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 6¼ 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 has thus far been erected in western America for irrigation-storage is the dam erected in the San Jacinto Mountains, in Riverside County, California, at the outlet of Hemet Valley, the location of which with respect to the irrigated lands is shown in Fig. 165. The view in Fig. 166 is rather an imperfect representation of the appearance of the dam from below. Fig. 167 is an end view which shows the arched form of the dam.

The dam is built of granite rubble, laid in Portland-cement concrete, and was designed to be carried to the ultimate height of 160 feet above the stream-bed. Its present height is 122.5 feet above base, or 135.5 feet above

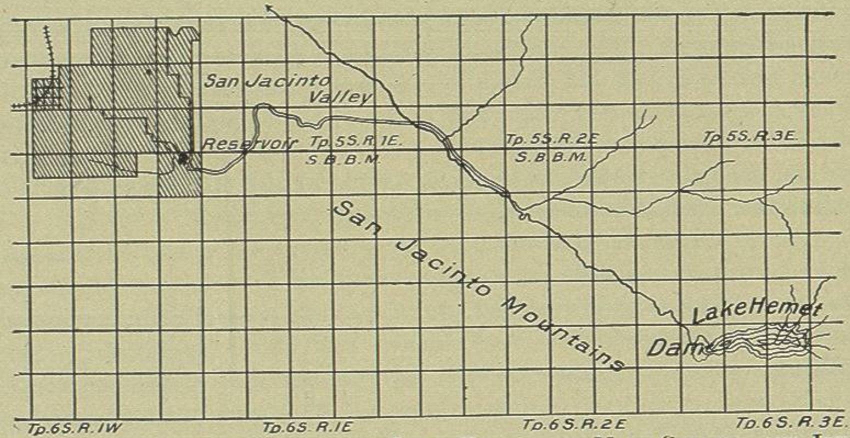

Fig. 165.—Map Showing Location of Lake Hemet, the Main Conduit, and Irrigated Lands

lowest foundations. It is 100 feet in thickness at base, and has a batter of 1 in 10 on the water-face, and 5 in 10 on back. Its present crest is 260 feet long, while the length on base is but 40 feet. The dam was built up with full profile to the height of 110 feet above base, at which point the thickness is 30 feet. Here an offset of 18 feet was made, and the remaining wall is 12 feet at base, and 10 feet thick at top. A spillway notch 1 foot deep, 50 feet long, was left in the center. Extreme floods may exceed the capacity of this spillway and pass over the entire length of the wall to the depth of several feet. This actually occurred in January, 1893, when the dam was 107 feet in height. The dam is arched up-stream with a radius of 225.4 feet on the line of its upper face at the 150-foot contour, although it has a gravity section, with the lines of pressure inside the center third, as shown on section in Fig. 169.

The site seemed to be more suitable for a masonry structure than any other type because the canyon is extremely narrow, the foundations excellent, and materials for construction abundant. After due consideration of all alternative possibilities the writer was directed to prepare plans suitable for the maximum height to which a dam could be built to advantage at this

site, and in the summer of 1890 the plant was assembled and excavation begun. The stripping to bed-rock occupied several months, with the aid of a cableway for conveying the waste to a dump below the dam. In this operation a large hole was developed in the rock, 13 feet in depth, within the lines of the base of the dam. This hole was found to be filled with gravel, firmly cemented in place so tightly that it might safely have been built upon had its limits been known. After the hole was cleaned out a center trench was cut in the bed-rock up the sides, as a key or anchorage, to receive the masonry.

The cement and all tools had to be hauled up the mountain, a distance of 23 miles from the nearest railroad station, over a road whose maximum grade is 18%, making a total ascent of 3350 feet, and descending to the dam from the summit nearly 600 feet. The hauling was done at a cost of $1 to $1.50 per barrel, and occupied a considerable time in delivering a sufficient quantity to make a beginning, and it was the 5th of January, 1891, before the first stone was laid.

The total amount of cement used was about 20,000 barrels, which cost delivered about $5 per barrel.

Work was prosecuted without interruption until January 24, 1892, when severe weather and floods compelled a suspension of construction for four months, when the 45-foot level was reached.

On resumption of work the following spring it was pushed to the 107-foot contour, when the workmen were again driven off by a storm and freshet on January 9, 1893, when the reservoir was filled so rapidly that many of the buildings and tools were submerged before they could be removed. The work remained at this stage until the fall of 1895, when the dam was completed to its present height and all machinery and tools were brought down the mountain. At its present height the dam contains 31,105 cubic yards of masonry.

The concrete used to embed the blocks of stone was mixed in the proportion of 1 of cement, 3 of sand, and 6 of broken stone, crushed to pass through a $2\frac{1}{2}$-inch ring. Mortar was only used in laying the facing-stones and pointing the joints on the exterior faces. Both concrete and mortar were mixed by a cubical iron mixer, one of a number that had done service on the San Mateo dam in northern California. The sand used was clean and sharp, and was constantly brought to the dam by the small living stream flowing from the mountains, the sand being rolled along its bed. It was accumulated in a little reservoir formed by a temporary log dam, and conveyed to the mixing-platform by an endless double-wire-rope carrier, fitted with triangular buckets, placed at intervals of 20 feet. By this means the sand was hoisted 125 feet and carried horizontally 400 feet to the mixing-platform, where it was stored in a bin. This device was very simple, inexpensive, and quite effective, and the sand was always washed clean. Fig.

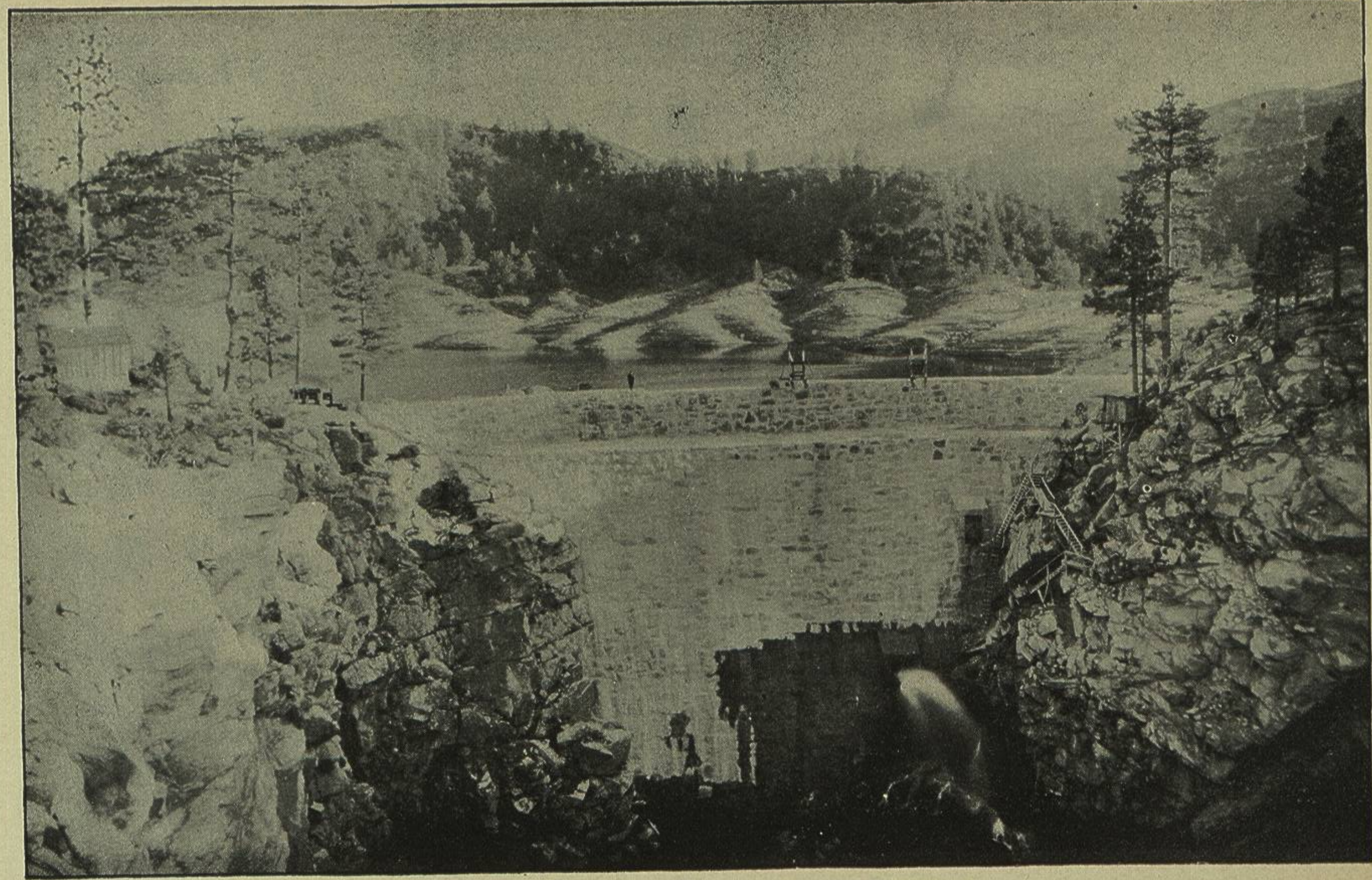

Fig. 166.—Hemet Dam, Riverside County, California.

Fig. 167.—Hemet Dam as Finished, showing the Spillway Ridge South of the Dam.

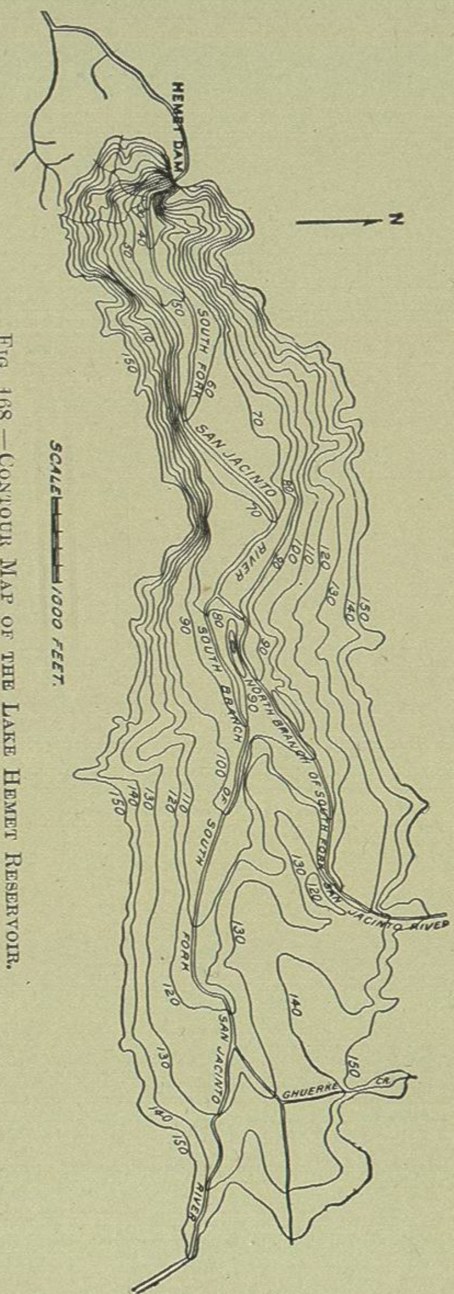

FIG. 168.—CONTOUR MAP OF THE LAKE HEMET RESERVOIR.

170 shows a view of the plant for crushing the stone and mixing the concrete. A portion of the sand-conveyor is also visible in the photograph, as well as one of the engines used on the cableways, and the cars for the

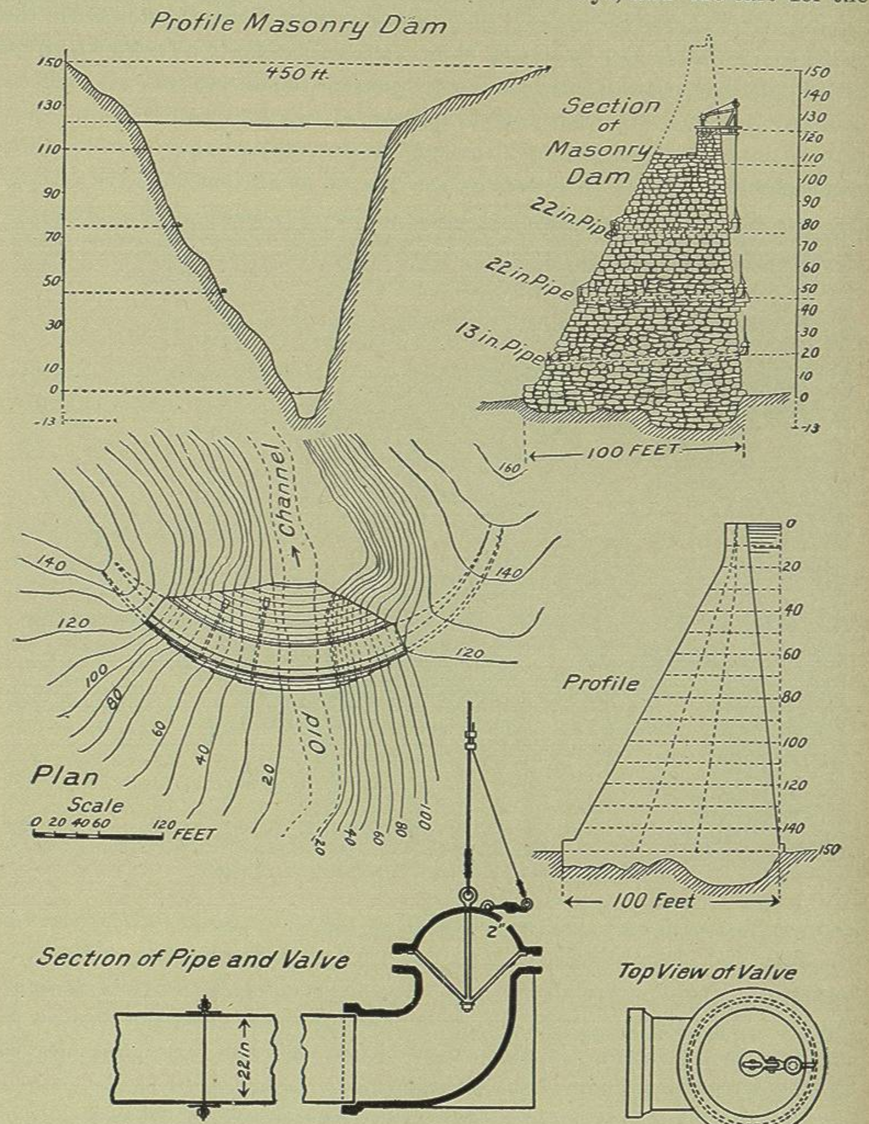

FIG. 169.—HEMET DAM, RIVERSIDE COUNTY, CALIFORNIA.

delivery of concrete to the dam. These latter ran along a tramway, laid on a trestle built from the mixing-platform along the face of the vertical cliff, some 300 feet, to the dam at the 80-foot level. When the dam reached this level an elevator was built to a higher line of trestle.

The stone was all quarried within 400 feet of the dam, on both sides of the canyon, both above and below the dam. It was hoisted and conveyed to the wall by two cableways, each about 800 feet long and $1\frac{1}{2}$ inches in diameter. The cables crossed the dam nearly at right angles with the chord of the arch, but diverging from each other, and were anchored to convenient trees on either side of the gorge. Their position was seldom changed, except to lift them higher up into the tree-tops, and to erect "A" frames on top of the masonry to support the cables, when the wall had reached such a height as to require it. Loads of 10 tons could be hoisted

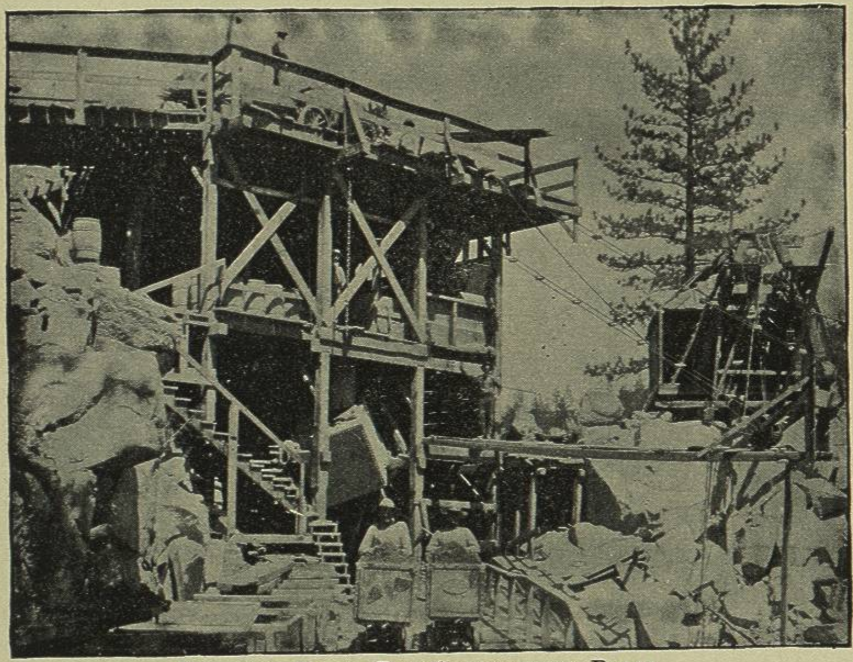

FIG. 170.—HEMET DAM CONSTRUCTION PLANT.

and handled with ease, and with the aid of two derricks, one at each end of the dam, the rock brought by the cables was placed where required. The loads were readily transferred from the cableway to the derricks while in the air. The trolley which traveled on the cableway, and the devices for sustaining the hoisting-line as the load moved back and forth, were devised on the ground and operated satisfactorily.

The derricks were actuated by water-power obtained from a 36-inch Pelton wheel located below the dam and propelled, under a head of 75 feet, by about 80 miner's inches of water, brought from the stream by a flume 1.5 miles long to the edge of the cliff at the mixing-platform, and thence in a 13-inch riveted steel pressure-pipe. The pipe passed through the line of the dam and was embedded in the masonry. Subsequently it was cut off at the upper face of the dam and was made available as the lowest outlet of the reservoir. Two other outlets were provided, consisting of 22-inch lap-welded steel pipes, placed at the 45-foot and 75-foot levels, near the left wall of the canyon. These pipes were provided with cast-iron elbows turning upward and flaring to 30 inches diameter, just inside the line of the dam. They are closed by semi-spherical cast-iron covers, which are raised and lowered by wire ropes passing over a pulley and windlass that are provided for each, and stand on an overhanging frame bolted to the top of the masonry. These covers are ordinarily removed and replaced by cylindrical fish-screens that stand on the top of the elbows, and the main control is had by gate-valves set on each pipe at the lower line of the dam. When these valves are open the water spouts freely into the air and falls in a spray upon the rock below. This water is collected in a pool a short distance from the dam, and passes over a weir for measurement, before beginning its 5-mile plunge down the canyon, to the final point of diversion into the main flume.

When construction began, the reservoir-site was well covered with pine forest, and, as it was desirable to clear the flowage tract, the trees were cut and sawed into lumber. Over one million feet B.M. of this lumber was used for buildings, flumes, and staging about the dam, and half a million more was hauled to the valley for flumes and trestles. Much of the firewood cut from the tree-tops was also hauled down the mountain by the returning cement teams. The main conduit is partly built of this mountain pine, and, although it is knotty and inferior lumber for general purposes, the flume made of it did good service for six or eight years before it was recently replaced with California redwood, which is much more durable. The conduit is 3.24 miles in length from the pick-up weir, just above the junction of South Fork and Strawberry Fork, to the mouth of the main canyon, where it connects with a 22-inch riveted iron pipe, 2 miles long. From the end of this pipe an open ditch, lined with masonry 8 to 10 inches thick, and plastered with cement mortar, conveys the water 5 miles to a 20-acre distributing-reservoir, located near the highest corner of the irrigated lands. This reservoir has a capacity of about 90 acre-feet, and from it the water is distributed by some 30 miles of pipe, flumes, and lined ditches. The slope of the land is 40 feet per mile from east to west, requiring small conduits for distribution. The main canyon flume was built of $1\frac{1}{2}$-inch lumber, and is 38 inches wide, 18 inches deep, and has a grade of about 140 feet per mile. It was calked and battened, smeared with asphalt inside, and whitewashed on the exterior with lime. The ditch-lining consists of granite cobbles of 10 inches maximum diameter, laid in equal parts of lime and cement mortar. It is 2.75 feet wide on bottom, 7 feet at top, 2.75 feet deep, and has a capacity of 60 second-feet or 3000 inches.