to the total loss from a large water surface, seems to be $\frac{67.02}{114.055}$, or 0.59, or, say, 0.6.

Mr.
Chaffey.

ANDREW M. CHAFFEY, Esq. (by letter).—Careful reading of Mr. Cory's paper leaves the agreeable impression that he has sought to be fair and unprejudiced in handling a very complicated subject. Two other publications dealing with the Imperial Valley project have appeared, one mentioned by the author*, and another† consisting of short monographs by settlers, promoters, etc., gotten out by E. F. Howe, editor of the *Imperial Valley Press*. Both are rambling sketches, rather than histories, unsystematic, full of inaccuracies, and partisan and misleading statements, and hence untrustworthy and unsatisfactory. Mr. Cory's paper, therefore, is to be regarded as the first serious history of Imperial Valley, and will unquestionably be heavily drawn on by future writers. It is most fortunate, therefore, that it is being fully discussed, its inaccuracies pointed out, its engineering and historical matter supplemented by those qualified to do so, and, more particularly even, that several of the facts brought out by the author may be gathered together so that the reader interested in details may not fail to catch their true significance.

The writer was associated with his father, Mr. George Chaffey, in the management of the project from April, 1900, to February, 1902, and, for more than twelve years, has been collecting original documents and data relating to Imperial Valley. To these, doubtless much the most complete in existence, the author, unfortunately, did not have access, due to the fact that, curiously enough, he and the writer did not become acquainted until after the appearance of this paper.

On page 1251 the author states that the first practical step toward the irrigation of the Colorado Desert was the incorporation of the California Development Company in 1896. The writer feels that this is exceedingly misleading. Incorporating a company with large capital stock, appropriating vast quantities of water, by posting notices and recording the same, all at most nominal cost, acquiring options for small cash payments, getting out reports setting forth the merits of a project, and hawking the scheme about in financial centers, cannot rightly be considered as "practical steps" toward carrying out any enterprise. It is just this sort of "shoe string" promotion which Mr. Mead doubtless had in mind when writing his discussion on this paper (page 1509) and pointing out the folly of letting irresponsible

* "Born of the Desert," by C. R. Rockwood, 1909-10.

† "The First Decade," Imperial, 1910-11.

companies go ahead without any public supervision whatsoever. On the contrary, the first "practical step" was taken when Mr. George Chaffey signed the contract (April 3d, 1900) to build canals into Imperial Valley. Many readers of the paper will undoubtedly get the impression from it that the California Development Company was at such time a going concern, and that its promoters had already produced tangible results. As a matter of fact, though it had been in existence nearly four years, it had as assets the two options on land—one in Mexico and one in California—mentioned by the author, as to each of which the Company was in default, and an idea, a project of large and attractive proportions on which not one shovelful of earth had been turned, and toward the consummation of which not one single practical step had been taken. Its obligations, aside from its capital stock, were various debts, aggregating a considerable sum, and \$350 000 worth of what was called land scrip—issued prior to 1900 at 10 cents on the dollar and dissipated in promotion expenses—which was retired at face value in cash or in exchange for water stock of the various Mutual Water Companies at market price at the most inopportune time, namely, just before the water distributing system was completed in the valley.

Mr.
Chaffey.

The contract recited that the California Development Company owned, through a subsidiary Mexican Company, 100 000 acres of land in Mexico through which the canal must run. But for this representation (which turned out to be untrue) the contract would assuredly not have been made. The idea in reality was free to Mr. Chaffey, or to any one else for that matter. Indeed, Mr. Chaffey, at the request of Dr. Wozencraft, had considered the proposition in the early Eighties, before the later promoters had even heard of it.

To say, therefore, that at this date (April, 1900) there was a "practical change of management," that the engineering policy changed, or that "original plans were not carried out," is to create an absolutely erroneous impression. To quote Mr. Chaffey himself:

"I saw a way to accomplish the object with the means at my command by disregarding the Rockwood Survey altogether, adopting another line by which the bank of the canal would be made to serve as a levee to prevent the flood waters of the Colorado from finding their way into the Alamo, and utilizing many miles of that natural channel for the main canal."

This contract of April 3d, 1900, provided that Mr. Chaffey was to construct such canals as were necessary for the purpose of taking water from the Colorado River just above the Mexican boundary line to where the central main canal intersects the same boundary line in Imperial Valley, "said canals to have a capacity sufficient to deliver four hundred thousand acre-feet of water per annum at said last-named point"; that no more money should be expended "than is neces-

Mr.
Chaffey.

sary in such construction"; that the construction cost of such canals should not exceed \$150 000; that such construction was to be "at actual cost to first party"; that Mr. Chaffey was to receive \$12 000 per annum salary for five years, payable when the Company was able to pay it, and one-quarter of the Company's capital stock; and that he should have charge of the Company's finances as well as its engineering works during that period.

It is felt that the foregoing abstract of this contract will suffice to indicate clearly its fairness, to say the least, to the Company.

From this date until the contract was terminated—April 3d, 1900, to February, 1902—Mr. George Chaffey and associates furnished the necessary money, and, dividing the engineering responsibility with no other person, designed and built the diversion works and located and constructed the main canal—including the Central Main west of Sharps Heading and in the United States—as it exists to-day. During this period he was assisted in the business management, in planning the system of Mutual Water Companies—which system, by the way, the author to the contrary notwithstanding, the California Supreme Court, in the case of *Thayer vs. California Development Company*, has recently not only held to be legal, but has highly commended—and in making the tri-party contracts, by the writer and by Messrs. L. M. Holt (who with Mr. Chaffey evolved in 1881 the first Mutual Water Company ever incorporated, at Etiwanda, Cal.), N. W. Stowell (who was the first to introduce concrete water conduits to irrigation construction in California in 1878, and who had large experience with irrigation works), and J. W. Swanwick, who was largely responsible for the tri-party contracts.

A great deal has been stated in the public press and in governmental reports—and Mr. Mead in his discussion (p. 1509) might easily be understood by the careless reader as coinciding therewith—condemning the California Development Company as an irresponsible corporation at all times prior to the Southern Pacific Company's taking over the management in June, 1905. This was far from being true during the period when Mr. Chaffey was directing its affairs—April, 1900, to February, 1902. The men just mentioned were those he associated with him; all except the writer were unusually experienced in the different phases of irrigation work and development, and financially able to build the canal. Mr. Chaffey himself was a man of wide experience gained in the practice of his profession of Civil and Mechanical Engineer. Best known as the founder of Ontario, Cal. (1883), he had founded Etiwanda, Cal. (1881), and had developed the irrigation systems in both places to such a state that the visit of a Royal Commission from Australia in 1885, resulted in his proceeding with his brother to that country and establishing the irrigation dis-

districts of Mildura and Renmark, both at this time populous and prosperous communities, conceded by all public men to be "the great object lesson in irrigation for the rest of Australia." In 1882 Mr. Chaffey produced the first electric current (generated by water-power) in Southern California, and in 1884 lighted the City of Los Angeles with electricity. A large number of the first settlers in the Imperial Valley were actually from Etiwanda and Ontario; all were experienced irrigationists, and it is safe to say that 90% of them made their purchases because they personally knew of Mr. Chaffey's previous successes.

Mr.
Chaffey.

The writer, of course, agrees with Mr. Mead that the State or Nation should protect settlers on and investors in irrigation projects, examine and approve engineering plans, etc., etc., and especially he agrees with his comments regarding water right laws, the unfortunate condition of which is responsible for most of the financial disasters which have overtaken irrigation enterprises in the West, and of which the California Development Company is, perhaps, the most notable example. At the same time, it must be admitted that the greatest and most rapid irrigation development the world has known is that responsible for what is known as Southern California, and the Government—State and National—in no wise helped and not seldom added severe handicaps. It is sometimes said that Southern California has been built on "shoe strings"—certainly, many of its most successful enterprises have been started with inadequate capital, on confidence in the proponent's resourcefulness. Under such conditions, people are "live wires" to a degree beyond the comprehension of officials and employees of powerful corporations and of the State and National Governments. Much of the resentment toward, and often unfair criticism of, the U. S. Reclamation Service, by owners and officials of, and settlers under, private irrigation undertakings had its beginnings in the attitude of those who never need to consider for an instant financial arrangements, discounting securities, etc., toward "flimsy" work and the twists and turns of men driven to their wits' end when doing things with insufficient capital. It is well enough to say "Don't try them if you cannot get enough money to insure success." Such a policy would undoubtedly prevent not a few failures; but, on the other hand, by it the Southern California of to-day would not have been for decades to come.

The Imperial Valley is possibly the most striking example of this. In the first place, if the soil had been first examined by Government experts instead of by practical farmers, the project would have been condemned *in toto* and the region still original desert. Next, work was begun with small capital in hand, and in 10 months' time, and at the cost of less than \$100 000, Mr. Chaffey put water into the burning desert 60 miles away from the Colorado River, and along lines, engineering, legal, and financial, which experience shows would have meant large success to all (had the Government only kept its hands

Mr.
Chaffey.

off), and by doing so realized the visions of the dreamers and the hopes of the promoters who for half a century had dreamed and promoted, and accomplished nothing. In less than 2 years, the Imperial Main Canal, essentially as it is to-day—except the \$75 000 head-gate at Andrade—and more than 400 miles of distributing ditches, were completed and the water was ready to turn on to 100 000 acres of land, at a cost to the settlers averaging less than \$10 an acre; and the capital at hand was less than the promoters had expended in the hitherto vain effort to get started.

In contrast is the Government Yuma Project, with unlimited capital: \$3 000 000 initial appropriation and more than \$3 000 000 later; time, 8 years; acreage, 100 000; cost, \$70 per acre; bitter disappointment and heavy loss to settlers relying on Government estimates as to money, and, more particularly, time required to complete the work. As a part of the Yuma Project, Imperial Valley would now be in exactly the state it actually was in 1902—eleven years ago—as far as development is concerned. In the meantime, in 1905, it was sending out \$5 000 000 worth of products, and at present more than \$10 000 000 worth. The gain in time has more than paid all the real damage *per se* done by the runaway river.

As the author has pointed out, this misfortune would never have occurred had it not been for numerous unnecessary and inexcusable obstacles. For some of these there is possibly some excuse, or at least explanation, but the soil survey and report was the most disastrous and inexcusable of all. The space devoted to it by the author in his paper is out of all proportion small compared to its significance, and the facts about it should be elaborated somewhat.

As stated by the author, a few samples of soil from this region were analyzed in 1893 by the Director of the California Experiment Station, University of California, Professor Hilgard, and again in 1896-97, and also in 1900, when the Imperial Land Company began active work. In the summer of 1901, the Bureau of Soils, U. S. Department of Agriculture, requested the co-operation of the promotion companies in making a study of and report on the soils of the Imperial Valley. This was gladly given, and, on October 17th, Mr. J. Garnett Holmes, of the Bureau staff, arrived and began work. Later, his immediate superior, Thomas H. Means, M. Am. Soc. C. E., and others of the Bureau, joined him, and on December 20th (in 63 days) the field work was completed. It took only 3 weeks (January 10th, 1902) to issue a preliminary report, "Circular No. 9," covering the 169 sq. miles of territory which had been examined. Before this circular reached California, an Associated Press dispatch from Washington advised that:

"The condition of soils in the Colorado Desert in San Diego County, as disclosed by a survey just completed by the Agricultural

Department in the vicinity of the new irrigation plant at Imperial, is reported to be 'much more serious than was anticipated.' This is the expression used by Milton Whitney, Chief of the Bureau of Soils, in a preliminary bulletin which he has deemed best to issue by way of warning."

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This refers to the report which the author says was "unfavorable, * * * and calculated to deter sensible people from settling in the region." This is a more than conservative way to put this matter, as is shown by the single extract—by no means the strongest of many—which the author quotes on page 1271.

In 1903 the U. S. Department of Agriculture, Bureau of Soils, issued the "Soil Survey of the Imperial Area, California (Extending the Survey of 1901), Advance Sheets of Field Operations of the Bureau of Soils, 1903." This document, under the head of "Present and Prospective Development," on page 31, makes the statement:

"The sole dependence of the people of the Imperial Area must always be agriculture. * * * The source of wealth, therefore, is limited to the soil, and to a greater extent than in almost any other part of the country. Thus the problem confronting at least a part of the farmers in most arid regions is here—where alkali is so generally distributed in the soils and the conditions so unfavorable to reclamation—about as serious as it could well be.

* * * * *

"The people of the Imperial country should recognize the fact that aside from the general problem of securing water for irrigation they have to solve perhaps the most serious agricultural problem of the arid West. Here is found a most refractory soil, much of it impregnated with alkali. The only way to benefit the land is to carry away the salts. The application of gypsum cannot be of the slightest benefit. Little or no benefit will be derived from running water across the land with the expectation of flushing the alkali off the surface. * * * The water must pass through the soil and find ready egress through natural or artificial drainage ways.

"The quantity of salt taken out of the soil by alkali-resistant crops, such as sorghum and sugar beets, is not appreciable, the benefit to the soil in such cases resulting mainly from the prevention of evaporation at the surface through cultivation and from the leaching of the salts into the subsoil by irrigation water. If the subsoil be practically free from salt, as is often the case in arid regions, this vertical distribution of the salts alone is often all that is necessary so to reclaim the soil that sensitive crops can be grown. But it has been shown that in the Colorado desert the subsoil is the greatest source of danger, so that every bit of salt removed should be permanently removed. * * * By far the greater extent of the soil of the valley is a sticky, plastic loam or clay, through which water passes very slowly. The natural drainage in the soil itself is very poor, and to be anything like adequate it must be supplemented by artificial drains to carry off the ground

Mr. Chaffey. water as the salts are washed down from the surface. * * * Tile drains are the best and in the end the most economical for draining the land. They are, however, expensive, and the question is, will it pay?

* * * * *

"That it will eventually pay to drain these lands there can be little doubt, but in the present state of the country concerted action will be difficult and individual effort futile."

In February, 1902, the University of California, College of Agriculture Experiment Station, issued Bulletin No. 140, entitled "Lands of the Colorado Delta in the Salton Basin." This bulletin gave essentially the same results of soil analyses, but was much more careful in its comments, and on pages 50 and 51 gave crop reports from actual settlers which were excellent. It also stated, after giving a list of native plants from the Salton Basin, on page 44, as follows:

"The list of plants here given is notable for the absence of most of the species considered elsewhere as prominent alkali indicators. We miss at once the salt—or alkali—grass (*Distichlis*); the 'Grease-wood' of Nevada (*Sarcobatus*) and that of the San Joaquin Valley (*Allenrolfea*); the samphire (*Salicornia*); and the tussock-grass (*Sporobolus arioides*) * * *. But as a whole the collection made does not speak of 'irreclaimable' alkali land so far as we know their habits. * * * Taken as a whole, the native vegetation does not altogether confirm the unfavorable impression derived from the leaching of the soil samples."

In addition to these soil reports, in January, 1902, several interviews, written up in a sensational manner, appeared in the daily papers in California, practically condemning the Valley and virtually warning investors and settlers from the field. These were the most disastrous of all in their effect on the enterprise.

Experience has proved that these reports were fundamentally wrong in their conclusions, as less than one-half of 1% of the lands brought under cultivation has failed to produce most satisfactory, indeed, phenomenal crops. Nevertheless, the Government's publications were such that the author's statement: "It seems certain that, had the territory not been already settled in very large measure when these reports were sent out, Imperial Valley would yet be unreclaimed" (page 1271), is undoubtedly absolutely true.

The author is in error on page 1264 in referring to the elevation of the bottom of the Chaffey head-gate. This structure was started in March, 1901, and work was rushed as rapidly as possible. When completed, its floor was 3 ft. below the river bottom, and, to make the gate more secure, three 2 by 12-in. sand-boards were put on the toe of the A-frame, to be removed when the sand and silt became settled

around the structure; there was no necessity for removing them while Mr. Chaffey was directing affairs, and, later everybody apparently forgot about them and they were never taken out, the idea thus obtaining that the floor of the gate was at the top of the sand-boards when in reality it was much lower, and as low as it was possible to place it that season. Working at high pressure against a rapidly rising river, the head-gate was finished, and Mr. Chaffey himself turned the water through it on May 14th, 1901.

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Before leaving this subject, and in view of the controversy that has raged regarding the necessity of the fatal cut in Mexico (made more than 2 years after Mr. Chaffey had severed his connection with the Company), it is interesting to note, from Government records, that the old Imperial Canal, from the old intake, carried throughout the Summer of 1904 and until October, 1904, when the Mexican Intake was cut, more water than ever before, and quite enough to supply the users in Imperial Valley.*

The author's statement (p. 1255) that the initial price charged for water stock was \$5.75 is misleading. Those who purchased during the construction period were given bonds of the California Development Company equal in amounts to their initial payments, bearing 5% interest and acceptable at their face value for the last installments on their notes. Hence, those paying \$3.00 cash on their water stock purchases got water rights at \$5.75 per acre. Only \$80 000, par value, of the bonds were thus given out to water stock purchasers on total sales of 50 000 shares in Imperial Water Companies Nos. 1 and 4, the settlers coming in having so little cash and speculators so little faith that they could not or would not take full advantage of the opportunity offered.

The author is again in error as to the reasons for the termination of the five-year construction contract between Mr. Chaffey and the California Development Company. It was not because the former was frightened out by the soil reports, but because it was found that the power of attorney to vote, for five years, stock, which, with his own, constituted a majority and control, was found ineffective on account of the certificates not having been actually turned over. Success had been achieved and these shares of stock began coming in for transfer. It became a matter of buy or sell, and the original promoter's idea of value was deemed to be too inflated, so Mr. Chaffey made the best terms possible for his holdings and withdrew in February, 1902.

The author's outline of the Delta Investment Company and its activities is also misleading, and in some respects entirely erroneous.

* See "Progress Report of Stream Measurements for the Calendar Year 1904," by the late W. B. Clapp, M. Am. Soc. C. E., Water Supply and Irrigation Paper No. 134, p. 27, and compare with measurements in previous years.

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The facts are that in the fall of 1901 it became apparent that the sales of water stock would not produce sufficient money for the work that must be done, and Mr. Heber organized the Delta Investment Company in the hope that by giving it a favorable contract to purchase the bonds and mortgage notes of the California Development Company, outside capital could be attracted to the new company. The Delta Investment Company was launched with the consent and approval of those owning or representing all the stock of the California Development Company. By the terms of this contract, the Delta Investment Company agreed to purchase bonds and notes from the California Development Company to the amount of \$21 000 in cash per month for twelve months, thus guaranteeing the California Development Company \$252 000 in cash, the amount estimated as absolutely necessary to spend during the coming year in a permanent intake head-gate, canals, and other necessary works. In consideration of this guaranty the Delta Investment Company had the right for 12 months to purchase any or all of the bonds and mortgage notes of the California Development Company at 50% of their face value.

As the whole enterprise was still considered by outsiders as an experiment, and the banks of Los Angeles refused to concede any value whatever to the Company's "securities" for loaning purposes, or to purchase them outright at any figure at all, and the soil experts had commenced giving out their unfavorable opinions, the only reasonable criticism of this contract is that it was unfair to the Delta Investment Company and, consequently, unfair to those stockholders of the California Development Company who were large stockholders in the Delta Investment Company, in that it indirectly threw on them the burden of financing the California Development Company without adequate remuneration.

That the privilege of buying the bonds and mortgages at 50 cents on the dollar did not prove especially attractive is best shown by the fact that only a small fraction of the holdings of the California Development Company changed hands under it during the 4 months it was in operation. Mr. Cory, therefore, is correct in stating (p. 1260): "It must be admitted that the Delta Investment Company took over such securities at a larger price than could have been obtained from any other source," but quite incorrect in stating either that there were "many" or "large" or "apparently dishonest" transactions between the two corporations, or in giving the impression that it was a hardship on the California Development Company to part with \$2 in its so-called "securities" for \$1 in hard cash. As a matter of fact, the California Development Company could well have afforded to be much more liberal, and the writer knows that if any one had come into the

office at that time with \$252 000 in gold coin and offered it in exchange for \$1 000 000, face value, of the so-called "securities," there would not have been a voice raised against taking the money, it was so urgently needed. Mr. Chaffey.

Finally, the author is entirely mistaken in saying that March 1st of that year found the California Development Company "with all its bonds gone, its collateral notes and mortgages largely depleted, no money in the treasury, and deeply in debt." The facts are that at that date it had \$47 000 of its bonds on hand, \$525 000 of mortgage notes, \$235 000 of accounts receivable, besides lands, canals, machinery, equipment, etc., and unsold water stock estimated (at the selling price at that time) to be worth \$2 235 000, and its liabilities, including \$453 000 of bonds and deferred payments to Hanlon and Andrade, were less than \$500 000; in truth, from a few months after Mr. Chaffey started work, the California Development Company never was without an ample supply of mortgage notes and bonds in the treasury, but outsiders had not sufficient faith in them to buy them for cash.

In view of what was accomplished in the 22 months ending February, 1902, and the fact that some of the best men in Los Angeles would have joined him and furnished large amounts of capital, provided he had secured full control, it is doubtless safe to say that had he taken control, instead of retiring from the company, there never would have been any runaway Colorado River and the development of the Valley would have been even much more rapid than it has been.

C. E. GRUNSKY, M. AM. SOC. C. E. (by letter).—The problems of the Lower Colorado River have a wonderful charm. They are presented by Mr. Cory in a most comprehensive and attractive way, and he has done the Profession valuable service in putting on record and making available for convenient reference the results of an experience on river work which is unique in character and magnitude. Mr. Grunsky.

So long as there was a fighting chance, in 1906 and 1907, the engineers under Mr. Cory's guidance and upon the wise determination of Mr. Harriman were to keep up the fight. How the fight was won has been well told by Mr. Cory. The writer takes pleasure in again expressing his admiration of the able way in which the work was handled.

At the outset, every one, so far as the writer knows, believed that the work of making a closure in the fall of 1906 would be greatly facilitated by the use of brush mattresses on which to dump the rock. What the work done on the Colorado in 1906 and 1907 has clearly demonstrated is that, with adequate transportation facilities, a brush mattress on which to drop the rock is not essential. It is only necessary to place the rock more rapidly than the water can undermine and bury it.

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Without the spur track from the Southern Pacific main line down to the Lower Mexican Heading, the first attempt to close the break would have been a failure, and yet the writer recollects distinctly that plans were under discussion for the beginning of this work, under which reliance was to be placed on water transportation. The outcome has demonstrated clearly that, when such work is to be done, every possible contingency should be foreseen so that every emergency can be met properly. It was a wise precaution, too, to keep an equipment and a force on hand and available for repairs during the high water of 1907, even though, as it turned out, they were not needed.

At that time the levees were new, and the river brought down an unprecedented volume of water—a maximum of about 100 000 sec-ft.* Naturally, it would be expected, therefore, that the levees had at once been subjected to a severe test. This might have been the case if the conditions on the lower river had remained as in years past; but they had been undergoing a rapid change, with the result that the new levee was only wet here and there, and there was no opportunity to observe what might have happened if the water had been 3 or 4 ft. up on the levee.

The writer made a special study of the problem of the Lower Colorado River for the Secretary of the Interior in the early summer of 1907, and his observations at that time and in the two preceding years as Consulting Engineer in the U. S. Reclamation Service, together with many years of familiarity with certain features of the river, are the basis of the comments which are now prompted by Mr. Cory's paper.

As early as 1883, or thereabouts, Gen. G. W. Shanklin, at one time State Surveyor General of California, and Mr. Duncan Beaumont called the writer's attention to the New River country, as a part of the Imperial Valley was then called, and the desirability of making an instrumental survey to see what could be done toward accomplishing the irrigation of that valley was discussed. It was known at that time that the only practicable route for a canal would be across Mexican territory. The situation appeared to be too complicated, and nothing was done; but the writer, from that day to this, has never lost interest in the problem.

In 1896 the writer explored a portion of the Colorado River below the Grand Canyon and confirmed the selection of a dam site at the lower end of Iceberg Canyon, as the best available, in a long stretch of river, for a low dam to be used in creating a fall for power. He reported at that time that it would be feasible to construct a dam of loose rock on a sand foundation by blanketing the bed of the river for a considerable distance up and down stream with broken rock, using large blocks for the down-stream portions of the work, allowing

* Erroneously estimated at 115 000 sec-ft. by the U. S. Geological Survey in Water Supply Paper No. 249.

the water to bury these as deep as it would, and using finer material in the up-stream face, which would ultimately be made impervious or nearly so by the river silt. The plan of that day involved the complete turning of the Colorado over a low spur of the mountains. Mr. Cory's experience at the Lower Mexican Heading confirms the feasibility of carrying out work of this character.

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Several years later the writer was stationed for three months on the Colorado a few miles above the mouth of the Virgin River, and had additional opportunity for observation. At that time boilers were to be set for mining operations, and brick was wanted. No clay deposit could be found. The most promising mud-bar in the river was sampled. The mud could be balled up and would crack somewhat in drying. It was submitted to a chemist at San Francisco and reported to be composed almost entirely of very fine silicious sand entirely unfit for brick-making.

Above the Virgin River the water of the Colorado, at low and high stages, carried a large quantity of this silt in suspension. This would settle quickly when the water was dipped from the river in a glass, and within a few seconds the water was clear enough to drink. There was certainly comparatively little clay in the silt carried by the river water at this point. This observation leads the writer to assume that the main Colorado must be the principal source of the fine, light sediment, other than clay, which the river carries to the delta, and accounts, too, for the preponderance of material of this character in the river delta; it also makes it appear probable that the clays, bedded as the author describes, probably have originated in other parts of the river's water-shed.

During the low stage of the river, above the Virgin, the writer had occasion to erect a mast or pole on a gravel bar for the support of a cable. The gravel was unusually firm. It consisted of all sizes from cobble-stones down to sand, and in its dry condition appeared to be almost cemented. The mast was erected and large boulders were piled around it. When the river rose the gravel around the mast became wet, softened, lost its cohesion, and acted very much like a quicksand; the mast required additional support or it would have fallen.

A heavy crankshaft lying above the water on another portion of the gravel bar commenced to sink into the gravel when this was wet by the rising water, and was with difficulty supported until it could be transferred to safer ground.

These facts are alluded to as a warning against placing too much reliance on gravel for the facing of bank or levee slopes. The gravel, in the case of the Colorado River levee, serves a most excellent purpose, and its use is not criticized, but gravel has no particular virtue as a material for resisting the attack of a current, and will have but little resisting power when used in spur dikes. It is an excellent

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material, however, as in the case of the levees on the Mexican side of the Colorado, for blanketing the levee, serving as a protection for the earth slope against wind erosion, and checking to a large extent the activities of burrowing animals.

The Colorado below Yuma, as explained by Mr. Cory and as noted by the writer in a paper presented to this Society in 1907, is flowing down the slope of a delta cone. While undisturbed by human agency its floods annually watered broad areas, and the rank vegetation which sprang up on these areas was an effective barrier opposed by Nature to the concentration of the river's flow along new channels, even though some of the water going over-bank should long ago, if topography alone is considered, have cut out a new course for the river. The river has been compelled by these restraining forces to hold for more than 500 years to the course as geographers first knew it from Yuma to the Gulf.* However, though the river, unaided, could not break away from this general alignment, it swung back and forth, within restricted limits, on an ever-changing serpentine course. The river along the thread of the stream has a fall of about 1 ft. per mile, and the average fall along the air line from Pilot Knob to the Gulf is about $1\frac{1}{2}$ ft. per mile.

When attempts are made to confine a river of this character between levees there is trouble. Under the attack of the river, the banks will continue to break away, first at one point and then at another, and no amount of care in the location and construction of levees can insure them against destruction from this cause. To check the caving bank is difficult and expensive, even when adequate facilities are at command, as has been well set forth by Mr. Sellev. In ordinary cases, it is out of the question to eliminate entirely this source of danger to levees located comparatively near the river bank.

It is natural, then, that the levees in the case of such a river should be set far back from the banks. In this location on the Colorado the levee cuts off the river bends and, therefore, follows a line of greater slope than the river. This is actually the case below Yuma, except for the first long stretch below Pilot Knob, where the river is straight for some 8 miles and the levees on each side are parallel with the stream and comparatively near the banks. Below this straight reach, the river channel, down to the Arizona boundary, is about 30 or 40% longer than the levees on their present location (Plate LVI).

If the river rises above banks and water stands against these levees, some barrier must be interposed to its flow if erosion at the base of the levee is to be prevented.

Even when constructed as was the original levee at the Lower Mexican Heading, with borrow-pits on the land side, the work of levee

* *Transactions, Am. Soc. C. E.*, Vol. LIX, p. 6.

building gives more or less open space for the water on the river side along the levee, and there will be concentration of flow there which will rapidly cut channels in the light silt soil of the delta. The spur dikes, as built by Mr. Cory, offer some obstruction to this flow, and are of value under certain conditions; they have been of use during such moderate bank submersions as have occurred since the levee was built, but under a real test, with water 4 or 5 ft. on the bank, they would serve to concentrate fall and would start local cutting which might prove quite as dangerous as the general erosion due to uniform flow along the levee. It may be stated in a general way that the efficiency of such spurs for the same aggregate quantity of material in them will ordinarily increase as distance between them is decreased.

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While Consulting Engineer in the U. S. Reclamation Service and adviser to the Secretary of the Interior, the writer reached the conclusion that it would be hopeless to endeavor to carry out the proposed scheme of building levees along the Gila River just above Yuma. Levees along the banks of the Gila cannot be maintained short of an expenditure for bank revetment which the value of all the land to be there protected would not justify. The situation is somewhat more favorable on the Colorado, which, owing to a lighter gradient, is less erratic than the Gila, but there, also, the fact should be recognized that it presents no ordinary problem.

The land to be protected on the Lower Colorado is of such extent and of such fertility and potential value that there should be no hesitancy in taking every step that may be necessary to bring the Colorado under permanent control.

The Secretary of the Interior was advised by the writer in 1907 that the Colorado should be given permanent banks from Pilot Knob about as far down as the Arizona boundary. He was advised that this work might cost from \$50 000 to \$150 000 per mile of bank, involving, as it would, permanent loose rock revetment of banks; and that the United States should be prepared for an expenditure of from \$4 000 000 to \$5 000 000, of which a portion should be contributed by Mexico because the benefits of the work would accrue to Mexico as well as to the United States. He was also advised that there should be created at once an International Engineering Commission, with full power to undertake the work of giving the river a permanent direct channel, as indicated, and to give consideration to all other problems arising on this stream. At the same time, the irrigation problems were reviewed, and the need of an early action for the protection of the Imperial Valley was pointed out.

At that time the Imperial Valley had to depend on a foreign corporation, *La Sociedad de Yrrigacion y Terrenos de la Baja California*, for protection against overflow and against complete and permanent submersion of the valley by the Colorado. It had to depend on

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this company, and it is still dependent thereon, for its irrigation water, which, after being diverted from the river in the United States, is turned over to the Mexican Company by which it is re-delivered into California. Such an arrangement needs the sanction and protection of higher authority. The arrangement cannot be regarded as entirely satisfactory until, under some treaty or other convention with Mexico, the right of a diversion of Colorado River water through Mexico is permanently assured to the people of the United States, and the two countries acting in harmony adopt adequate measures for keeping the Colorado out of Salton Basin.

Circumstances have favored the maintenance of the work done on both sides of the Colorado prior to 1907 below Pilot Knob. In that year the river carried more than the ordinary quantity of water; but the delta had been dry for two seasons, the river banks were free of grass and weeds, which had been largely burned off, and the over-bank flow, therefore, was far in excess of what would have occurred if the river had not been out of its natural course from 1905 to 1907, and if well-watered banks had been covered with dense vegetation. Due to its bare banks and to the consequent large over-bank flow at low elevation, the river did not rise as high and there was not as much water against the levees as there might otherwise have been. Then, too, in the spring of 1907, the cutting off of Nigger Bend and the shortening of the channel at that point by 2 or 3 miles had some effect in lowering the high water as far up stream as Yuma, and then—in 1909—came the relief at the Abejas. It may be assumed, therefore, that the behavior of the levees on both sides of the river, in 1907 and in the following seasons, is not a conclusive test of similar structures.

The writer inspected the levees on both sides of the river at high water in 1907. On the west side the levee below the dams at the Lower Mexican Heading had not been wet. At and near these two dams, completed a few months before by Mr. Cory, where the borrow-pits were on the land side, there was some seepage under the levees. Miniature, pin-head, under-water volcanoes made this apparent to the eye. The water in the borrow-pits was but little lower than in the river; consequently this seepage was caused by a pressure head of only a few feet. No doubt, it would have increased somewhat with a rise in the river. It was the result of the slow movement of the soil-water inland from the river.

On the Arizona side the borrow-pits were carrying a small quantity of water; they were not bank full. The abatis work across the borrow-pits appeared to be catching considerable trash, and each barrier of this kind checked in some measure the velocity of flow for a short distance up stream, but gave the impression that under ordinary conditions of bank submersion such structures would have been quickly cut out by the water passing around their ends. The writer was not

impressed with their efficiency, although they undoubtedly did some good under the conditions which prevailed in 1907. Mr.
Gruosky.

In 1910 the writer again had an opportunity to inspect the levee on the west side of the Colorado, and noted that where the checker-board arrangement of borrow-pits had been adopted the spill from one into the next, even with very slight river bank submersion, had caused some channel cutting, making clearly apparent an inherent weakness of this arrangement.

After a number of favorable seasons these outside borrow-pits will to a large extent be refilled with sediment from the river. If located close to the bank and on no greater slope than the river, the refilling of such pits along such a river as the Colorado may occur quite rapidly. Until thus refilled and overgrown with vegetation, they are, to almost the same extent as a continuous borrow-pit, a menace to the integrity of the levee whenever the latter follows an alignment along which there is an excessive fall, as is the case on the Colorado with the Paredones levee and with those above and below the Abejas.

In reporting to the Secretary of the Interior on the matter of river treatment, the desirability of using hydraulic dredges in the construction of the levees was referred to by the writer, and he still believes that, wherever the location will permit, the bulk of the levee work on the Colorado should be done by this method. The first work would then be the excavation of an ample trench, the material from which would form the river side restraining embankment for the hydraulic fill. The hydraulic fill would then be deposited in the rear of this, refilling the trench and bringing up to the desired height an embankment so wide of base that underflow through cracked soil and through burrows would be made impossible.

The writer is of the opinion that the control of the Colorado between permanently fixed banks should not be projected beyond some agreed point near the Arizona boundary line. If the river is kept on a proper alignment down to that point, it can wander about over a large lower portion of the delta without menace to the Imperial Valley. It will then, as it does to-day, send its waters, at least in large part, into the Volcano Lake region, and will warp up first one and then another section of its lower delta region. In the far future, then, the time may come when complete control to the Gulf can be economically justified.

If controlled mainly by giving the river a direct alignment between permanent, well-protected banks, supplemented with levees, as far down stream as here indicated, the protection of the Imperial Valley and the whole Alamo and New River country will be complete, if the cross-levee to the northward of Volcano Lake from the base of the Cocopah Mountains to the Colorado at the Lower Mexican Heading

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and up the river to Pilot Knob be brought up to proper height and be protected adequately, particularly against wave action.

The writer desires to note that the various estimates of flow of the Colorado, even those based on gaugings, are to be accepted with caution. Some additional information relating to methods of gauging should be given before these estimates are accepted as conclusive. This applies particularly to the measurements made at the river's high stages. It is understood that some special precautions are now being taken to insure accuracy of soundings and the correct placing of the current meter at the intended depth; but in 1907 the writer knows that this was not done, and that the maxima then recorded are too great by from 15 to 20 per cent.

The two-point method of gauging was at that time used. The gauging was made from a car supported by a cable. In mid-stream the car was from 5 to 8 ft. above the water surface. A sounding was made immediately before the velocity was measured. The heavy sounding lead was lowered from the car to the water surface and a reading of the paid-out line was taken. Then it was lowered to the bottom of the river and another reading was taken, the difference between the two being recorded as the depth. No allowance was made for the line swinging out of the vertical, due to the force of the current, which was about 7 ft. per sec. in mid-stream. By observation from shore on June 24th, 1907, the correction to be applied to the recorded mid-stream depth of 45 ft. was found to be about 6 ft. The recorded depth determined the required immersion of the current meter. When the meter was supposed to be at one-fifth depth, or 9 ft. below the surface, it was in reality barely below the surface; and when it was supposed to be at four-fifths depth, it was but little deeper. The only value of the velocity measurements as made lies in the fact that they can be used to determine surface velocity. They were recorded, however, as applying to the two-fifths and four-fifths points, with a resulting over-estimate of mean velocity. In this particular case the recorded discharge should be reduced 15% to give approximately the flow of the river on that day.

The errors of observation as above noted were, of course, called to the attention of the Reclamation Service and the United States Geological Survey, but no correction has been applied, and the writer does not know how long such methods of gauging were maintained at that station.

In Water Supply Paper No. 249 of the U. S. Geological Survey, page 45, the discharge is noted for June 24th, 1907, at 112 000 sec-ft. Of this quantity 11 000 sec-ft. were flowing in the north channel of the river and 101 000 sec-ft. were recorded for the main stream. According to a proper interpretation of the measurements on that day, the main stream carried only 86 000 sec-ft., and probably somewhat

less. The aggregate discharge for that day should have been noted at 97,000 sec-ft., instead of 112,000 sec-ft. The error in the main stream gauging was about 17%, or the recorded main stream flow should be reduced 15 per cent. The same correction should undoubtedly apply to the entire period in 1907 during which the river was at or near its highest stage. The writer has no information as to whether the same method of gauging was still in use in 1909. If it was, there can be no doubt that in that year, also, there must have been a considerable over-estimate of discharge.

Mr.
Grunsky

Mr. Cory is right in his conclusion that the construction of reservoirs within the water-shed of the Colorado will have some beneficial effect in equalizing the stream flow and in reducing the maximum discharge. It is immaterial whether or not the storage possibilities have been over-estimated. This can only affect the extent of the reservoir influence; and yet, whatever this may be, it will not change the river problem, except as to its magnitude. The river will still have its varying volume of flow. Its channel will adjust itself to the new conditions. The same lack of channel capacity will be felt at high stages on the lower river as is felt to-day, and the same problem of keeping the delta channels of the river on the Gulf slope will confront the river engineers of the future as confronts those of to-day, except only that there will be somewhat less water and correspondingly less silt to be reckoned with.

Perhaps a word should be said about the Laguna Weir. The change in the original design from a paving with large blocks of rock to a paving with concrete was due to the fact that the granite which had to be removed at each end for the sluice-ways was not of a character which could be used for this paving work. It was anticipated by the engineers who designed and approved the structure that the granite at the "Lagunas" which appeared to be disintegrated and rotten at the exposed surface would be of good quality when cut into; but, as the work progressed, it was found that the hills afforded very little sound rock within the limits of the prescribed excavation, and that at the best quarry sites near the weir only a small proportion of the rock was suitable for paving. This situation was carefully considered before a modification of plans was recommended by the Board of Consulting Engineers which had this matter under consideration in 1906.

The writer, though not desiring to criticize unfavorably the works which have been carried out at Laguna for the diversion of water into two canals, one on each side of the river, has never been in full accord with the general arrangement of the structures at that point. The plans for these structures were approved before he had anything to do with the Reclamation Service, and no one is more pleased to learn that they are rendering satisfactory service. Nevertheless, he

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would call attention to the fact that the decrease of depth of overflow over such a structure, resulting from its great crest length, 4700 ft., is not necessarily of sufficient importance to outweigh the disadvantages that will result from the use of a dam with so long an overfall crest. The storage of silt in the reservoir space above the dam, in the case of such a river as the Colorado, is of no importance. This space, except for a channel of ordinary width leading to the sluice-gates, is soon filled with silt and overgrown with willows and cottonwoods. There is a strong tendency for drift to lodge, and, within a few years, there may be such obstruction to a concentrated flow in lines parallel to the original course of the river that it may be difficult to keep the waterways open to the two ends of the weir without permitting one or the other to parallel and endanger the structure. The conditions at the weir, in a few years, may be such that water will go over it at uneven depth, and, in that event, the great length will fail to accomplish fully the desired purpose. At any rate, there will be trouble from time to time in keeping the water on a proper course to the two ends of the dam. The removal of silt which the sluice-gates will permit is dependent on the depth of the sluice-ways below the sills of the canals. The silt which the river will deposit in the large channel leading to a sluice-way, while the water is forced to rise to the crest of the dam, can of course be sluiced out from time to time by opening the gates, but this will be restricted to the deposit in a channel. It is not the accumulation in a reservoir, and this fact should not be lost sight of in planning such structures. Even this, however, may be worth while. The writer believes that the river should have been forced into a definite position above the weir by making a section thereof, probably 800 ft., a few feet lower than the rest of the structure and then arranging flanking walls to be overtopped at highest stages of the river and to serve as training walls of the large-capacity channels leading to the sluice-gates, which would, as at present, serve to keep the channel open to the head-gates. One great advantage of such an arrangement would be the concentration and depth of flow necessary to carry drift of whatever size over the dam.

Mr.
Clarke.

CLARENCE K. CLARKE, Esq.* (by letter).—Although this paper and Mr. Sellew's discussion of some phases of the subject seem to have covered the ground quite thoroughly, it appears to the writer that room remains for a few statements of fact concerning the "rough and ready methods" of dealing with the river which Mr. Sellew does not accept as a solution of the engineering problems pertaining to the subject.

Being one of the men referred to by Mr. Sellew as "red-blooded fighters, who did not know when they were whipped, but * * *

* Chf. Engr., Palo Verde Mutual Water Co.

fought on to victory unmindful of its cost," the writer desires to correct an erroneous impression. The crevasse in the river bank and levee in 1907 was closed by railroad men, who used methods with which they were familiar; they tried no experiments and devised no new engineering practice. They knew they were not whipped at any stage of the game, and they kept at the job because they had done the same thing on a smaller scale many times and were confident of ultimate success.

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The use of the water of the Colorado for the irrigation of land creates the problem of control. There is no other reason for subjecting that river to control. The problem, so-called, as the writer sees it, presents three phases: 1, direction of the flow of the river and control of its meanders, involving bank protection; 2, exclusion of overflow water, by levees, from land susceptible of reclamation and irrigation; 3, safe and certain diversion of water from the river into irrigation canals.

The Lower Colorado has no fixed channel, because of the character of the soil, which is a deposit of silt, readily eroded. The current swings back and forth, cutting the banks and changing the meander line, and an apparently insignificant obstruction sometimes causes shifting of the channel for miles. A sudden shift of the channel from one bank to the other may leave a canal intake dry and put an irrigation system out of business. It may cut across a tongue of land, changing a wide bend into a tangent and forming a new bend lower down. Therefore, one factor of the problem is the maintenance of a defined course of the river between permanent banks. That may be accomplished by adequate protection of the banks and control of the meanders. It is advisable and feasible to straighten the course of the river at some points, and by increasing its velocity, to check its tendency to swing from side to side. The shortening of the river, resulting from the elimination of many horse-shoe bends, would increase the scouring action of floods and their silt-carrying capacity, and greater volumes of sand and silt would be transported to the lower delta and deposited there, building up large areas of land and accelerating the work that the river has been doing for ages. By the control of the lower river, the floods could be diverted into the basin of the Laguna Salada, and that shallow basin could be converted by silt deposit into an arable and fertile valley. In time, of course, the deposition of silt would work back, and the normal grade of the river would be re-established, necessitating the adaptation of levees to the new condition.

It is the writer's purpose to point out that this is not a problem calling for the invention of new methods of river control.

Bank Revetment.—Effective bank protection can be provided most readily and economically by laying a railroad track on the top of a

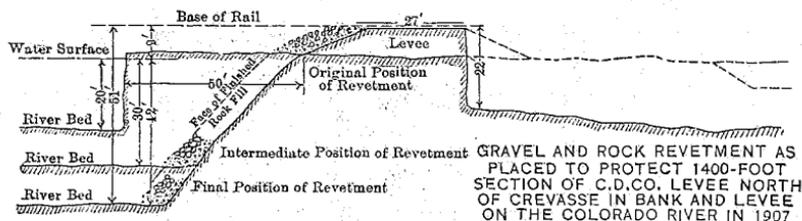
Mr. Clarke. levee; and, as other writers have suggested, it may be applied in sections as needed. That tracks on the levees along the Lower Colorado are indispensable to their maintenance and the defence of the banks against undercutting attacks by the river, has been the writer's fixed conviction since his first experience with the river; and he notes with gratification that Mr. Sellew has revised his former opinion on the subject and concluded that the railroad track facilitates the work of levee protection to a degree that more than offsets the cheapness of the methods heretofore used by the Reclamation Service on the Colorado.

Having the "firing line" established by the track on the levee, it is important to provide an abundant supply of "ammunition" and means of rushing it to "the front." Quarries and gravel pits are opened, and are equipped with derricks to handle large rock, and steam shovels to handle small rock and gravel. When the river begins bank cutting and threatens to undercut the levee, train loads of gravel and rock are taken to the point of attack and dumped at the toe of the levee. Gravel is dumped first in order that it may underlie the heavy rock and prevent the sluicing out of silt and sand where the rock lies on the bottom. When the bank caves, the rock on the berm falls into the trench dredged for it by the river, and if the scouring continues and the trench is deepened, more rock is dumped to reinforce the revetment and raise it to the crest of the levee. Small rock and steam-shovel material serve to fill and face the revetment. When such revetment has dropped to the river's lower scour plane and has been completed by proper reinforcement, the work of bank protection at that point is done permanently, and the levee thenceforth is safe from undercutting.

An illustration of this method of bank revetment was the saving of a section of the C. D. Co. levee, as a part of the work of closing the break with what Mr. Cory calls the Clarke Dam, in January, 1907. The river swung in against the levee north of the break and threatened to destroy 1 400 ft. of the embankment and widen the crevasse from 2 600 to 4 000 ft. The width of the berm between the toe of the levee and the bank varied from 30 to 50 ft. for the greater part of the 1 400 ft., but near the north end of the section the current had washed away most of the berm, and in the bight the water was close to the toe of the levee. To divert the current from this bight, a jetty 90 ft. long was built out from the upper side. The jetty consisted of two rows of piling, 5 ft. between rows and 8 ft. between piles in the row, the piles being "staggered" or alternated. The piles were 40 ft. long, and were driven in 26 ft. of water. Before the completion of the jetty, the discharge of the river was increased to 40 000 sec.-ft. by a freshet in the Gila. Gila freshets carry great volumes of heavy silt in suspension, and this material drops readily when the velocity of the current is checked. It was not necessary to oppose any other barrier or baffle

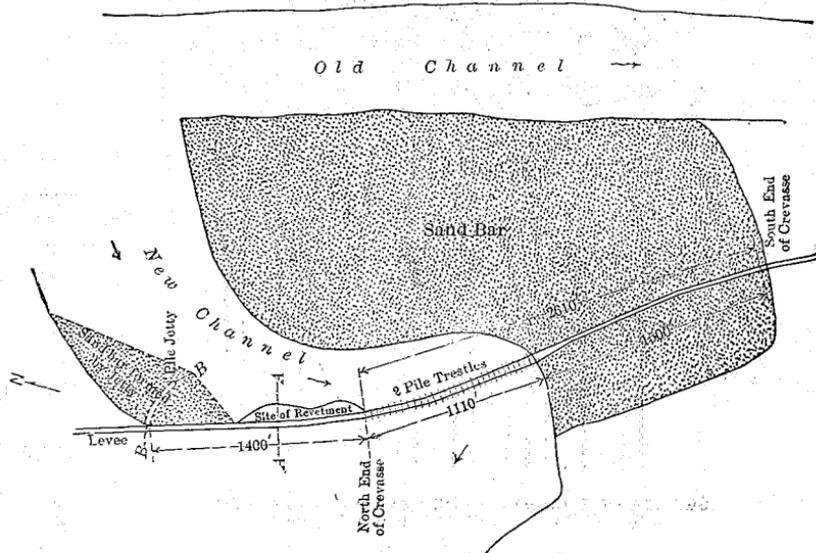
than the piles to this heavily laden flood, and no brush was placed in the jetty. Eight days after the completion of the jetty, the river discharge fell to 15 000 sec-ft., and a bar was exposed on each side of the jetty and extending $13\frac{1}{2}$ ft. beyond its outer end, where the water had been 26 ft. deep. The rapid formation of the bar was due to the Gila silt. To accomplish similar results with Colorado River water alone, more obstruction, in the form of fascines or wire entanglements, would be required, and the process of bar formation would be slower.

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SECTION ON A-A

FIG. 84.

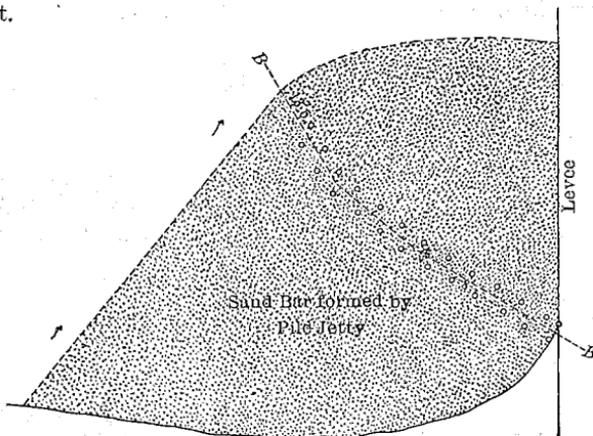


PLAN SHOWING METHOD OF DEFENDING LEVEE AGAINST ATTACK BY RIVER DURING CLOSURE OF COLORADO RIVER CREVASSE BY S.P.R.R. ENGINEERS IN 1907

FIG. 85.

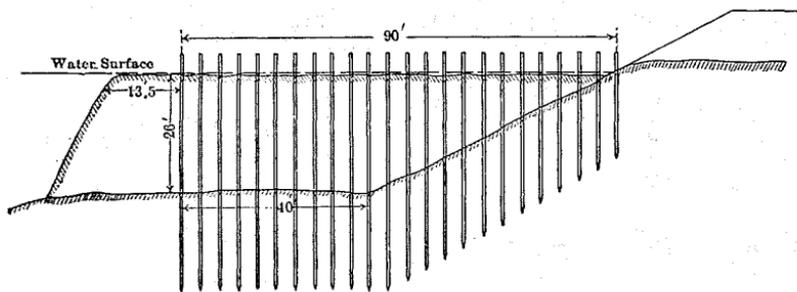
When the jetty was built, the levee embankment was widened toward the river with gravel and rock, the track was moved to the extended fill, and large quantities of gravel and rock were unloaded, covering the berm to a width of from 8 to 10 ft. from the toe of the

Mr. Clarke. levee. As the river cut away the bank and deposited the gravel and rock at the bottom, where the material was needed, more rock was unloaded. The depth of water at the bank, when the cutting began, was from 20 to 25 ft. This depth increased to 42 ft. as the river dredged a trench, and at that depth the scouring action ceased. When the revetment was completed and the 1 400-ft. section of levee had been protected, the height from river bottom to base of rail on the levee was 51 ft.



PLAN OF PILE JETTY

FIG. 86.



SECTION ON B-B

SECTION OF SAND-BAR FORMED BY PILE JETTY FROM
C.D. LEVEE ON THE COLORADO RIVER, 1907

FIG. 87.

Gravel is a factor of vital importance in this method of placing rock on a sand or silt bottom, a detail which appears to have escaped the notice of some of the "innocent bystanders," who watched the closure of the crevasse and predicted utter failure of the work. The plan of providing revetment material at a threatened point and leaving to the river the work of dredging a trench and placing the rock, has been approved recently in a practical way by so eminent a river engi-

near as Mr. Sellew, who used the method last year in defending one of his levees from attack. As he does not refer to the use of gravel as a bed for rock revetment, presumably that essential detail of the method was omitted.

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This method of bank protection, however, is no innovation, and, in his application to the closure of the Colorado crevasse of practice that is old to "fring-line" railroad engineers in the West, the writer cannot lay claim to originality. He used the same method on the San Pedro River, between Benson and Fairbank, in Arizona, many years ago. In 1891, the roadbed of the Northern Pacific along the Puyallup River, in Washington, was protected in identically the same way within less than 4 miles of the Tacoma depot, where doubtless many "innocent bystanders" observed the work.

Control of the River.—The general application of this system of revetment to the banks of the Lower Colorado, in the writer's opinion, would solve, simply and at comparatively low cost, the problem of keeping the river within defined bounds and protecting levees against undercutting between flood seasons. Combined with the straightening and shortening of the river's course and control of the meanders, this revetment of banks would increase the efficiency of the channel. Trees and other obstructive growth on the bars and flats would be removed by the river itself, and its carrying capacity would be sufficient eventually to take care of floods.

Experience has demonstrated that the revetment here described, consisting of gravel and rock, and placed from the lowest scour plane to the crest of the levee, constitutes a permanent barrier and solves the problem of control of the Colorado.

The resulting rock-reveted permanent barrier would be similar in all essential features to that contemplated in the suggested plan of river control attributed to Gen. Marshall, which involves the excavation of a trench to the ascertained scour line by the use of dredges or power shovels.

A serious objection to the suggested plan referred to is that it would be applied without reference to immediate need for defense, and would entail large expenditure for dredging and revetment where protection might not be required for many years. The cost of excavating trenches to the scour line, along both banks of the Lower Colorado, with dredges, would be enormous, and it has been demonstrated that such expenditure is quite unnecessary. The river can be depended on to do all the dredging and to place the gravel and rock at the bottom of the trench.

Only the National Government could or should undertake the task of controlling the Colorado, as it has prosecuted the work of protecting lands along the Mississippi against inundation. The first step in the project obviously would be to construct levees along both banks

Mr. Clarke. and lay tracks thereon. During the progress of this work, gravel and rock quarries should be opened and equipped with the requisite loading appliances, and cars should be provided to carry the material to the front. In case of attack on the levees by the river, material would be sent to the threatened points, and the work of permanent revetment would be done at those points. After the completion of the levees, the means and material for revetment would be kept in readiness; during each flood season the river would be observed vigilantly; and every attack on the levees would be met promptly.

This method would distribute the work over many years. Conceivably, 50 years or more might pass before the banks would be reveted throughout the course of the lower river, but during that time the stream would be virtually under control. The cost also would be distributed, and no very great expenditure probably would be called for in any one season. The ultimate result would be absolute control of the river between permanent barriers defining its course.

Control of Meanders.—Emergency methods of control of meanders and of the direction of the channel, used on the Colorado, are simple and comparatively inexpensive, and may be applied by settlers to the temporary protection of their riparian lands. The writer had occasion to resort to these methods in January, 1913, for preservation of the flow of water through the intake of the Palo Verde Valley irrigation system.

The Palo Verde intake is cut through a rock projection into the lower part of a wide bend in the river. The river developed a tendency to cut across the bend by the chord of the meander arc, and, if unchecked, the channel would shift toward the Arizona shore, and leave a wide bar in front of the intake. This tendency was shown in the cutting away of the nose of a bar that extended from the Arizona or eastern shore to about the middle of the bend, and it was necessary that the bar should be maintained. This was accomplished by driving posts and placing fascines and sand bags on the point of the bar. A fascine jetty was built out from the Arizona bank, $1\frac{1}{2}$ miles above the bar, and pointing down stream at an angle which would direct the current into the bend above the intake. The cost of this work was small, and the effect was all that was required. The channel was kept in the bend close to shore, and the supply of water through the intake was assured for the season.

By similar means, when the river begins cutting the bank and threatening destruction to lands or levees, a bank-caving current may be converted readily into a silt-depositing eddy. Fascine jetties—rows of driven posts with bundles of brush placed between them and anchored with sand bags—may be built quickly by the farmers, and danger may be averted if detected early and if the remedy be applied at the first indication of trouble. Such temporary defences are avail-

able in advance of the permanent system of protection, consisting of levees, railroad tracks, and rock revetment, and may be built by intelligent farmers without the aid of engineers. Mr. Clarke.

Levee Construction.—The writer did not participate in the exhaustive discussion of the relative merits of river-side and land-side borrow-pits in levee construction on the Colorado, which followed the failure of Col. Ockerson's levees and was carried on recently by many engineers in the technical press. The subject having been reopened by Mr. Cory and Mr. Sellew, however, it seems pertinent to call attention to a few facts which have been overlooked or ignored by both.

Mr. Cory explains clearly and correctly the failure of the levee below the Hind Dam in December, 1906, which was due solely to the absence of a muck-ditch under the levee. He gives reasons for the omission of the muck-ditch, chief of which was the supposed necessity for confining expenditure, as closely as possible, to the repair of the break. Mr. Cory says the desirability of muck-ditching was fully realized, and it was a part of the original design, but because levees had been built without muck-ditches on the Colorado, and some one advanced the theory that a cracked adobe foundation would be made tight by pressure when wet, the vital necessity of muck-ditching was not recognized, and the builders of the levee decided to "take a chance." The theory of the closing of adobe cracks proved unsound. Water followed the cracks under the levee and caused the break.

Mr. Sellew admits that water did go under the levee because of the absence of a muck-ditch, but he contends that "the damage caused by a head of 15 in. against the levee was due primarily to the presence of land-side borrow-pits."

The borrow-pits, 3 ft. deep, were separated from the levee by a berm 40 ft. wide, and it is manifestly absurd to assert that there could be any relation between the pits and a 15-in. head against the levee. The pressure angle of the greatest head against any levee on the river would not reach the pit. According to Mr. Sellew's theory, an inside borrow-pit $\frac{1}{2}$ mile back of the levee would increase the static head and cause failure of the work. Mr. Cory left an opening for attack when he said the increased total head was "the only pertinent objection to land-side borrow-pits." Experience has demonstrated, however, that the objection is impertinent, irrelevant, and immaterial. No land-side borrow-pit levee, properly muck-ditched, on the Colorado, has been broken or even damaged by the river, but every river-side borrow-pit levee has been breached or destroyed, and every flood season since levees were first built on the river has seen a strenuous fight to maintain them. The river-side borrow-pits are invitations to the river to side-wipe the levees with currents of eroding velocity, and a levee not blanketed heavily with gravel, or rip-rapped with rock or mattresses, melts away like a bank of salt. Every levee breach has been

Mr. Clarke. caused by current erosion, not by static head or pressure. No levee has been pushed over by the river.

"*Last Word*" on *Borrow-Pits*.—Quoting from Mr. Sellew's discussion, page 1482:

"Regarding the advantages and disadvantages of land-side and river-side borrow-pits, the writer has fully expressed himself, so that it is not necessary to comment further. Particularly is this so when the author [Mr. Cory] states that he 'realized that this [land-side borrow-pits] was not in accordance with the usual practice.'"

The implication that Mr. Cory confessed judgment against the land-side borrow-pit and yielded every point to Mr. Sellew in the argument, seems to the writer no more than a verbal quibble. A practice may be "usual" and still not the best possible under all conditions.

Doubtless there is satisfaction in the belief that one has routed all opponents in argument and said the last word on a debated subject, but it does not appear to the writer that any one of the eminent engineers engaged in the borrow-pit discussion has warrant for "laying that flattering unction to his soul."

It might be inferred from Mr. Cory's statement, that the land-side borrow-pit method of constructing the C. D. Co. levees in 1906-07 was "decided on after careful consideration of the advantages and disadvantages," that there was doubt on the subject in the minds of the men on the job. The matter may have been—in fact was—debated persistently by the "innocent bystanders," but there never was any question of methods in the minds of the railroad "fring-line" engineers having direct charge of construction. It is and has been for years, not only the usual practice, but the invariable rule of railroad engineers in the West, that nothing between an embankment and a river shall be disturbed. The protection afforded by earth in place and by trees and brush must be maintained intact. That was why the land-side borrow-pit system of construction was adopted as a matter of course. It was followed until the bystanders, tired perhaps of being innocent, got themselves appointed as a "consulting board" and after two attempts succeeded in getting an imperative order from financial headquarters to the engineers on the job to conform to the usual practice of the levee builders on the Yuma Project. Had they succeeded earlier, the levee could not have been built at all during the flood period. From the moment the water came over the river bank, work of any sort on the river side of the levees was impossible.

Experience in railroad construction and maintenance in regions subject to floods, in the building of dams and levees in the Delta of the Colorado and in the Palo Verde Valley, and in the control and maintenance of irrigation canals of large capacity, has left the writer in no doubt concerning the essential principles of levee construction on the Lower Colorado River.

The first requisite pertaining to the location of a levee in this region is a careful underground survey to determine the sort of material to be encountered in excavation for muck-ditches. Large deposits of unfit material, such as adobe, heavily alkaline soil, and certain kinds of sand, must be avoided by detours. Seepage is the only factor detrimental to the land-side borrow-pit plan, and that is to be eliminated by the muck-ditch. The theoretical additional head against the levee, due to a borrow-pit 40 ft. in the rear of the levee, is a negligible factor. Under conditions actually encountered on the Colorado, there is not any additional head, either in fact or in theory. That objection to the land-side borrow-pit is not even theoretically plausible.

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Clarke.

Essential Features.—The essential features of efficient levee construction on the Lower Colorado are: location avoiding bad ground and careful muck-ditching to exclude seepage; land-side borrow-pits, leaving all natural protection on the river side undisturbed; gravel blanket to resist erosion and to minimize attacks by burrowing animals; railroad tracks on top of the levee to facilitate maintenance and to make possible the protection of banks and levees by permanent rock revetment.

Mr. Sellev is unquestionably right in his conclusions:

“That in their present state, the levees are at the mercy of the meanders of the stream, except throughout those portions where a railroad occupies the levee top”; and, “That bank revetment, permanent in character and reasonable in cost, when compared with other methods, can be readily and quickly accomplished with rock placed from railroad trains operated on the levee tops and connecting with existing quarries which are within a reasonable distance.”

The first conclusion is sustained by the history of all the Colorado levees, and the correctness of the second was demonstrated clearly in 1907 by the holding of the 1 400-ft. section of levee against the attack by a flood of 40 000 sec-ft. at the time of the last closure. The permanency of rock revetment thus constructed, however, depends on the placing of gravel as a bed for the rock. That is a vital detail of the method.

In rip-rapping levees and reveting the banks at the toes, in the opinion of the writer, grading to uniform slope is not only unnecessary, but inadvisable. It is better to place the gravel and rock on the natural ground. Setting rip-rap by hand on the face of a levee makes a neat looking job, but it is needlessly expensive, and the protection is less effective than that secured by the gravel and rock method.

Before leaving, finally, the subject of closure of the crevasses and the preservation of Imperial Valley in 1906-07, the writer desires to put on record the fact that the accomplishment of the work was due primarily and exclusively to the independent judgment and courage

Mr. Clarke. of Mr. Harriman, who persisted in his belief that the breaks could be closed, and his determination to close them in the face of opposition, and regardless of the positive assertions of a host of eminent engineers that closure was a physical impossibility.

Submerged Weir.—Mr. Cory has described briefly the submerged rock weir placed across the river at the intake of the Imperial Valley Canal in the summer of 1910, and has mentioned its unexpected stability and durability. Mr. Sellew does not discuss the weir or its effects directly, possibly because he did not view its construction with favor, but his comment on Mr. Cory's statement concerning the permanency and efficacy of rock fill in the crevasses has bearing on the subject. Of the rock fill Mr. Sellew says:

"How it would act as an overflow weir, carrying 150 000 sec-ft., even if covered with concrete, is problematical. In addition to a concrete top, crest and foot-walls appear to be necessary to prevent the top from being undermined, and, if these are provided, the resulting structure will not differ materially from Laguna Dam either in design or cost."

This is a case in which accomplished facts fail to justify speculative theory, and it appears to be in order for the writer, as the builder of the weir, to state the facts and show the actual effects of the installation.

Construction of the weir was necessary because of the recession of the bed of the river, following the diversion of all its flow into the Abejas channel, and because of the lack of a powerful dredge to keep the floor of the 1 900-ft. intake from the river to Hanlon gate as low as the sill of the gate. The discharge of the river was diminishing, and danger of complete diversion of the channel from the intake was imminent. The placing of a weir to check recession and direct the current was the only practicable rapid method of returning the water to the canal and saving a \$6 000 000 crop in Imperial Valley.

A trestle, 960 ft. long, composed of four-pile bents, 15 ft. between centers, was built across the river, below the intake, to the Arizona shore, at an angle of approximately 70°, the Arizona end being the farther up stream. Caps, stringers, ties, and rails were placed on the structure, and steam-shovel rock from the adjoining quarry was dumped from the trestle and spread to a width of 50 ft. No brush at all was used, and no derrick rock was dumped. As the weir was designed to be temporary, no gravel was placed either before or with the rock. The discharge of the river during the progress of the work was about 9 000 sec-ft.

The weir was constructed in 21 days, at a cost of \$22,500, of which amount \$4 000 was recovered in salvage of rails, ties, stringers, and caps. The quantity of rock used was 12 800 cu. yd., of which 9 600 cu. yd. were placed in the weir, the rest being used torevet the banks

and raise a spur track above the high-water mark of 1909. The angle of the weir to the current served to point the channel to the California shore, and also served other purposes familiar to "firing-line" railroad engineers. Mr. Clarke.

The weir arrested the recession of the river bed, turned the water into the intake, averted a water shortage in the Imperial irrigation system, and saved to the farmers of Imperial Valley crops worth \$6 000 000 or \$7 000 000. Also, the successful construction and operation of the weir demonstrated that the farms of Yuma Valley, dried out and virtually abandoned for 5 or 6 years, could have been watered at small expense, and could have produced and marketed crops to the value of \$1 000 000 a year while awaiting the completion of those great engineering monuments, the Laguna Dam and the Colorado River Siphon. It is evident that the lands of Yuma, Cibola, and Parker Valleys can be provided with water by the construction of weirs, and brought under cultivation at nominal expense.

Although the piling of the trestle was cut off above the rock fill and removed in the spring of 1911, the rock weir remained in place. How such a fill would stand an overpour of 150 000 sec-ft., even without a concrete top, is not problematical in any sense. The weir at the intake has endured two freshets, one of 150 000 sec-ft. and the largest on record, and it still remains. It has neither crest, core, nor foot-wall of concrete, and it is not covered with concrete, but its top has not been undermined. It differs radically and widely from Laguna Dam in design and cost, but its function is the same. A permanent rock-fill weir, built with gravel, large rock, and steam-shovel rock, and having a cross-section width of 200 ft. on the bottom, certainly would stand any overpour that the Colorado could muster, and its cost would be comparatively small.

Useless Dredging.—Although the work of a dredge in the intake above the concrete gate was of material aid in getting an adequate supply of water to the canal, the writer cannot concur in the opinion that the operation of the dredge *Imperial* below the gate was of the slightest efficacy or value at any time. The dredge has dug a hole below the gate; the hole has been filled with sand; the dredge has dug it again, and so on in one continuous round of costly futility, like the labor of Sisyphus. Had the *Imperial* been placed above the gate, it would have been useful. When the banks of the Alamo channel, constituting the main canal, had been raised and strengthened to carry safely a large flow, the discharge of from 2 500 to 3 000 sec-ft. through the gate solved the problem of water supply for the valley canal system. In an hour and a half 2 500 ft. of water sluiced sand from the canal below the gate to the depth of 1 ft. The Alamo Canal is an efficient channel for 5 miles below the gate, when carrying 2 000 sec-ft. or more, and dredging is wholly useless.

Mr. Clark. When the writer took charge of work on the C. D. Co. system, he found two large dredges, the *Delta* and *Gamma*, at work in the main canal at an operating cost of \$9 000 a month. The dredges were useful in straightening the course of the Alamo, cutting across bends and building up banks, but when they operated in the canal to remove silt and sand, they only moved a hole up and down stream. Careful instrumental observations and cross-section surveys showed that the floor of the canal behind a dredge was at the same level as before the dredge reached it.

The writer put the dredges out of commission and tied them up, thereby saving \$9 000 a month. It is doubtful if a dredging barge, occupying more than one-third of the width of a canal carrying Colorado River water (laden heavily with silt and sand), can be operated efficiently to remove deposits.

The removal of quicksand from the Imperial canals is a problem to be solved by the managers of the main supply system. Sand in the canals of the Mutual Companies constitutes a menace, and is a cause of great increase in maintenance expense. The deposit of sand in these canals and in farmers' laterals is avoidable. Doubtless a small percentage of sand brought through the head-gate is removed by the *Imperial*, but all of it could be removed more economically by other means at the lower end of the Alamo main, and it is obviously the business of the C. D. Co.'s Receiver to take care of that sand instead of sluicing it out upon the valley farms.

Summary.—The writer has endeavored to make clear, by statement of fact and description of work accomplished, that there is no abstruse problem involved in placing the Lower Colorado under control and confining its floods to a determined course.

The meanders of the river are subject to direction by simple and inexpensive means, the current at the early stage of its wandering tendency responding as readily to the guiding hand as does a bridle-wise horse to the touch of rein upon the neck.

The permanent revetment of the banks has been demonstrated to be comparatively easy of accomplishment by methods familiar to, and applied by, railroad engineers in the West for many years.

That a railroad on the top of a levee is indispensable to maintenance and to application of the rock-fill method of bank revetment has been shown conclusively by experience. Costly experience has proved the unwisdom of removing any natural protection from the berm on the river-side of a levee, and has established the correctness of the railroad "firing-line" practice in the construction of embankments along streams, particularly those flowing through regions of alluvial formation.

Submerged weirs, to raise the bed of the river, arrest the recession of scour planes, and divert water with certainty and safety into canal

intakes, may be built as permanent structures by the simple and inexpensive method of dumping gravel and rock from trestles, without placing any crest or core-walls, or using a pound of cement. Mr. Clarke.

The operation of dredges for the removal of sand from main irrigation canals is ineffective and a waste of money where water can be carried in large volume at sluicing velocities.

U. S. MARSHALL, ASSOC. M. AM. SOC. C. E. (by letter).—The author's statements regarding the very unfavorable soil report on the Imperial Valley, issued by the U. S. Department of Agriculture (which actual results have proven to be unjustified), and the belief expressed that, had this soil report been issued before the reclamation of the valley was well under way, the effect would have been a complete condemnation of the project, are serious matters and worthy of most attentive consideration. The writer has had similar experience, and has no doubt that many others interested in reclamation work have encountered this same bugaboo of an adverse Government soil report. It is certainly the duty of the U. S. Bureau of Soils to rectify some of the wrongs done to different parts of the country through adverse reports on various soil types. The writer knows of no case where this has been done in a way which has had any practical effect. Mr. Marshall.

The object of a soil survey should be to determine what the land is adapted to and what methods of cultivation are indicated and required. The findings of a survey should be, by all means, of a constructive and not of a destructive nature, and the chief purpose should be to find some beneficent use for the soil surveyed. Any report that condemns a soil type as worthless, unless based on the most thorough investigation, necessarily does a most serious and inestimable injury to the area reported on.

It should be the office of the Government to encourage the development of waste land, but certainly some of the soil reports would discourage even a preliminary investigation of the areas in question. Because of the usual high respect for Government experts and their disinterested attitude in such matters, their statements, official and otherwise, are generally taken as expressions of ultimate facts, and unimpeachable as to the conditions of the soils reported on. However, in the West, to-day, there are notable cases of great districts, with proven agricultural value, which were condemned by the Government Bureau of Soils.

The writer's experience with an adverse soil report will serve as another example, supporting these statements. While one of the engineers was making a report on a proposed 60 000-acre levee reclamation project in the Sacramento Valley, California, on which it was estimated \$2 000 000 would be spent for levees and drainage works, the following developed:

Mr.
Marshall.

The project had advanced to the point where the parties who were to finance it had paid for 26 000 acres of the land involved, and plans were being hurried for the reclamation works, when the U. S. Department of Agriculture's "Soil Survey of the Marysville Area, California," was called to the attention of one of the several representatives of the purchaser. This report, issued in 1911, was the work of Messrs. A. T. Strahorn, W. W. Mackie, H. L. Westover, L. C. Holmes, and Cornelius Van Duyne, and on page 30 contained the following comment regarding that part of the area in which this project was located:

"When protected from overflow by levees, this soil will be saturated for some portion of each year on account of the high water level outside the levees. Extensive drainage ditches and pumping plants would remedy this to a considerable extent, but to keep down the level of the water table for such extensive areas would be very expensive, and only the most profitable crops would justify the expense. The physical condition of the soil is about as unfavorable as it possibly could be, owing to water-logged condition and consequent nonaeration. Should the type ever be thoroughly protected from inundation, the agricultural value of the section will probably depend upon the introduction of crops suitable only to low, moist land that will yield a considerable return for the labor and money invested.

"The following table gives the results of a mechanical analysis of a sample of the soil of this type [amounts given in percentage by weight]:

Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.
0.0	0.5	0.7	3.4	1.8	41.0	52.7"

This report, coming from the Government, and obviously unbiased, seemed to this representative to be a solar plexus blow to the project, and he felt that the purchaser had been misled. The parties effecting the sale felt that their reputation was in jeopardy. They had never seen the soil report, but were positive, because of actual results, that the soil was very productive. The engineers were censured for failing to bring the report to the attention of the parties interested, and it seemed certain that the whole project would fall through.

In an effort to re-establish confidence, a large number of representative farmers, experienced in handling bottom lands, were taken over the area and asked to pass judgment on the soil. All agreed that any land supporting a heavy tule growth was valuable when reclaimed, as much of this identical soil which had been reclaimed in the Sacramento Valley produces great crops. Much of the land in this area, however, is not covered with tules, and these bottom-land farmers would not vouch for it because they could see no native tule growth, which was the basis for their conclusions. In this diffi-

culty the writer had recourse to the United States Government surveys made in 1854 and 1864. In these notes frequent reference was made to tule growth encountered. On platting these, a map was obtained showing that the tule growth in 1864 covered nearly the whole of the area in question. This was accepted as convincing proof of the continuity of soil type, and the purchaser was reassured to the extent that reclamation is now going on.

Mr.
Marshall.

There will thus be created for the community a vast acreage of exceptionally productive ground which, had it been impossible to offset the adverse report of the soil experts, would have continued a worthless expanse of duck marsh, and the reputation of many men of high standing would have been shattered and confidence in their integrity and judgment lost. Further to re-establish the reputation of the land and prove the mistaken character of the soil report in question, comparisons were made with the "Soil Survey of The Woodland Area, California," by the U. S. Department of Agriculture. This area adjoins that of Marysville, and was reported on by Messrs. C. W. Mann, J. F. Warner, H. L. Westover, and James E. Ferguson. The soil type commented on so adversely in the Marysville Area is reported on as follows in the survey of the Woodland Area, page 25:

"Where this soil type is protected from overflow and is free from alkali it is adapted to grain, sorghum, Egyptian corn, hay, and other forage crops.

"The texture of the soil * * * is shown in the following table [by percentages]:

Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.
0.1	0.7	0.9	3.3	1.4	41.2	52.3"

The survey of the Woodland Area was made prior to that of the Marysville Area. The mechanical analyses of the two soil types are identical. In reporting on the Woodland Area there could have been no mistake in advising on its adaptability for the crops mentioned, for, at the time the survey was made, the land was producing a very heavy alfalfa crop.

It should be remembered that all information, used in showing the original Marysville Area report of this soil type to be grossly in error, was as available to the Government soil experts as to the writer, and that for their most adverse report on the soil in question there is no real excuse. Nevertheless, as it was obvious that an error had been made, a supplementary report revising the survey of certain soils in the Marysville Area has been issued by the Government, in which the former report was corrected and the mistakes excused on the ground that at the time the survey was made the soil in question was covered

Mr.
Marshall.

with water, thereby making thorough investigation difficult! Certainly this was reason enough for failure to get good first-hand data; but why should a report be made condemning many thousands of acres of land on such flimsy investigation?

The writer dissents from Mr. Sellew's comments as to the propriety of including the discharge records at Yuma prior to 1903, in Table 3. All available data should always be given, with explanations, and thus permit the reader to draw his own conclusions according to his own experience and judgment. Furthermore, the result of taking the yearly rainfall for the entire 265 000 sq. miles of water-shed of the Colorado River as the combination of yearly rainfalls at eight different stations scattered over the water-sheds, which it was assumed gave a fair average, does not seem to be justifiable. This is shown by plating the average rainfalls and yearly run-offs, as given by Mr. Sellew for 1903 to 1912, as in Fig. 88. This proves that there is no law that can be deduced connecting yearly rainfall and run-off totals on a water-shed as large as that of the Colorado River, and that one cannot tell with any more certainty than a guess what the run-off of the Colorado River was by using the rainfall data of the eight rain-gauge stations selected.

Therefore, to condemn the discharge records at Yuma prior to the establishment of permanent gauging stations there, as being too low, because they do not conform closely to what one might expect from the rainfall records given, in the writer's opinion, is wrong. The early data are not precise, but they are valuable and should have weight in the consideration of the problem.

That there may be long cycles of high and low yearly discharge of rivers is well established. The writer calls to mind some investigations which he made into the past levels of the Great Salt Lake. By inquiry from old settlers and by searching records it was found that in the last century Great Salt Lake had two cycles, and probably three, of extreme high and extreme low water, and, according to such

COMPARATIVE PRECIPITATION AND RUN-OFF
COLORADO RIVER VALLEY
1903-1912.

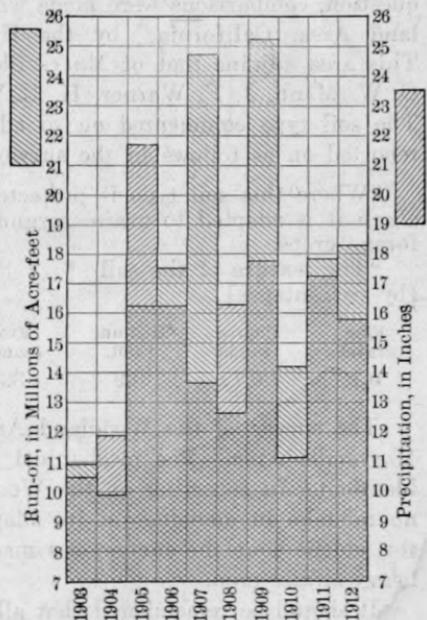


FIG. 88.

experience, the lake should be high at this time, and such is the case. Mr. Marshall
The lake is now some 8 ft. higher than it was at the time of the construction of the Lucin Cut-off in 1902, and this rise has taken place in spite of the fact that, for irrigation purposes, much more water than formerly is now being diverted from the rivers emptying into the lake.

H. T. CORY, M. AM. SOC. C. E. (by letter).—The writer has been Mr. Cory
surprised and greatly interested at the reception of this paper by those connected with the several interests involved. Though especial effort was made to be fair and dispassionate in the presentation of the various features of the work and situation, yet so much bitterness has been engendered between many of the various agencies in the development of the region that it was felt impossible to write anything worth while and avoid causing, in many quarters, a feeling of unfairness. The discussions by Mr. Sellew and Mr. Chaffey contain all matters of that kind of which the writer has been able to learn, and Mr. Chaffey's discussion deals primarily with matters concerning which the writer at no time had any personal knowledge. The other discussions, numerous conversations, letters from officials of the Southern Pacific Company, of the United States Reclamation Service, of the Interior and State Departments of the National Government, of the California Railroad (Public Utilities) Commission, of the California Development Company and most of the Mutual Water Companies in Imperial Valley, of the Imperial Irrigation District, and from Mr. Rockwood and several of his associates in the project, have all expressed appreciation for the fairness of the presentation. In several cases minor changes in wording have been suggested, but it is a source of much pleasure that all these seemed to be not only fair but an improvement, and every one of these changes has been made.

The writer must confess that he has often felt very pessimistic and impatient about the unreasonable attitude and stubbornness of a prejudiced man, and therefore such a result is most interesting and encouraging. Possibly, after all, misunderstanding is responsible for much of the failure to appreciate the work and real motives of others. At any rate, this is a striking illustration of men of affairs taking a common ground, or at least a tolerant appreciation of others' actions and opinions, when all the facts of a complex situation are systematically set forth in an apparently fair and comprehensive way, even with the handicap of strong feelings in the matter based on partial or misleading information. If such better understanding will result in less misapplied energy in completing the work thus started, the writer's efforts will be very well repaid.

The next most interesting things brought out by the discussions are the opinions as to the contents of the paper. Mr. Sellew regrets

Mr. Cory. that the record of engineering operations was "partly obscured by a mass of legal and financial entanglements which properly have no place in a purely engineering article." Mr. Elwood Mead, on the other hand, finds that this same obscuring "mass of legal and financial entanglements" is the most valuable part of the paper, saying:

"The chief value of this paper, however, is not found in its description of the engineering methods used, but in the social and political conditions, attending irrigation development in the West, which it reveals. * * * as these are fundamental features of irrigation development, it is that portion of the paper which the writer proposes to discuss."

Mr. Buck confines his discussion largely to criticizing sharply Mr. Sellew's view. President Swain, in his annual address recently delivered before the Society, urges engineers to feel that their duty is to study and deal with financial, legal, and even social entanglements, and not those only of physics and applied mechanics. The views of various individuals in this regard are no doubt characteristic of their respective holders and the result of their life experiences.

Mr. Robson has added a more detailed study of the evaporation at the Salton Sea and shows that the figures given in the paper were somewhat too large, surprisingly small though they seemed. It might be well to point out that the coefficient, 0.6, derived by Mr. Robson for 6-ft. pans becomes, by Professor Bigelow's formula, 0.49 for 4-ft. pans and 0.4 for 2-ft. pans, in estimating the evaporation from large water surfaces from experimental small-pan data.

Mr. Knowles expresses the feeling, shared by many engineers as well as laymen, that reservoirs on the head-waters and along the tributaries of streams subject to disastrous floods offer the best means of flood control in theory, and oft-times in practice. It is probable, as a matter of fact, that Messrs. Knowles, Sellew, Grunsky, and the writer are not far apart in this matter, and that all agree that the extent to which such methods may be feasible differs with each stream. Mr. Knowles asks for data relative to this question, but it is believed that those presented by Mr. Sellew and the writer are all there are.

Concerning these data, however, it is important to remember that neither Mr. Sellew nor the writer has any personal knowledge of the storage possibilities in the water-shed, and both agree that the available published facts are not sufficient to determine the feasibility of complete, or the extent of practicable, reservoir control of the Colorado River. Consequently, the conclusion reached by Mr. Sellew, as a result of his analysis, that there is but one available reservoir site—Browns Park with a capacity of 2 200 000 acre-ft.—on the entire Colorado River water-shed, is not only startling but quite unwarranted. Furthermore, the statement that "storage on the Gila is out of the question, as this stream carries more silt during its flowing season

than the Colorado," is quite out of accord with the opinions of his superiors in the U. S. Reclamation Service, as the Roosevelt Dam has just been completed, creating a reservoir behind it having a capacity of 1 284 000 acre-ft. at a cost of \$3 697 000, according to the first item of Table 23. This reservoir is on the Salt River, one of the main branches of the Gila, and has all the latter's essential characteristics.

As a matter of fact, many reservoirs will no doubt be constructed on the Colorado River water-shed, including probably the Kremmling site, in spite of the fact that at present it "is in the hands of interests foreign to irrigation or storage development," and these reservoirs will have considerable beneficial effect in reducing flood flows; it is immaterial whether or not the storage possibilities have been over-estimated, as this can only affect the extent of such an influence; but, as Mr. Grunsky says:

"Whatever this may be, it will not change the river problem, except as to its magnitude. * * * The same lack of channel capacity will be felt at high stages on the lower river as is felt to-day, and the same problem of keeping the delta channels of the river on the Gulf slope will confront the river engineers of the future as confronts those of to-day, except only that there will be somewhat less water and correspondingly less silt to be reckoned with."

This is especially true because below Yuma the river is practically a "joint track" for the Colorado and the Gila, which are very different types of streams, but each at times alone causes approximately equal maximum flood heights from Yuma to the Gulf. Of course, the floods on the Gila are flashy and those on the Colorado are long sustained, but that does not signify as much as might be thought, so far as river control is concerned. Fortunately, severe Gila and Colorado floods never occur simultaneously.

As to the quantity of water—the discharge of the Colorado at Yuma—the writer believes that the first half of Table 3 should be given, agreeing with Mr. Marshall that it is always best to set forth all available data, with explanations—as was done in this case—and let the reader decide what to use and what to discard. The recorded discharges prior to November, 1902, are by no means as reliable as those after that date, but that does not mean that they are worthless, though it does mean that they must be used with care and discretion. In this matter the comments of Mr. Grunsky on the reliability of the measurements taken since that time, especially at high stages, are very pertinent.

In any event, it seems clear that, beginning with 1905, the discharge of the river has been markedly greater than normal, and that long periods will occur when the discharge will be markedly less than normal—as is pointed out very well by Mr. Marshall. In the case

Mr. Cory. he mentions the water is within $4\frac{1}{2}$ ft. of the rail base on miles of the very expensive Lucin Cut-off crossing the Great Salt Lake, and the water is still rising. The relationship between yearly rainfall and run-off, even on very large water-sheds, and especially if few widely scattered points be taken, is by no means constant, as Mr. Marshall says, and as the writer and doubtless many others have learned from time to time to their discomfiture. With the existing data it is not safe to decide in more than a tentative way as to either maximum or minimum quantities. Mr. Sellew's maximum figures as regards river control are probably fairly close to the truth, but, with respect to the minimum for estimating safe irrigable acreage, caution must be used. Fortunately, it will be at least another decade before all the lands easily covered by canals in these regions can be brought under complete cultivation, and the dry cycle of years will probably be well under way, so that the safe limit of land which can be served by the natural flow of the river will be determined in time to avoid excessive development.

With respect to the rise of the river bed at Yuma, Mr. Sellew is correct in the opinion that much more information is necessary before definite relations can be established regarding it. The Southern Pacific Company, however, has kept gauge heights at Yuma since 1878, and these records show a steady rise of the river bed (taking averages), or a steady increase of the river discharge. The reader can judge which is more probably occurring. Also, the old maps on record in the British Museum, in archives at Madrid and Mexico City, and in the Bancroft Library in the University of California, have been carefully studied by Mr. Godfrey Sykes, of the Carnegie Institution, in connection with this very matter, and the final figures he has adopted (which will appear in a volume on the Colorado Desert by the Carnegie Institution, now in press) check well with the "memory of a steamboat captain," Capt. Mellon, of Yuma, quoted by the writer in the paper.

Undoubtedly the difference in elevation at any two points on the river will change as the length of the river between these points is modified by meanderings of the stream; and, also, the two points, Laguna Weir and the conglomerate hills at Yuma, are the only ones on the lower river which may be regarded as definitely fixed—as was pointed out in the paper and again by Mr. Sellew. The latter, however, has mistaken effect for cause when he concludes that the increase of 4 ft. in difference of gauge height of the river at Yuma and Laguna Weir "is plainly caused by the meanders of the river" between these two points. This stretch of river had a normal length of nearly 14 miles, from 1856 to 1909, and this had increased to 17 miles in

1912, because the stream had lowered at Yuma more than 3 ft. as shown by the diagram Fig. 3 (for reasons set forth in the paper), though no change is possible at Laguna Weir. The stream has re-established its normal grade per mile by lengthening itself, and, as the bed at Yuma rises again, a corresponding shortening will follow.

Mr.
Cory.

It would seem that the comments in the paper as to the design and methods of construction of the Laguna Weir were not clear, either to Mr. Sellev or Mr. Grunsky. Fig. 89 shows diagrammatically a cross-section of the weir as built, and as the writer proposes. The resulting structures would not differ in function, concrete top, crest or foot walls, appearance when completed, or general design in the sense of cross-section above ground.

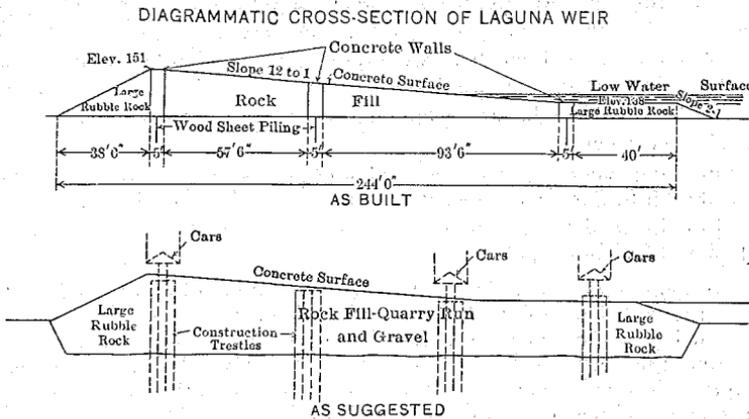


FIG. 89.

The difference is in the omission of the concrete cross-walls (which were very expensive in time and money) in the second design, and changes in method of construction by driving the river sideways ahead of rock and gravel filling from trestles, and thus making it do all the excavation. The result would be a greater yardage of rock in the structure, but the total cost of it in place, including excavation and everything, would certainly not have been any more than the costs given for the material placed in closing the central section of the weir—undoubtedly it would be materially less on account of the much more favorable conditions and the larger quantities. The figures given by E. D. Vincent, M. Am. Soc. C. E., Resident Engineer on the work, and quoted in the paper, are, in round numbers, \$1 per yard, made up of the following items*:

* *Engineering News*, June 10th, 1909.

Mr. Cory.	Labor, dumping cars.....	\$0.020
	Labor, general.....	0.020
	Sundry supplies and implements.....	0.008
	Railroad hauling.....	0.217
	Depreciation, rolling stock and track.....	0.062
	Excavation, rock-quarrying.....	0.468
	Trestling.....	0.149
	Proportion of storage of apron rock.....	0.014
	Light and water.....	0.011
	Depreciation, special derricks.....	0.001
	Proportion of superintendence.....	0.032
	Overhead charges, Yuma and Washington offices..	0.038
	\$1.040	

Assuming the total quantity of rock in the weir proper to be even twice that in the structure as built, the amount required would be 750 000 cu. yd., or \$750 000. Concrete facing and other items would hardly increase this sum to \$900,000. As built, the weir proper cost \$1 672 168.20. Mr. Clarke's comments on such methods of construction are very pertinent.

This suggested cross-section and method of construction is fundamentally different from that which Mr. Grunsky mentions as recommending in 1896 for a low dam in the Colorado in Iceberg Canyon—a dam to be constructed

“of loose rock on a sand foundation by blanketing the bed of the river for a considerable distance up and down stream with broken rock, using large blocks for the down-stream portions of the work, allowing the water to bury these as deep as it would, and using finer material in the up-stream face, which would ultimately be made impervious or nearly so by the river silt.”

Such cross-section design and method of construction is of course entirely independent of Mr. Grunsky's suggestion that the weir top should not have been uniformly high but have had a section, say 800 ft. long, a few feet lower than the rest, to hold the river in a definite position above the weir and to insure sweeping drift of whatsoever size over the structure.

Mr. Clarke's comments on “useless dredging” are most interesting—they differ materially from reports made by those who recommended, built, and are operating the dredge *Imperial* immediately below the Concrete Head-gate. It seems probable that this dredge has not entirely solved the silt problem in the Imperial canal system, as its advocates have enthusiastically proclaimed. Future results will be watched most carefully.

The writer regrets that he did not make clear that no levee failures were caused by the flood of December 7th, 1906, on that portion of the Yuma Project built under Mr. Sellev's direction, for, on taking

charge of the Project, in October, 1906, Mr. Sellev at once ordered muck-ditching under all new levees. This had not been done before, and there were two failures from this cause opposite the Lower Heading on the Project levees, as stated in the paper and illustrated with a photograph, Mr. Sellev to the contrary notwithstanding. The writer remembers this most vividly, because his original design of levees included thorough muck-ditching, which was peremptorily ordered cut out as an avoidable expense, because, up to that time, none had been done in building the levees of the Yuma Project. After the disaster due to the flood of December 7th, 1906, careful examination of the damage to levees on both sides of the river was made and data were collected to show convincingly those not on the "firing line" that, with thorough muck-ditching, all completed levees on the river would have been effective, and the two failures from this cause on the Project levees were considered very significant.

The writer is inclined to agree with Mr. Sellev that the second break might not have occurred had the borrow-pits been on the river side, because of the peculiar facts of the short duration of that particular flood and the location of the breaks it caused. Nevertheless, the levee would have failed just the same in the several places. Also, muck-ditching would have prevented all trouble. When failure occurs, future construction designed with special reference to preventing that type of failure alone is most unwise, and it was felt that a failure similar to that which happened with the extension of the levees built later by Mr. Ockerson would be quite as disastrous as though caused by lack of muck-ditching or anything else. The design adopted was expected to prove safe from both these dangers, and, thus far, has done so entirely.

It is true that the recommendations of the first and second consulting boards as to levee construction and reconstruction were not followed—a careful reading of these recommendations and of the paper will, it is believed, convince the reader that this was wise. Especial attention is called, for example, to the recommendation on page 1394 to comply with which would have cost \$12 000 per mile, though the total cost of the levees, exclusive of gravel blanketing, was considerably less.

As to the efficiency of the interrupted or checkerboard system of borrow-pits, Mr. Grunsky's observations coincide with the writer's, as set forth in the paper. There is no doubt that some—even though slight—additional security is obtained. The question in any case to be decided is whether it is great enough to justify the additional cost. The writer's opinion is that, as the materials grade more and more into those easily eroded, the available precautionary measures are, in their order of effectiveness: river-side borrow-pits with occasional short traverses; river-side continuous borrow-pits; river-side checkerboard

Mr. Cory. borrow-pits; land-side borrow-pits; hydraulic-dredge-built levees, as described by Mr. Grunsky; and, lastly, blanketing with cementing gravel, concrete, etc.

The effectiveness and cost of checkerboard borrow-pits, and consequently whether or not to use them, must be determined for each individual case. With those soils and conditions of vegetation, grade, etc., where they will afford all the needed added security, considerable additional cost is justified; and, where this is not the case, little or no additional expenditures for them is wise. Similarly, as to the cost, with small levees, narrow berms, and easily handled soil—so that the haul is of maximum importance—the additional cost as a percentage will be greater, and *vice versa*. This difference, as set forth in the paper, was actually determined carefully by building adjoining sections of levee with continuous and with checkerboard borrow-pits, using half of one camp on each section and interchanging men and teams daily. Every effort was made to secure otherwise identical conditions, and it is believed with unusual success. The levee was uniformly 8 ft. high, 10 ft. wide on top, slopes, 3 to 1, berms 40 ft., borrow-pits with 50-ft. traverses each 400 ft. in one case, and 100 ft. alternately borrow-pits and undisturbed in the other, depth of pits in both cases, 2½ ft. at levee end and 4 ft. at far end. The material was the Colorado Delta silt described at length in the paper. The costs, excluding contractor's profits, were found to be 19 and 25½ cents, respectively, per yard of embankment in place on completion; the settlement was very slight. This is in the ratio of 100 to 135.5. Mr. Sellew, with essentially similar work, done under normal instead of rush conditions, reports the costs as 11 and 13 cents, respectively—shop costs only—or in the ratio of 100 to 118. If the reader is interested as to the consistency of these two results, he can compute the average haul in the two classes of borrow-pits and check them up.

The method of constructing levees by hydraulic dredges, as suggested by Mr. Grunsky, has been used to a considerable extent on the Sacramento River, although the material from the muck-ditch is there usually deposited on both the river and land sides of the trench, and the hydraulic fill made in the excavation and space between the two banks. The soil in that locality is such that it does not erode easily, and, more often than not, the levees are located on the river banks. With levees set well back and with the shallow, muddy Colorado, it is very doubtful whether such methods could be used successfully for levee building on that river. Furthermore, the amount of work done, especially during any one year, will probably be so small, and the deterioration and cost of handling a dredge on the lower river so great, that the total levee cost would probably be much higher than by the present methods.

Mr. Grunsky points out that the levees along the river have not yet been subjected to a conclusive test, and suggests two points: seepage under the levees with land-side borrow-pits, and reasons why the levees have not yet needed to be as high as were built. As to the former; miniature, pin-head, under-water volcanoes did appear, but their number and size did not seem to be large, when the effective head was greater, and after a time they stopped entirely. In not a single case did any of these become in any way menacing. Furthermore, last year the water-table rose above the ground surface behind the Reservation Levee of the Yuma Project with river-side borrow-pits, covering a considerable area, and seriously interfering with crops. The action is a rise of the underground water, and not seepage under levee structures. Mr.
Cory.

The top grade line of the levees built under the writer's direction has proven to be higher than as yet required because of the abnormal overbank flow and cutting off of Nigger Bend in 1907 (as pointed out by Mr. Grunsky), and later by the Abejas Division, which did lower the river at Yuma, as shown by Fig. 3, and at all points below as far as the diversion, Mr. Sellew to the contrary notwithstanding. Indeed, it was this lowering at the Concrete Head-gate, which, with silting up in the Imperial intake, caused the building of the rock weir across the river at that point in 1910, as commented on by Mr. Clarke. Nevertheless, to have built lower levees would have been taking an unjustifiable risk. This is shown most strikingly by what happened with the levees near the Abejas Dam. In this case the levee grade was fixed by reference to the fresh high-water marks of the 1909 flood which had its outlet down the Abejas, but after that closing was to be held in the old river channel. This latter did not scour down as was expected* and, had the levees held, they would have been overtopped in the vicinity of the dam by a 100 000-sec-ft. river that summer. Fig 90† shows the situation there.

Mr. Grunsky believes the control of the Colorado between permanently fixed banks should not—at least for a long time—be projected beyond some agreed point near the Arizona boundary line, and in this he is joined by the Board of Review which reported on the failure of the Ockerson levees, the writer, and most of those who have been on the "firing line." The exceptions are Mr. Ockerson and Mr. Sellew. This is a matter of judgment, and all available data affecting the matter, for which a place could be made in a paper of this kind, have been given.

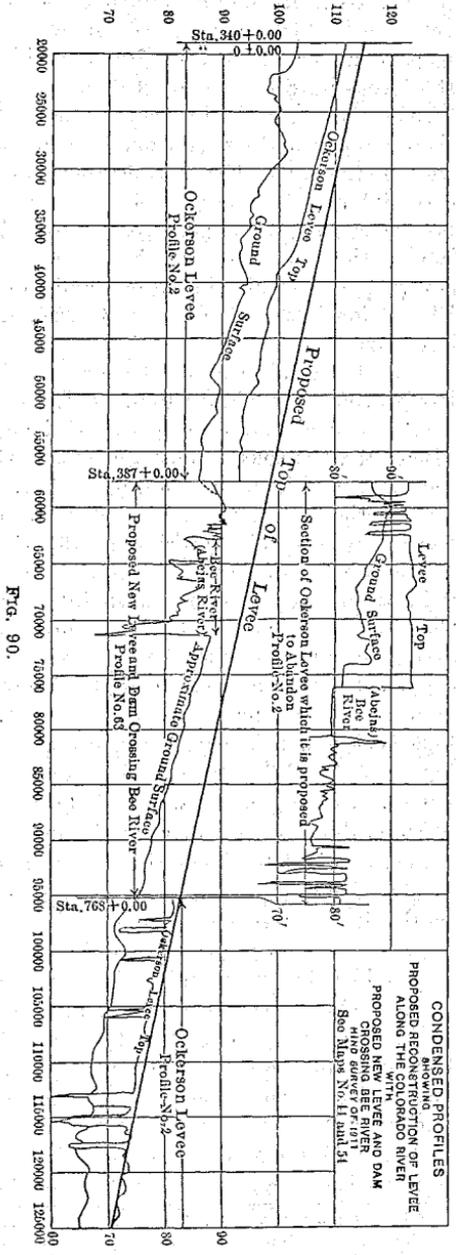
Mr. Follett confirms the writer's figures of land slope away from the river banks, and suggests the desirability of a secondary levee from

* See statement by Mr. Ockerson, *Engineering News*, Dec. 7th, 1911.

† Taken from House Document 504, 62d Congress, 2d Session.

Mr. Cory. the sand hills to the C. D. Co. levee, where it is a mile away from the river, with a gate structure where the main canal is crossed. This idea has been given careful consideration; the Board of Review just mentioned has reported that the money such a secondary levee of defense would cost could be more judiciously expended on the principal levees along the river. The writer agrees with the Board of Review in this.

The writer is surprised, on re-reading the paper on receipt of the discussions, to find that so little had been said about bank protection work. This was partly the result of touching as lightly as possible on unsuccessful river control work done by others, partly because of a tacit understanding with other members of the Society as to the contents of the paper and their discussions thereof, and partly because, since holding the levee embankment on the north side of the Second Break in January, 1907, by gravel and rock revetment, as set forth in the paper and in Mr. Clarke's discussion, the proper way to do such work has seemed obvious. Messrs. Grunsky, Hind, Clarke, Herrmann, and the writer went over this matter together in June, 1907, and agreed as to the general procedure on the lower river—practically



that concisely set forth by Mr. Clarke under the heading "Control of the River." Mr. Grunsky reported accordingly to the Secretary of the Interior at the time, and Mr. Sellew has now reached practically the same conclusions, except as to the important difference of revetting only at threatened points and so distributing the work over many years and letting the river do all dredging and placing gravel and rock well down to the limit of scour. In any event, the matter of funds will doubtless distribute the work over a long period, and the procedure recommended helps to arrange the "cutting of the garment according to the cloth."

Mr.
Cory.

With a railroad track on the levees, with large quantities of rock ready in near-by quarries and gravel pits in constant operation, and a very large railway organization which, at any time, on telegraphic notice, will send, for cost plus 10%, work trains, steam shovels, and a completely organized force, the methods of bank and levee production work here seem to the writer to be self-evident. All those who have had to deal with the lower Colorado, except Mr. Ockerson, agree as to the vital importance of a railroad track on these levees.

When thus equipped, and with the foregoing plan of river control and levee revetment, there is no reason for locating levees farther from the bank than needful to provide sufficient waterway for the greatest possible floods. Location farther back means on lower land and hence higher levees and greater difficulty to revet and hold when attacked by bend erosion. Such more distant levee location can at most mean a later date for completing the entire river revetment, and, outside of reasonable limits, this becomes a disadvantage rather than advantage.

Consequently, the writer still feels that:

"Because of the various successful and unsuccessful work done in the region * * *, the Colorado River Delta now presents no unusual, unsolved engineering difficulties; its problems are chiefly matters of statecraft, in both river control and irrigation."

The writer joins with Professor Forbes in regretting that the exceedingly interesting geological sketch and historical review of the Colorado Desert, prepared as a part of this paper, by Professor Blake shortly before his death, could not be utilized in that way. Fortunately, it will appear elsewhere, and its reading is commended to those interested in this subject.

Mr. Chaffey's discussion is of especial interest, not only to the writer and those locally interested, but to many members of the Profession who never had a personal interest in the Lower Colorado. The corrections and criticisms it contains the writer can only admit to be fair; he regrets the inaccuracies in the paper which called them forth, and takes this opportunity to express his pleasure at their being

Mr. Cory. presented. Since the paper was presented, the Supreme Court of California, in *Thayer vs. California Development Co.*, finally held the system of mutual water companies and triparty contracts to be legal, and, in addition, commended such plan. This is the first decision handed down squarely on this point, though in other cases the District Federal Court and the State Supreme Court had by indirection practically decided just the opposite. It is, indeed, a sad state of affairs when it takes from 1906, when the first litigation began, until 1913, for investors and settlers to know definitely whether their operations and organizations are within the law. Mr. Mead is right in saying that at least three-fourths of the irrigation enterprises have been financial disasters because the laws were such that there was no adequate security for the money expended. So it is that, in spite of the legality of the plan as finally decided and its excellent basic business principles, it would doubtless have been better had the project been carried out under the Carey Act.

The writer takes pleasure in expressing appreciation of the standing of Mr. George M. Chaffey in irrigation work in the West. The Ontario Colony he founded in 1883 was selected ten years later as a model for the irrigation exhibit at the World's Exposition, and in his work at Mildura, Australia, he designed, had built in England, and installed, the first centrifugal pumps driven by triple-expansion engines, there being four pumps on the same shaft with a total capacity of 320 cu. ft. per sec. lifted 20 ft. He is at present, among other things, head of the magnificent water system irrigating 10 000 acres of citrus lands near Whittier, Cal., including the highest priced agricultural lands in California (\$5 000 per acre). Furthermore, he is a man of affairs and of large means which he acquired principally in irrigation enterprises and banking, and hence has the confidence of moneyed interests.

The comments of Mr. Chaffey and Mr. Marshall on soil examination and reports are pertinent and worthy of serious consideration. The effect of the soil reports on the Imperial region was most serious.

It is nearly a year since the paper was written, and in that time the maze of litigation over the Imperial Irrigation System has, if anything, become more complex. Arrangements have been made to supply water to additional lands by the Receivers of both the American and Mexican Companies for 50 cents per acre-foot, with a 10% free allowance for seepage and evaporation, and with no "water right" or water stock charge or requirement. Thus the later comers are getting water for their lands on better terms than the pioneers in the region, and the opportunity for bettering the financial status of both parent companies by the sale of valuable water rights—and so in the last analysis having the new-comers bear a proper share of the inevitable

burden of readjustment, however that is to be accomplished—has been lost. This resulted from an unfortunate hostility between the two Receivers. Dr. Mead is certainly justified in his comments on laws governing irrigation projects. Mr.
Cory.

The development of the country is going on more rapidly than ever, and land values have increased very markedly, due to the growing confidence of the outside public. The 1913 shipment of perishable products alone is 3 880 carloads, as follows:

Cantaloupes	3 499
Watermelons	338
Tomatoes	10
Other vegetables	26
Miscellaneous	7

A new high-line east side main is nearly completed which will water an additional 150 000 acres, and surveys have been completed for a Mexican Canal following closely the Paredones delta divide, crossing New River near Volcano Lake and thence northwesterly to the International Boundary Line near where it is crossed by the West Side Canal. These canals have no especially noteworthy engineering features, however.

No progress whatever seems to have been made in international negotiations looking toward joint governmental river control or conservation and division of the Colorado's waters between the two countries.

A very interesting and complete description of the Colorado River Siphon of the Yuma Project, by George Schobinger, Jun. Am. Soc. C. E.,* has recently been presented before the Society.

*Now Assoc. M. Am. Soc. C. E.