The dam of the distributing-reservoir is of earth, 300 feet long, 14 feet high, and 8 feet wide on top. The reservoir is usually filled within a foot of the top of the dam. In construction a trench was excavated 9 feet deep under the center line, in the center of which a tight board fence was built, reaching to the top of the dam, to prevent the burrowing of ground-squirrels and gophers, a function which it effectually performs. The trench was refilled with puddled soil each side of the fence, and the puddle brought to the top of the dam. The area irrigated by the system in 1896 was 1092 acres, and is increasing each year as the tracts are sold to settlers.

This area was in 72 separate tracts, of which the average size is 10 to 20 acres. The rates charged for water are $2 per acre annually, with an additional charge during the nominal "non-irrigating season" (November 15 to April 15) of $1 per month for each tract for domestic service. In the town of Hemet, which is supplied by the same system, there were, in 1896, 55 taps, paying a uniform domestic rate of $1.50 per month. Water-power is used in the town to drive an electric dynamo for lighting the hotel and some of the buildings, the waste water flowing to a small reservoir.

The apportionment of water by the water-right contracts given with the deeds to the land is at the rate of "one-eighth of 1 miner's inch of perpetual flow from April 15 to November 15 of each year for each acre." This is equivalent to 46,224 cubic feet per acre per annum, or a mean depth of 12¾ inches over the land. The water-rate of $2 per acre would thus be equal to 4.3 cents per 1000 cubic feet, or 0.57 cent per 1000 gallons.

The altitude of Hemet Valley where the dam is located is approximately 4300 feet. The watershed area, as determined from the topographic map of the United States Geological Survey, is 69.5 square miles, the extreme elevation of which is about 9000 feet. This point is Tahquitz Peak, a spur of Mt. San Jacinto. The total drainage-area of the San Jacinto River above the mouth of the canyon is 141.8 square miles. The reservoir therefore receives the run-off from nearly one-half the entire drainage-basin of the river. The average yield of the shed has not been accurately determined, although it has been insufficient to fill the reservoir in any one season since 1895. The irrigation season of 1899 began with but 1000 acre-feet in the reservoir (gage 73 feet).

The present capacity of the reservoir is 10,500 acre-feet, but the addition of 27½ feet to the height of the dam will increase it 2½ times. The cost of the dam and irrigation-works has never been made public. The area of the tract depending upon the reservoir for irrigation is about 7000 acres, of which not more than half have been irrigated.

The Bear Valley Dam, California.—Probably the most widely known irrigation system in California is that of the Bear Valley Irrigation Company of Redlands, California, chiefly by reason of the remarkably slender proportions of the Bear Valley dam, which has been to the engineering

fraternity the "eighth wonder of the world," and has no parallel on the globe. The dam has no stability to resist water-pressure except that due to its arched form, and it has been expected to yield at any time, although it has successfully withstood the pressure against it for fifteen years, and is apparently as stable as it ever was. The probabilities are that nothing but an extraordinary flood or earthquake, or a combination of unusual movements, will ever accomplish its destruction. Such vast interests are now dependent upon the water stored by the dam that its failure would be a public calamity, greatly to be deplored. The settlements of Redlands, Crafton, and Highlands, which are among the choicest of the orange-growing regions of southern California, and the irrigation districts of Alessandro and Perris, are the outgrowth of this water-storage, although the Perris district receives but a small portion of its supply from this source. Prior to the construction of the dam in 1883–84, the natural streams entering the San Bernardino Valley had been entirely appropriated and used in irrigation, and had apparently reached the limit of their irrigable duty. No storage-reservoirs were then in service, and the creation of the Bear Valley reservoir for conserving the flood-waters of the Santa Ana River has more than doubled the area of land irrigated previous to its construction in the territory covered by its water, and has increased the valuation of property in far greater ratio The useful function of the storage-reservoir was never more fully exemplified than in this case. The Bear Valley dam was designed and built by F. E. Brown, C.E., a graduate of Yale Scientific School. The construction of the dam was a bold and difficult undertaking, as it was the pioneer enterprise of California for irrigation-storage, and the site is in a remote locality, to which the cement, tools, and supplies had to be hauled over a rough mountain-range from San Bernardino, descending on the opposite side to the Mojave Desert and again climbing the mountain to Bear Valley, a total distance of 70 miles. The cost of hauling cement was $10 per barrel, and its total cost delivered was $14 to $15 per barrel. Under such conditions, and with a scarcity of funds for what was considered a questionable experiment, it is not surprising that economy of masonry was practiced to such an extent that it is quite without a parallel for boldness of design. The dam is curved up-stream with a radius of 335 feet, and is 64 feet high from base to crest. The length on top is about 300 feet, and the thickness but 2.5 to 3 feet on top, and 8.5 feet at a point 48 feet below the crest, where it rests on a base of masonry that is 13 feet wide, making an offset of about 2 feet on each side at the center; but as the base was built with a curve of shorter radius than the upper 48 feet of the dam, the offset is not uniform, but tapers to nothing on the waterside at the ends of the base, and is fully 4 feet wide on the back. The lowest foundation of the base is 20 feet wide, as shown in Figs. 168 and 169. The entire dam contains about 3400 cubic

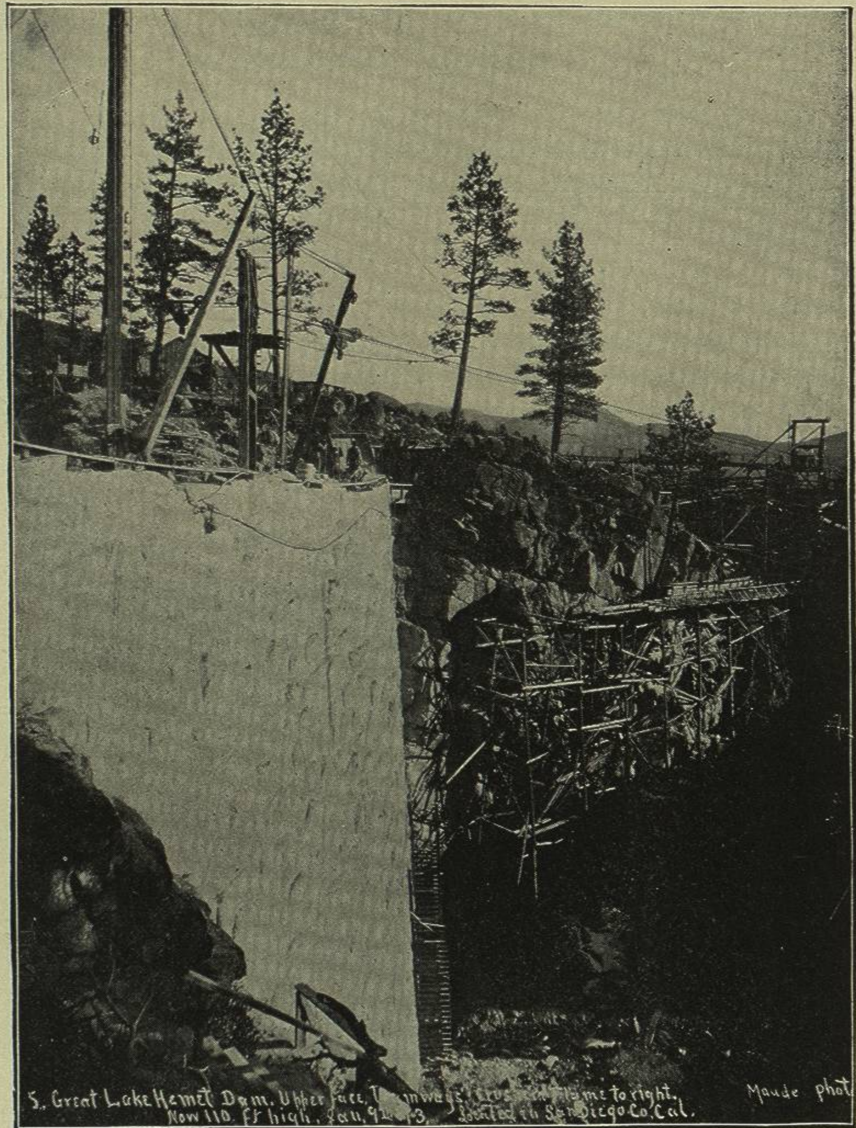

Fig. 171.—Lake Hemet (Cal.) Masonry Dam.

yards of masonry, in which were used about 1600 barrels of cement. It is reported to have cost $75,000, or over $22 per cubic yard, of which the cement alone cost but $7.50 for each cubic yard of masonry laid. That the plant and labor could have cost so much as $14.50 per cubic yard, which is several times the ordinary cost of such work, must, if true, have been largely attributable to the lack of adequate machinery, as well as extravagant management. The masonry is a rough, uncut, granite ashlar, with a

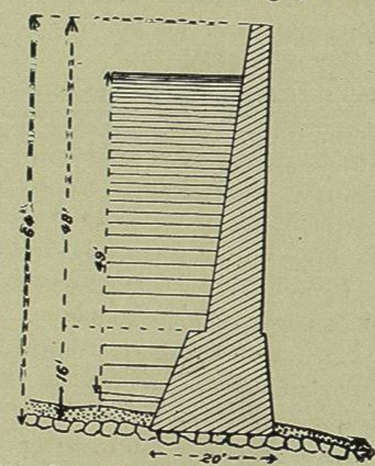

Fig. 172.—Cross-section of Bear Valley Dam.

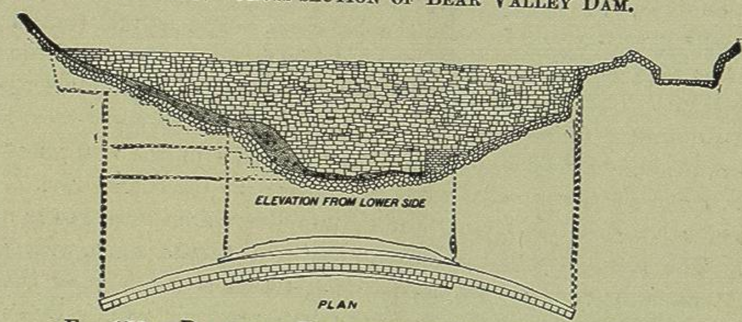

Fig. 173.—Plan and Elevation of Bear Valley Dam.

hearting of rough rubble, all laid in cement mortar and gravel. At the beginning an earth dam was erected, $2\frac{1}{2}$ miles above, 6 feet in height, to retain the summer flow. As the masonry rose water was let down to the main dam, forming a pond which floated timber rafts on which stone was transported to the site, and from which construction was carried on. Hand-derricks were carried on these rafts.

The work was evidently done slowly and with great care, as it has leaked but little beyond the usual sweating, which has left its marks in an efflorescence or deposit of lime, brought out of the mortar by the moisture oozing through. This occurred during the first few years after completion and has almost entirely ceased. When inspected by the writer in August, 1896, the water stood within 10 feet of the top of the dam with little or no visible leakage below.

The south end of the dam abuts against a projecting ledge of granite, standing boldly out from the side of the canyon 100 feet or more beyond the general line of the side slopes, illustrated in the photograph, Fig. 170. Over the top of this ledge, as far from the dam as it could be placed, a spillway, 20 feet wide, was excavated to a depth of 8.5 feet below the level of the extreme top of the dam (Fig. 175).

The extreme capacity of this spillway does not exceed 1700 second-feet, which is dangerously small.

The great Sweetwater flood of 1895 gave a maximum discharge of nearly 100 second-feet per square mile of watershed. A freshet of proportional volume from the Bear Valley shed would give a discharge of about 5600 second-feet, or more than three times the spillway capacity. Occurring at a time when the reservoir were full, such a flood would overtop the dam by a depth of 2 to 3 feet. The result might be disastrous.

The spillway was for a time closed with sand-bags to hold the lake to a higher level, but this device was substituted by movable flashboards, arranged in four bays, separated by suitable framework.

The only outlet or means of control of the reservoir is an iron gate made to slide on brass bearings, and closing a rectangular opening, 20 by 24 inches, leading to a culvert cut in the bed-rock. The culvert trench was made 2 feet wide and 3 feet high, flat on bottom and arched over the top with concrete. The dam was built over it, and the culvert simply passed through or under the wall. The gate is operated by a screw-stem that passes up through a 6-inch pipe, standing vertically in the water next to the dam, and reaching up to a wooden platform at the coping-line. The gate-stem, hand-wheel, and mouth of outlet culvert are shown in the illustration. The maximum discharge capacity of the gate when wide open with full reservoir is about 167 second-feet, which is much more than is ever required to be drawn. The capacity with reservoir practically empty is over 80 second-feet.

The top of the dam is not finished to a true level line, as the coping-stones have been omitted over about one-half the length, and this portion is 2 to 3 feet lower than the finished crest. It requires considerable nerve to walk over the top of the dam, because it has no hand-rail or parapet and is so narrow that few visitors care to attempt the feat. Water has stood for a considerable time within a few inches of overflowing, although it has never actually passed over the top, as the spillway has thus far been capable of carrying the surplus flood-water. The maximum volume stored in the reservoir, thus far, has been somewhat in excess of 40,000 acre-feet, and

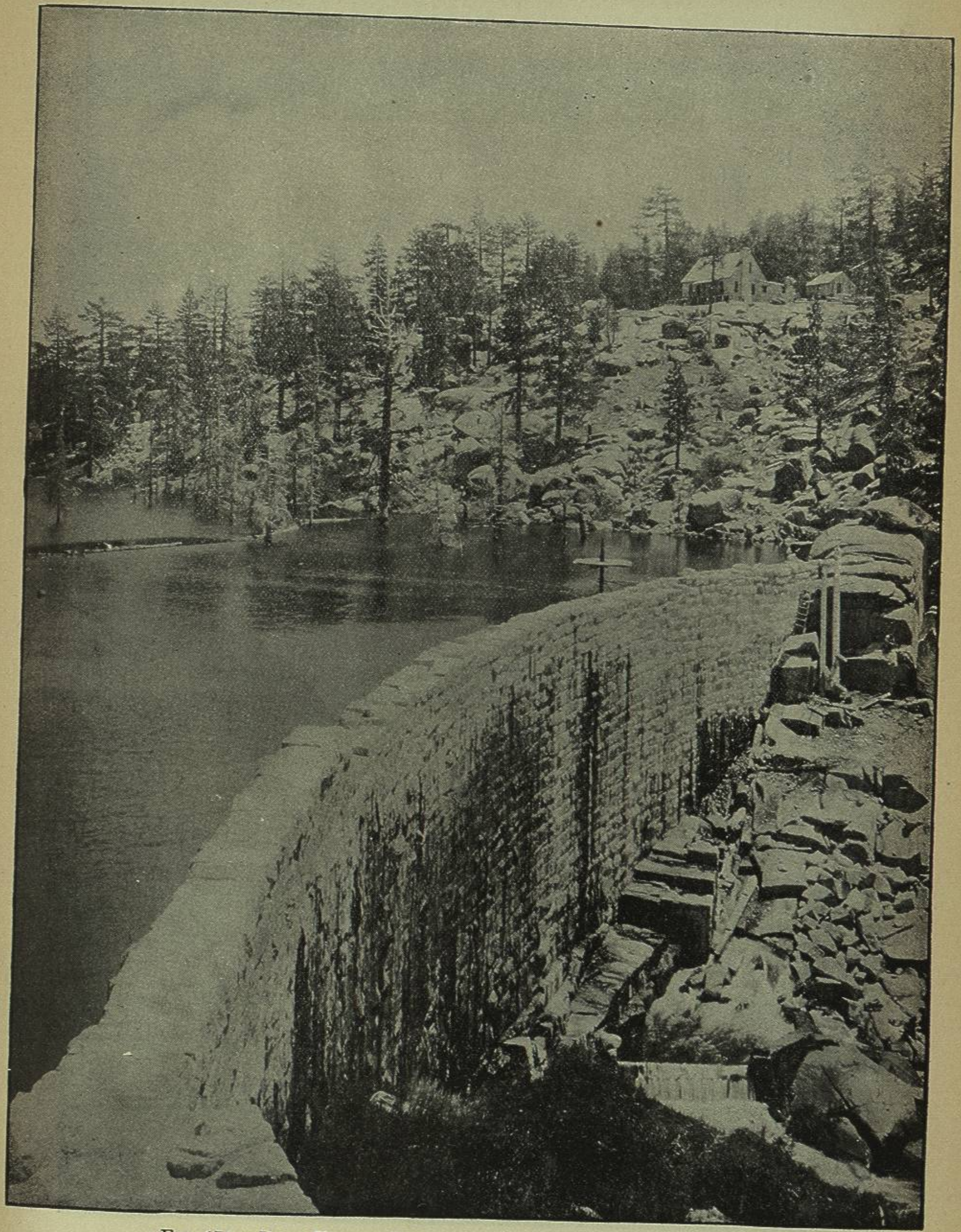

FIG. 174.—BEAR VALLEY DAM, LOOKING SOUTH, TOWARD SPILLWAY

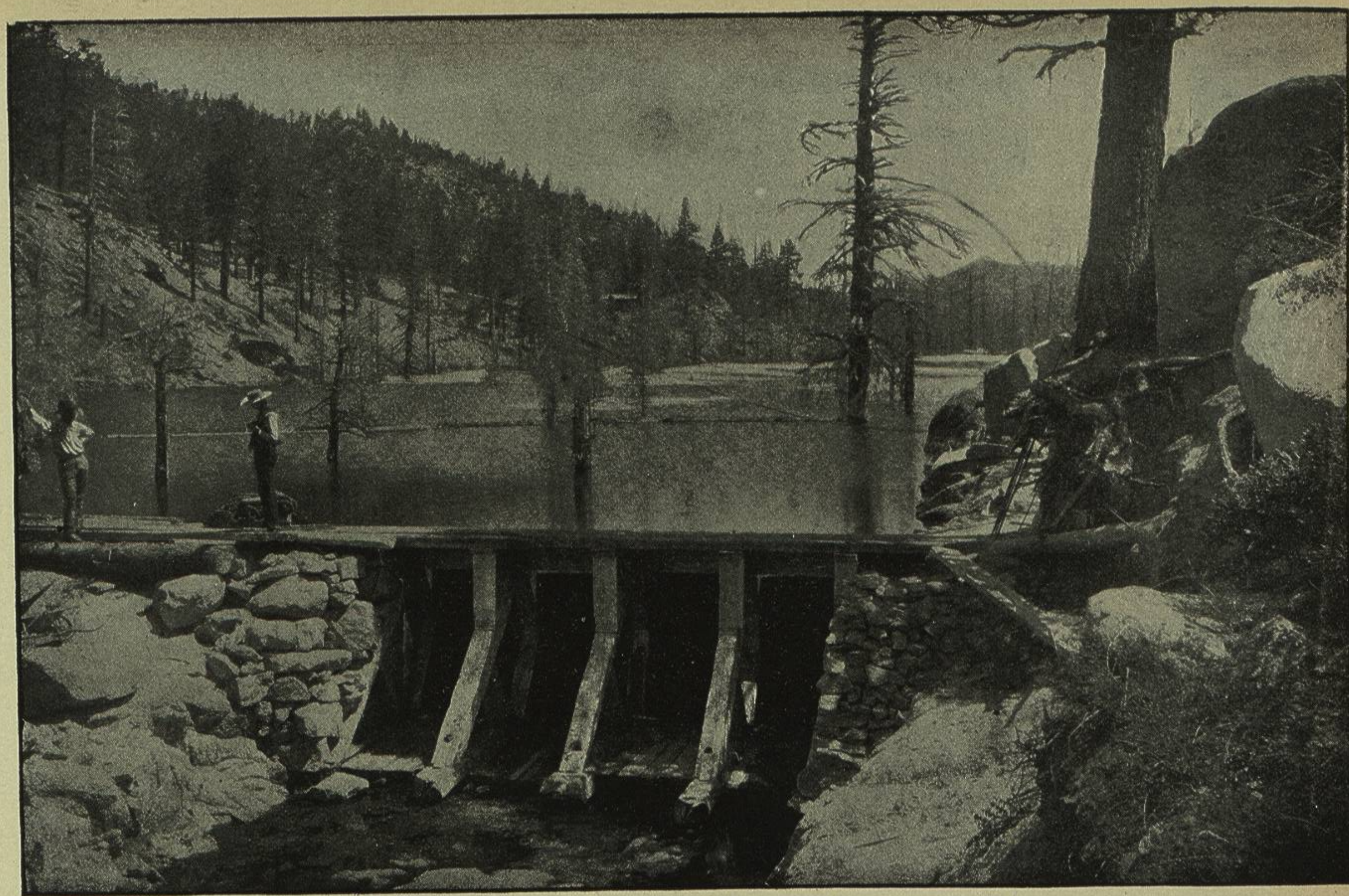

Fig. 175.—Spillway of Bear Valley Dam, with Flashboard Gates.

Fig. 176.—Base of New Rock-fill Dam, below the Bear Valley Dam (shown in Background).

in seasons of excessive precipitation the run-off has exceeded the reservoir capacity.

In order to be able to impound the entire run-off from the watershed, or the greater portion of it, the company at one time contemplated the erection of a higher dam, to be built about 200 feet down-stream from the present dam, and impound water to the 75-foot contour of the reservoir, or 11 feet higher than the crest of the existing structure, at which level the capacity of the basin is 80,000 acre-feet, flooding a surface area of 3060 acres to a mean depth of 25.3 feet. It was regarded as impracticable to add another foot to the height of the present dam, and no engineer cared to risk the responsibility of excavating at the toe of the wall for such an addition to it as would enable it to be raised to the desired height; hence it was deemed best to go a safe distance below to avoid jarring or disturbing the fragile wall, and there begin an entirely independent structure. The new dam was designed as a rock-fill, and was to be 80 feet in height above the base of the present dam, but was never finished beyond the foundations, which were laid in a substantial manner in 1893 (Fig. 176). It is a matter of regret that the second dam was not completed, as its completion was recognized as affording a rare opportunity for studying the arch action upon the present masonry wall. At the time it was begun a committee was appointed by the American Society of Civil Engineers to examine and measure the movement in the masonry incident to the loading and unloading of the arch. This could be quickly accomplished by emptying and refilling the pond between the two dams. If taken at the right time, the effect of a flood pouring over the crest of the thin masonry wall could have been observed, and much useful knowledge obtained on the subject of the strains in arched dams of which so little is now known.

The watershed tributary to the Bear Valley reservoir, as determined from the best available maps, is approximately 56 square miles, the maximum elevation of which is about 7700 feet, or 1500 feet higher than the valley. On the north and east the shed borders on the desert, and the precipitation shades off to a considerably less amount than is recorded at the dam.

The record of rain and melted snow at the dam from 1883 to 1893, the season beginning in each year on September 1st, is as follows:

	Inches.		Inches.
1883–84	94.60	1888–89	46.03
1884–85	28.06	1890–91	78.40
1885–86	65.51	1891–92	38.00
1886–87	24.00	1892–93	44.32
1887–88	62.30	1894–95	50.00
		Mean for 12 years	53.70

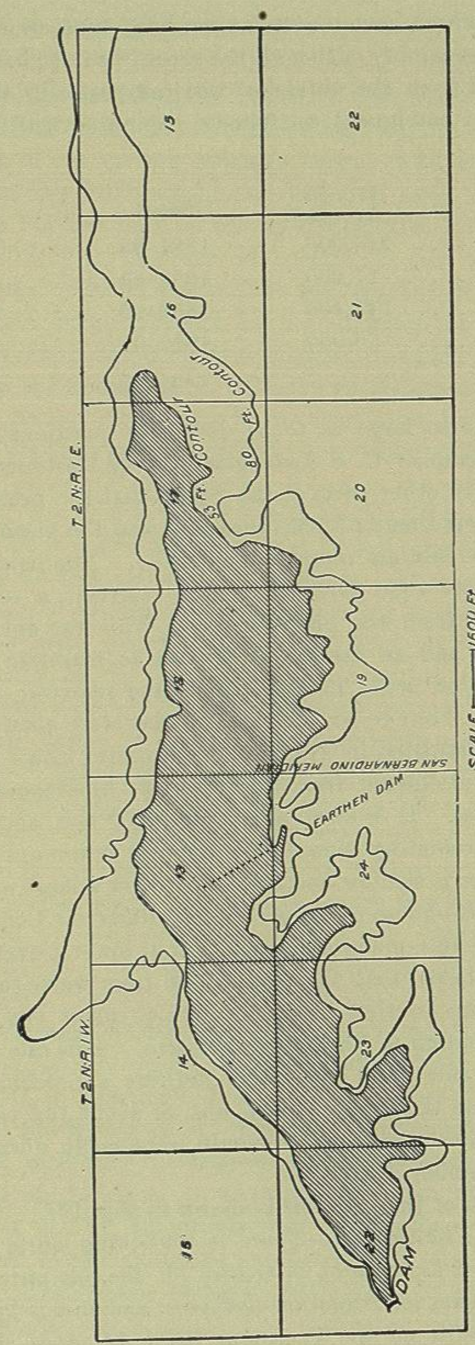

Fig. 177.—Map of Bear Valley Reservoir.

The dry years which have occurred since 1895 must undoubtedly reduce this mean very considerably, although the record has not been made public. In 1891 the run-off from the watershed was computed by Wm. Ham. Hall from the records of catchment, as follows, beginning with the completion of the dam:

Season.	Run-off. Acre-feet.	Season.	Run-off. Acre-feet.
1883–84	236,000	1887–88	132,400
1884–85	21,600	1888–89	70,400
1885–86	142,400	1889–90	211,600
1886–87	8,000	1890–91	186,800
		Mean	126,150

This estimate is so large as to be decidedly questionable. Mr. J. B. Lippincott, Hydrographer U. S. Geological Survey,* estimates, by comparison of observations in other parts of the State, that the probable maximum run-off of the shed is about 100,000 acre-feet, and the mean about 28,500. The minimum was doubtless reached in 1895–99. The irrigation season of 1899 began with but 1560 acre-feet in the reservoir, a small portion of which was held over from the previous year. This was entirely exhausted early in the season, and an attempt was made to maintain the supply by pumping from shallow wells in the bed of the reservoir, although with indifferent success. Four to six acre-feet per day were obtained for a time, but it was largely dissipated by evaporation in passing down the canyon.

The loss to be anticipated from this reservoir by evaporation is a subject of much interest. It is at an altitude of 6200 feet, and well sheltered from winds by surrounding mountains, favoring minimum loss. On the other hand the water is shallow and spread out over a large area. Observations made at the gate-house of the Arrowhead Reservoir Company in Little Bear Valley, in the same mountain-range, but at lower elevation (5160 feet above sea-level), indicate that the evaporation from water-surface is about 36 inches per annum in that locality, of which about 90% occurs in the eight months from March to November, inclusive. This rate of loss applied to Bear Valley reservoir when full would indicate a probable loss of over 20% per annum if no water were drawn out, or about 14% per annum if a uniform draft of 2500 acre-feet per month were made during the period from March to November, inclusive.

The general form of the reservoir is shown in Fig. 177.

La Grange Dam, California.—There is something quite unusual in a masonry dam 125 feet high which is erected for the sole purpose of diverting water from a stream for irrigation purposes, and this is the character of structure that was built on the Tuolumne River, 1½ miles above the town of La Grange, California, in 1891–94, by the Turlock and Modesto irrigation districts jointly. The Tuolumne River, as it leaves the mountains, on its way across the San Joaquin Valley, is cut down so deeply below the general level of the plain as to require a high dam to raise the water sufficiently to get it out on the irrigable lands. The dam is located at the mouth of a narrow box canyon and is in no sense designed or used for storage. It is 125 feet high on the up-stream face, 129 feet on the down-stream side, 90 feet in thickness at bottom, 24 feet at crest, and but 310 feet long on top. The wall is built as the segment of a circle of 300 feet radius, the arch being opposed to the direction of the water-pressure, although its profile is of purely gravity type, in which the lines of pressure are well within the middle third. On the water-face the dam is vertical for 70 feet below the top, and thence to the foundation has a batter of 1 in 20. The edges of the crest are rounded off on a radius of 3 feet on upper side, and 17.5 feet on lower side, leaving 6 feet of the crest level. At 6 feet below the crest the dam is 24.13 feet thick; at 69 feet below it is 52 feet thick; at 89 feet it is 66.25 feet; and at 97 feet, the top of the foundation masonry, it is 84 feet thick. The extreme bottom width at the highest point of the dam is 90 feet. The lower face has a batter of ½ to 1, from 70 feet below the crest, where a compound curve of 63 and 23 feet radii commences, which carries the face to its intersection with the battered face of the foundation masonry about 3 feet above low water. From this point the foundation batter is 1 in 7, to the bottom, about 32 feet in the deepest place. These dimensions give practically an ogee form to the down-stream face, which permits the water to follow the masonry without leaving its face in its descent, provided the depth be not more than 4 to 5 feet, and gives it a horizontal direction at the bottom. The curvature of the dam and the fact that the canyon is but 80 feet wide at the base of the dam, or top of foundations, so concentrate the stream that some erosion may be anticipated at the base, although nothing serious in that line has been reported.

* Nineteenth Annual Report for 1897, U. S. Geol. Sur., Part IV., p. 585.

The dam contains 39,500 cubic yards of masonry and cost $550,009. It is built throughout of rough, uncoursed rubble masonry, laid in Portland-cement concrete, in practically the same manner as that described in the construction of the Hemet dam. The work was done by contract, at $10.39 per cubic yard, including the excavation for foundations, but not including cement, which was furnished by the districts. The cement cost $4.50 per barrel delivered, and 31,500 barrels were used in the work.

It is believed to be the highest overflow dam in the United States, if not in the world. The volume of water passing over it may in extreme floods amount to 100,000 second-feet. The maximum flood that has yet gone over the dam was about 46,000 second-feet in volume, the depth on crest being 12 feet.