over the wasteway, spanning the 5-foot spaces between piers; in the roof of the gate-house over the shaft in the tunnel from which the heavy gates are suspended, and in the floor of the house; in the curved wall forming the auxiliary water-cushion dam, which is 10 to 15 feet high, and but 18 inches thick, and in the inclined apron of the wasteway. This construction is quite satisfactory, and shows no cracks anywhere. The rates of expansion and contraction of iron and concrete under changes of temperature are practically identical, and no separation of the two elements can occur by such changes.

There are no visible evidences of cracks in any of the masonry of the dam, nor any indications of a tendency towards crushing at the toe of the dam. This may be due to the fact that the stone is extremely hard and strong, and the mortar of prime quality. It may be further owing to the fact that arch action has resisted pressure from the top down to some neutral point where gravity alone suffices. There have never been any spouting leaks to indicate the transmission of an upward pressure upon the masonry of the slightest moment. The leakage through the wall was never of considerable amount, and has steadily diminished, so that when full the wall is practically dry over most of its outer face.

This leakage was reduced in amount in 1890 by carefully repointing the inside face as far down as the water was lowered in the reservoir, about 60 feet below the top, and applying successive washes of potash-soap and alum-water alternating.

Protracted litigation followed the building of the Sweetwater dam, over the attempted condemnation of a tract of about 300 acres of land at the upper end of the reservoir-basin, submerged by the impounded water. The land was comparatively valueless for agricultural purposes, but a jury gave an exorbitant judgment of its value on testimony erroneously admitted as to its special adaptability for reservoir purposes. This litigation lasted several years and was finally compromised, but the effect of it was quite disastrous to the progress of the country depending upon it for irrigation. During the progress of this litigation a tunnel, heretofore referred to, was opened around the south end of the dam, at the level of 25 feet above the lowest outlet, by means of which the flooding of the land could be avoided. In obedience to an order of the United States Circuit Court the reservoir, which had been filled, was ordered emptied, and an enormous volume of water was thus wasted at a time when it was greatly needed for irrigation.

Including the period of retarded growth during the progress of litigation the dam has been in service for thirteen irrigation seasons, during which time the impounded water has created values aggregating several millions of dollars, reckoning all improvements made in the district directly dependent upon it for water-supply. The area irrigated from it is now 4580 acres, chiefly planted to citrus fruits, of which the greater part is

devoted to lemons. A population of 2500 to 3000 people is dependent upon the reservoir for domestic water. The distribution for irrigation as well as for domestic use is entirely by pressure-pipes, and the agricultural community is as well equipped for fire-pressure and general water-supply as the average American city. All water for irrigation, and practically all domestic water, is measured by standard water-meters. The pipe system has cost in the aggregate some $800,000.

Run-off of Sweetwater River.—The area of watershed above the Sweetwater dam is 186 square miles, ranging in elevation from 220 feet above sea-level, which is the elevation of the top of the dam, to about 5500 feet at the summit of the mountain-range in which it heads. The mean elevation of the basin is probably about 2200 feet. There is practically no diversion of the stream above the reservoir, and no utilization of its water other than that of the dam. Hence the catchment at the reservoir represents the entire run-off of the shed. A careful record of this run-off has been kept since the construction of the dam. Its extremely variable character is shown by the following table:

TABLE OF MEASURED RUN-OFF, SWEETWATER DRAINAGE-BASIN.

Area 186 square miles.

Season.	Rainfall at Sweetwater Dam. Inches.	Run-off as measured at the Dam. Acre-feet.	Average Yearly Run-off in Second-feet per Square Mile.	Average Annual Run-off. Second-feet.
1887–88	.....	7,048	0.0524	9.74
1888–89	13.53	25,253	0.1875	34.88
1889–90	16.52	20,532	0.1525	28.36
1890–91	12.65	21,565.5	0.1602	29.79
1891–92	9.88	6,198.3	0.0460	8.26
1892–93	11.62	16,260.7	0.1210	22.51
1893–94	6.20	1,338.4	0.0099	18.45
1894–95	16.19	73,412.1	0.5452	101.40
1895–96	7.29	1,320.9	0.0098	1.83
1896–97	10.97	6,891.6	0.0512	9.52
1897–98	7.05	4.3	0.00003	0.006
1898–99	5.05	245.5	0.0018	0.34
1899–1900	5.54	0.0	0.0000	0.00
1900–01	7.05	828	0.0061	1.14
1901–02	4.86	0	0.0	0.0
1902–03	5.72	0	0.0	0.0
1903–04	6.39	0	0.0	0.0
1904–05	15.55	13,760	0.1022	19.00
1905–06	15.52	35,000	0.2600	48.35
1906–70	12.88	30,000	0.2228	41.44
Totals	190.46	259,654		
Mean for 20 yrs.	9.52	12,982.7	0.0964	17.93

The average annual run-off for twenty years has been 69.8 acre-feet per square mile of watershed area, while the maximum has been 395 acre-feet per square mile.

Of the entire period of twenty years recorded the run-off has exceeded the capacity of the reservoir in but four seasons. The remaining sixteen seasons have been so far below tthe full-reservoir capacity in yield of stream-flow as to justify the recommendation made by the writer on the completion of the dam that a full reservoir should always be considered as a two-years'

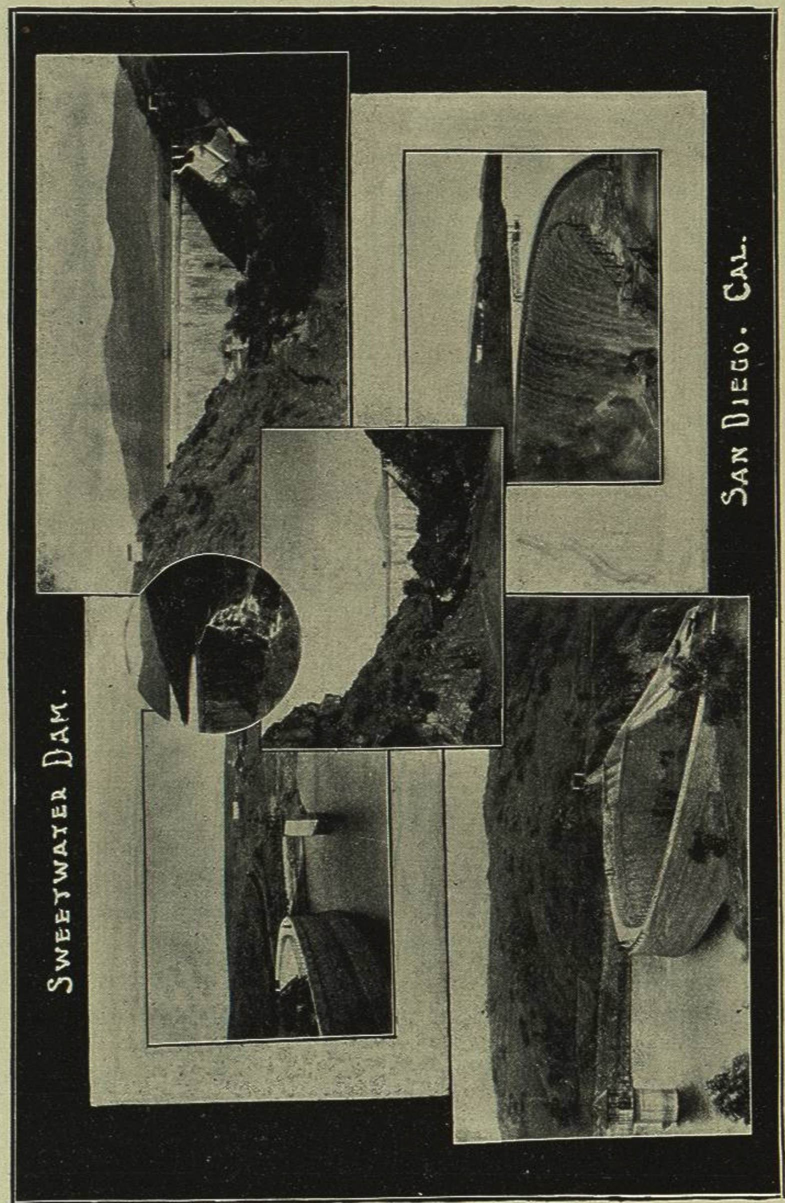

Fig. 164.—Sweetwater Dam, California, during Flood of 1895, and after Subsequent Reconstruction of Spillways.

supply, and that no more than one-half its capacity should be used in any one season. The percentage of probable mean rainfall which this run-off represents is remarkably small, in view of the mountainous and precipitous

character of a considerable part of the drainage-basin. The mean rainfall of 1894–95 was estimated at 27.14 inches, of which the run-off was but 26%. The following year, with an estimated mean rainfall of 16 inches the run-off was but six-tenths of 1%. This illustrates the great variation to which such streams are subject. When the rainfall in the lower two-thirds of the basin does not exceed 12 inches it is all absorbed in plant-growth and evaporation from the soil and does not feed the stream except when it comes in violent storms. Under such conditions the upper third of the basin supplies all the run-off, and if that portion does not receive more than 18 to 20 inches, the stream-flow is very small and of short duration. The record of catchment at the Cuyamaca reservoir, whose watershed is all on the mountain-top from 4800 to 6500 feet in elevation, adjoining the upper portion of the Sweetwater shed, clearly shows that the larger part of the run-off of all of these coast streams must ordinarily come from the higher mountains, and illustrates the value of elevation in any shed for purposes of yielding run-off for reservoirs.

The precipitation and catchment record kept at the Cuyamaca dam from 1888 to 1896 shows that the drainage-basin of 11 square miles gave an average yield of 491 acre-feet of water per square mile, while the mean of the Sweetwater during the same period was 100 acre-feet per square mile, or about one-fifth that of the Cuyamaca.

Since the great flood of January, 1895, the Sweetwater system to and including 1899 had not experienced a season of sufficient run-off to fill the reservoir, and had endured practically four years of continuous drouth, as the entire catchment in these four seasons was 8,034 acre-feet, or 36% of the reservoir capacity. As a result the reservoir was drained to the bottom early in 1899, and it became necessary for the company to develop and put in operation an entirely new and independent supply for the preservation of the orchards. Two independent gasoline-engine, centrifugal-pump pumping-plants were established in the bed of the reservoir about 1½ miles above the dam, by which water was drawn from 35 small wells put down in the shallow sand and gravel-bed; the water there stored in the subterranean voids was thus made to yield a constant flow of about 1 second-foot. This was conducted in a flume to the dam, and there admitted to the tower and the distributing system. The pumping was done with gasoline-engines, the lift being about 18 feet. In the valley below the dam three substantial pumping-stations were installed, with steam-pumps, drawing from a large number of wells, bored at intervals of 100 feet along the suction-pipe leading to the pump. In this manner the stored water in the sandy bed of the valley was made to produce 4 to 5 second-feet additional. The season was successfully passed owing to the energy with which the supply was developed, the orchards were kept alive and thrifty, and no great suffering was experienced, although it seemed inevitable at the beginning of the irrigation season of 1899 that the orchards would perish, or at least that there would be a total loss of fruit, if not of the trees. Pumping operations extended from May to November 23, 1899, during which time the total volume pumped was about 458,000,000 gallons, or 1402 acre-feet. The area irrigated was approximately 3800 acres. Deducting from this total the amount of water used for domestic service, the mean depth actually applied to the orchards averaged 3.⅜ inches. This small amount, supplemented by thorough cultivation, proved sufficient to save the orchards and keep them in healthy growth, which is an interesting demonstration of what can be done in an emergency.

The cost of the pumping-plants and wells so quickly inaugurated as a substitute for the reservoir was about $27,000. The cost of pumping was about 6½ cents per 1000 gallons, which was covered by an increase in rates, to which the community cheerfully acceded as an emergency. The season of 1899–1900 having failed to give any run-off to the reservoir, all the pumping-plants in the reservoir-basin and below the dam were reinstalled, and an auxiliary plant, consisting of 40 wells, 2 inches diameter, 50 feet deep, pumped by a 22-H.P. gasoline-engine and 6-inch centrifugal pump, was added to the main plant at Linwood Grove, while at Bonita the same number of wells were sunk, and pumped by two 6-inch centrifugal pumps, placed in tandem and actuated by gasoline-engines. In this way they managed to tide over the third year of drouth.

Sedimentation of Sweetwater Reservoir.—Prior to the construction of the dam some apprehension was felt as to the probability of the speedy filling of the reservoir with sand brought down by the stream, which had been thought to be so large in volume as to destroy the usefulness of the reservoir in a short time. The writer made some observations on the load of sediment carried by the stream in flood during the construction of the dam, which led him to conclude that the reservoir might be filled with water a thousand times before becoming entirely filled with sediment.*

Careful re-surveys of the reservoir made by Mr. H. N. Savage, chief engineer, since it became empty, demonstrate that the total filling has been about 900 acre-feet since the construction of the dam, or at the average rate of 75 acre-feet per annum. The total volume of water that has entered the reservoir in the first 12 years was 180,966 acre-feet. The measured solids deposited from this water have therefore averaged a trifle more than one-half of 1%. The deposit has been almost directly as the depth, being greatest at the dam, where the depth of silt of almost impalpable fineness is 2½ to 3 feet. The addition made to the reservoir capacity after the flood of 1895 was 4.6 times the accumulated sediment of twelve years, or, in other words, sufficient to offset the filling of half a century.

* The Construction of the Sweetwater Dam. Trans. Am. Soc. Civil Eng., vol. xix. p. 214.

Evaporation.—The percentage of water lost in storage-reservoirs by evaporation is the most serious factor which the projectors of such enterprises have to anticipate. It is subject to wide variation due to differences in mean depth, exposure, temperature, winds, and relative humidity, but it is always in operation, and subjects the reservoir to a constant loss, so great that it must be considered in all calculations of reservoir duty, as, in extreme cases, it may amount to 50% per annum.

Careful measurements of evaporation in a floating pan at Sweetwater dam shows the annual loss to be about 54 inches in depth. It is about 2 inches during the month of January, and over 8 inches per month during July and August. This causes an annual loss of about 15% of the stored water, and as a reservoir must always be held back for dry years, so that practically a reservoirful is at least a two-years' supply, the loss is really 30% of the total supply, leaving but 70% of the reservoir capacity available for use, one-half of which only can be safely counted on each year. This reduces the available annual supply to about 8000 acre-feet.

At the Cuyamaca reservoir, on the adjacent watershed, the average loss reported during nine years prior to 1897 was 56¾ inches in depth per annum. This loss amounted to 25.5% of the total water caught and stored during that time, which is nearly double that of the Sweetwater. This difference is due to greater surface exposure per unit of volume stored. The Sweetwater reservoir has an exposure of 39.8 acres per 1000 acre-feet of capacity when full, while the Cuyamaca has an exposure of 84 acres per 1000. This is an illustration of the advantage of great average depth in reservoirs, and an argument in favor of high dams for effective conservation of water.

Conduits.—The main pipe leading from the dam is 36 inches in diameter for 1600 feet, thence 30 inches diameter for 28,200 feet to Chula Vista. It has a minimum capacity for delivery of 1260 miner's inches (25.2 second-feet) to an elevation of 90 feet above sea-level, which is high enough to cover the larger part of the settlement. This pipe was found to be inadequate to the demands upon it, because in practice the maximum rate of consumption is about double the mean rate, and for the further reason that the higher levels could not be supplied and at the same time permit the maximum discharge to the lower levels. To remedy this lack of efficiency a second conduit, 24 inches diameter, was built in 1895 on the north side of the valley of the Sweetwater. It is of riveted steel, 30,142 feet in length, and cost $65,000. It has a minimum capacity of 450 miner's inches (9 second-feet) and is used chiefly for high service. It connects at the dam with one of the 30-inch pipes laid through the tunnel. The distributing system of pipes, from 4 to 24 inches diameter, is over 65 miles in length, and has cost over half a million dollars.

Hemet Dam, California.—The most massive and imposing structure that