close a gap in the ridge a short distance north with a wall about 25 feet high. The outlet to the dam is a tunnel 390 feet long, driven through the hill on the north side of the channel, through which a 54-inch riveted iron pipe is laid. The tunnel is $7\frac{1}{2}$ feet wide inside the lining, and of the same height, and is lined with four courses of brick, 21 inches thick.

The tunnel is intersected by a brick-lined shaft, 14 feet clear diameter, placed just inside the dam in the reservoir. Inside this shaft is a stand-pipe connecting with the main outlet-pipe. Three branch tunnels, carrying large pipes, open out from the reservoir to this stand-pipe, each pipe being controlled by gate-valves that are placed in the main shaft. This is an admirable form of outlet, as all the pipes from the shaft are accessible to inspection and repair. The ends of the tunnels under water have plain cover-valves over elbows, and are provided with fish-screens that are put into position from floating barges. A main pipe, 44 inches in diameter, leads from the dam to San Francisco. The present crest of the dam is 281 feet above tide-level.

When the reservoir is filled it submerges the old Crystal Springs reservoir and dam, the latter being an earth structure which did service for many years until superseded by the new dam. A smaller reservoir, that formerly supplied the town of San Mateo, was also obliterated from view, and the water at highest level will extend up the valley of the north arm of the creek nearly to the toe of the San Andreas dam.

The old Crystal Springs reservoir had a tributary watershed of 14 square miles, which yielded a mean annual run-off of 319 acre-feet per square mile during the eight years from 1878 to 1886. The mean rainfall during that period was 34.95 inches. This run-off is equivalent to a mean of 14.4% of the mean rainfall, the maximum having been 34% and the minimum 0.5%.

The Pilarcitos and San Andreas watersheds, whose catchment is retained by earthen dams, receive a much higher precipitation, especially the former, which is more directly exposed to the saturated wind-currents from the ocean. The average precipitation over all the Spring Valley Water Co.'s sheds, during the seven years from 1868 to 1875, was 43.5 inches, from which the mean run-off was 35.5%, including loss by evaporation. These watersheds are partially wooded, undulating pasture-lands, uncultivated, covered with deep soil, and clothed with native grasses that spring up annually from seed and have little permanent sod. The results of the measured catchment from these areas indicates that, in general terms, on watersheds of this character from 20 to 35 inches of rainfall are annually taken into the soil and absorbed in plant-growth and evaporation.

Pacoima Submerged Dam, California.—One of the most novel and interesting masonry dams erected for impounding water in California, where so many novelties and experimental works have been carried out, is a slender

little reservoir wall built across Pacoima Creek, in the San Fernando Valley, 20 miles north of Los Angeles, for the purpose of forming an underground reservoir, whose storage capacity consists solely of the voids in the gravel-bed filling the valley of the stream.

The creek drains a watershed whose area is 30.5 square miles above the point where it issues from the mountains. Here it flows over exposed bed-rock, and the normal summer flow, which diminishes gradually from about 100 to less than 10 miner's inches, is entirely diverted by a pipe-line and used below for irrigation. The dam in question is located $2\frac{1}{2}$ miles further down, where the channel of the stream is contracted to a width of 550 feet by a ledge of sandstone which crosses it at about right angles. Between the dam and the mouth of the canyon is a continuous bed of gravel, in places half a mile wide, which, though lying on a heavy grade, constitutes the storage-reservoir. The dam was constructed by excavating a straight trench (shown in Fig. 196), 6 feet wide, from side to side of the channel, down to and into the sandstone bed-rock. In the center of the trench a wall of rubble masonry was laid, 3 feet wide at base, 2 feet at surface, using the cobbles excavated from the trench, and a mortar of Portland cement and sand. The mistake was made of not filling the entire width of the trench with concrete, thoroughly rammed between the side walls, which would probably have insured satisfactory water-tightness. As it was, the space each side of the wall was refilled with gravel, and the wall was not thick enough or sufficiently well pointed to be entirely water-tight. The general height of the wall is 40 feet, the maximum being 52 feet. Plan, profile, and section of the dam are shown in Fig. 198. Two gathering-wells are provided in the line of the wall, each 4 feet inside diameter, reaching from bottom to top.

Three lines of drain-pipes, 8 and 10 inches diameter and made of asphalt concrete, laid with open joints, are placed inside the dam leading to the wells, the function of which is to gather the water and feed it to the wells. Outlet-pipes 14 inches diameter, one from each well, lead to either side of the valley. These are placed 13 feet below the top of dam and connect with a main leading to the pipe distributing system supplying the irrigated lands. When the reservoir is drained down to the level of these outlets further draft is made by pumping, which is required for about 100 days during late summer and fall.

The cost of the dam is given at $50,000, and the volume of masonry was about 2000 cubic yards. It is a piece of amateur work, built without engineering advice, but it serves a useful purpose, though not at all commensurate to its cost. It is, however, a type of dam that may be applicable to other localities more naturally favorable than this.

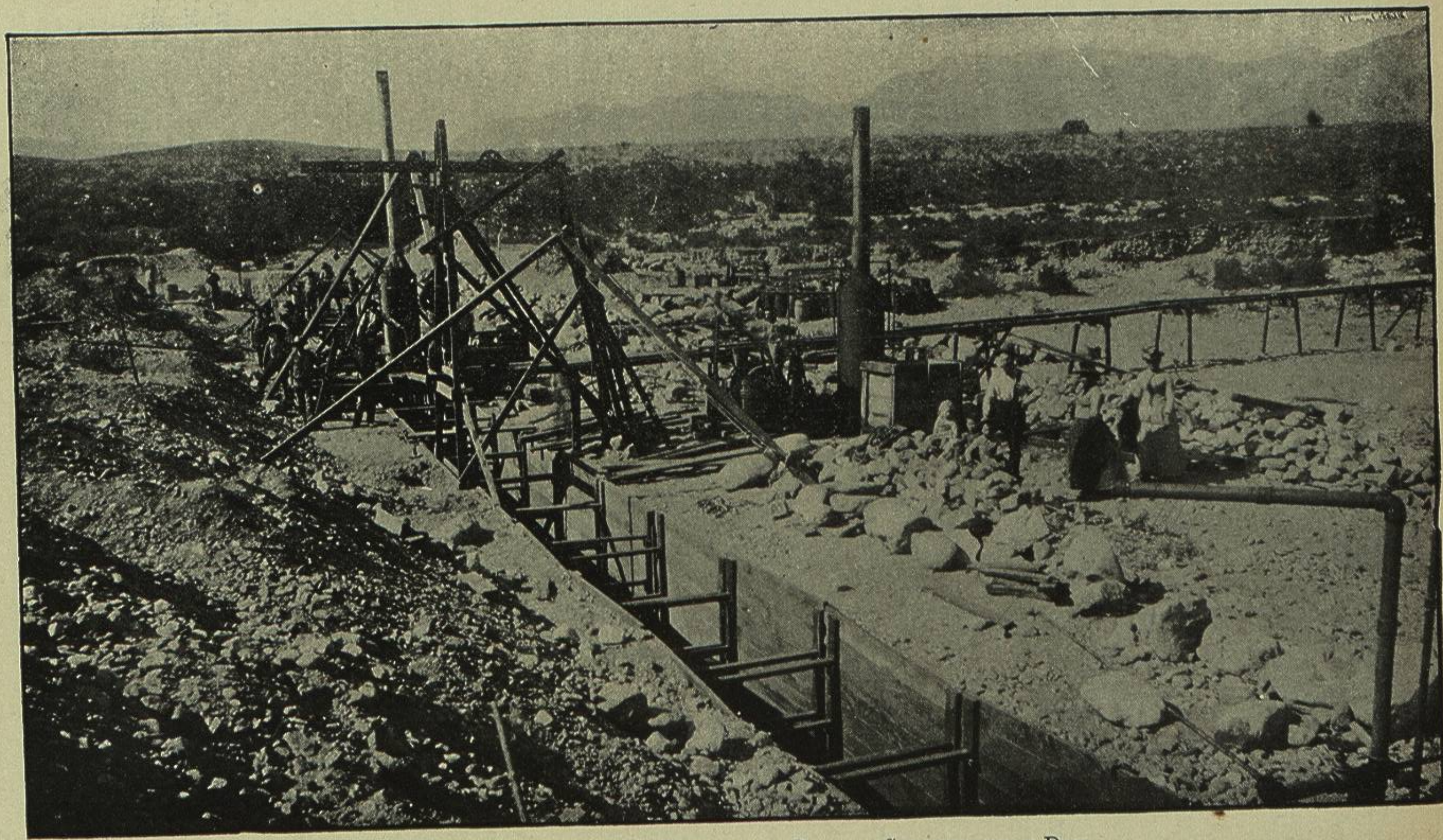

Fig. 196.—Excavation of Trench for Pacoima Subterranean Dam.

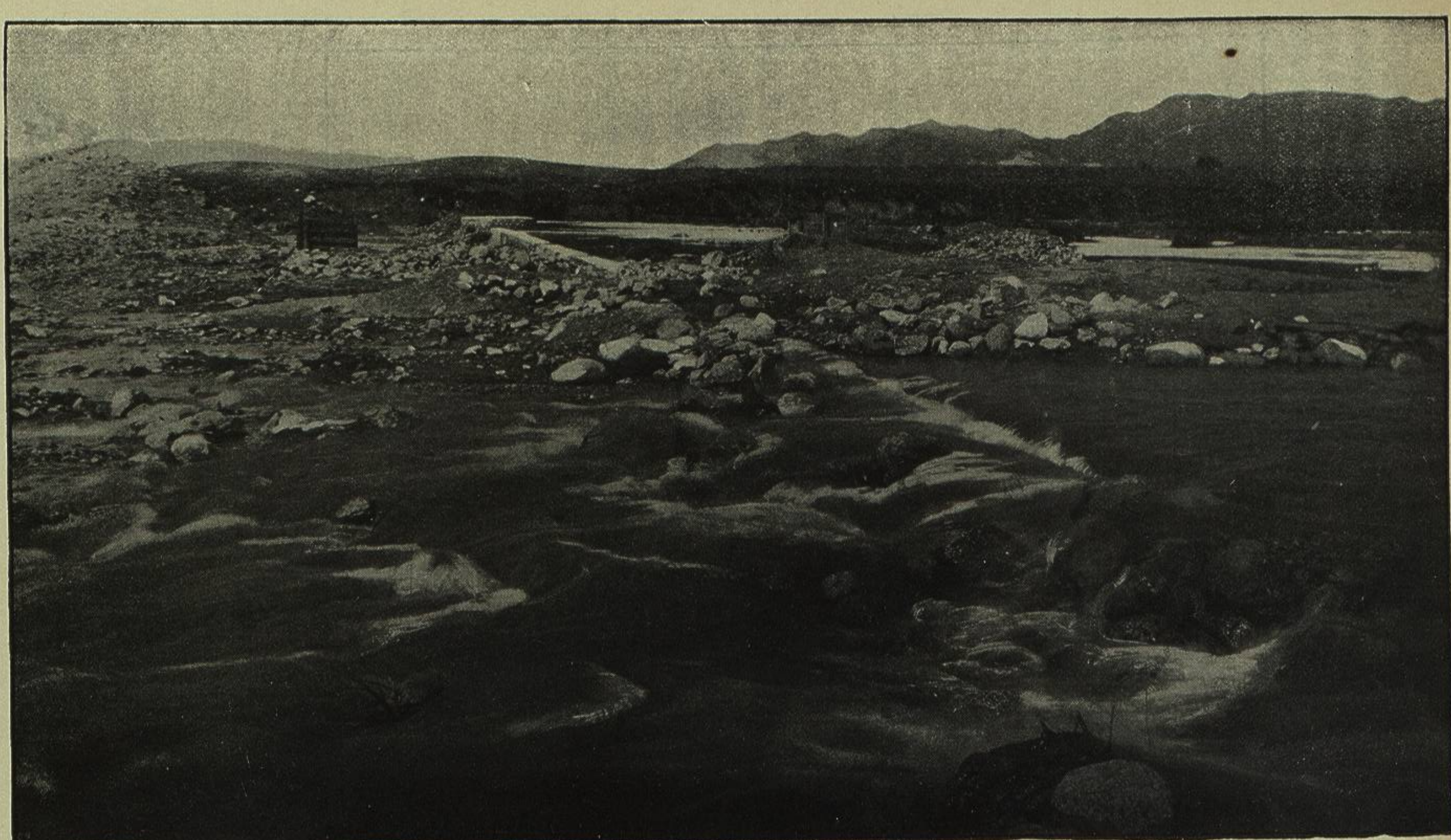

Fig. 197.—View of Flood passing over Pacoima Subterranean Dam.

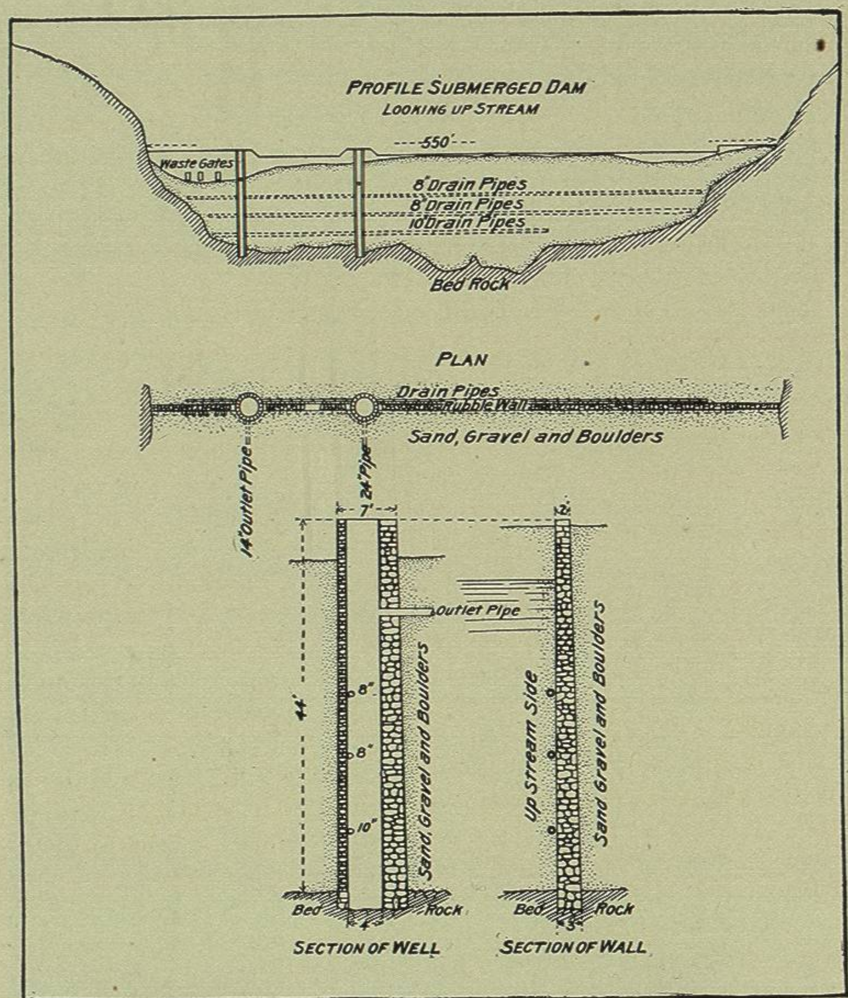

FIG. 198.—PLAN AND PROFILE OF PACOIMA DAM.

The dimensions and capacity of this novel reservoir cannot be clearly determined, but its surface area is approximately 300 acres, its mean depth probably 15 to 20 feet, and its capacity equivalent to the volume of voids in the gravel, or 1300 to 1500 acre-feet.

Agua Fria Dam, Arizona.—One of the tributaries of the Gila River, which joins it from the north, below the city of Phœnix, is the Agua Fria River, heading in the mountains near Prescott, and draining some 1400 square miles of mountainous territory. The Agua Fria Land and Water Company have erected a masonry diverting-weir across the stream, at a point 1½ to 2 miles above the northerly line of Gila Valley, and have projected a storage-dam 1¼ miles higher up the stream, at a point called the Frog Tanks, to impound the flood-water for irrigation of the plains, beginning some twenty miles west of Phœnix.

The dam is projected to the height of 120 feet above the bed of the stream. The width of the canyon is here 298 feet at the level of the sand, but at top the dam will be 1160 feet long. Sections of the two dam-sites and profiles of the dams are shown in Fig. 201. Soundings have been made over the greater portion of the channel width, and what is presumed to be bed-rock has been found at depths of 9 to 15 feet, but for a space of 50 feet no bottom was found with 24-foot sounding-rods. As the greatest depth to bed-rock at the diverting-dam below was but 40 feet, this depth has been assumed for the maximum of the unexplored 50 feet at the upper site, thus making the extreme height of the dam 160 feet. The reservoir to be closed by this dam will be 5 miles in length, flooding an area of 3200 acres and impounding 108,000 acre-feet. With a dam of gravity profile, with base of 124 feet and crest 8 feet wide, the volume of masonry required is computed at 128,650 cubic yards.

The enterprise, when completed, is expected to furnish water for irrigating 50,000 acres of superb valley land that is now an absolute desert. A main canal has been projected, 25 miles in length, with a capacity of 400 second-feet, and some four miles of the heaviest work was completed from the dam down the left bank to the point where the canal is intended to cross the river by a 700-foot flume. This canal is 18 feet on bottom and is to carry 8 feet depth of water, on a grade of 2.11 feet per mile. The diversion-dam, upon which about $100,000 had been expended at the time work was suspended in the fall of 1895, will have a top length of 640 feet, a maximum height of 80 feet, a top width of 10 feet, and a base of 65 feet. When finished it will contain 17,200 cubic yards of masonry, and will have cost in the neighborhood of $150,000.

The only apparent purpose of this dam was to save the construction of a conduit, 1¼ miles in length, in the canyon between the storage-dam proper and the diverting-weir. The storage dam must be built before the scheme is of any value, or before there is any water available for irrigation.

The reasons which led to this error in judgment were, first, a misapprehension as to the depth to bed-rock at the lower site. In fact, the dam was begun without a sufficient knowledge of what a great undertaking it was to be, and so much money had been expended before it was known or suspected that the extreme depth finally reached was to be so great that it was then

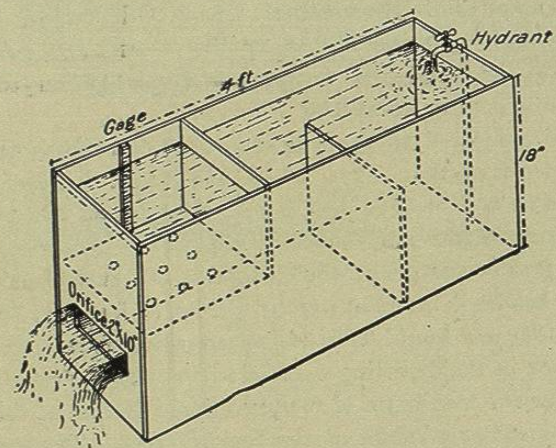

FIG. 199.—MEASURING-BOX USED BY MACLAY RANCHO WATER COMPANY.

too late to abandon the work. The second reason was the confident expectation that the volume of underflow that would be brought to the surface of the dam would reach from "500 to 1000 miner's inches," which, if realized, would have enabled the projectors to use the canal at once in the reclamation of the desert land entered under the United States Desert Land Act before the main reservoir could be made available. This "underflow" development was, however, a sore disappointment, as the flow when finally secured amounted to less than fifteen miner's inches, about what had been predicted by the writer when consulted on the subject a year or more before.

The cross-sectional area of the two channels in which the underflow was passing beneath the surface is approximately as follows:

East Channel	504 square feet.
West "	2635 " "
Total	3139 " "

If the voids in the coarse sand with which these channels are filled could be assumed to be 28% of the entire area, which they are approximately, the

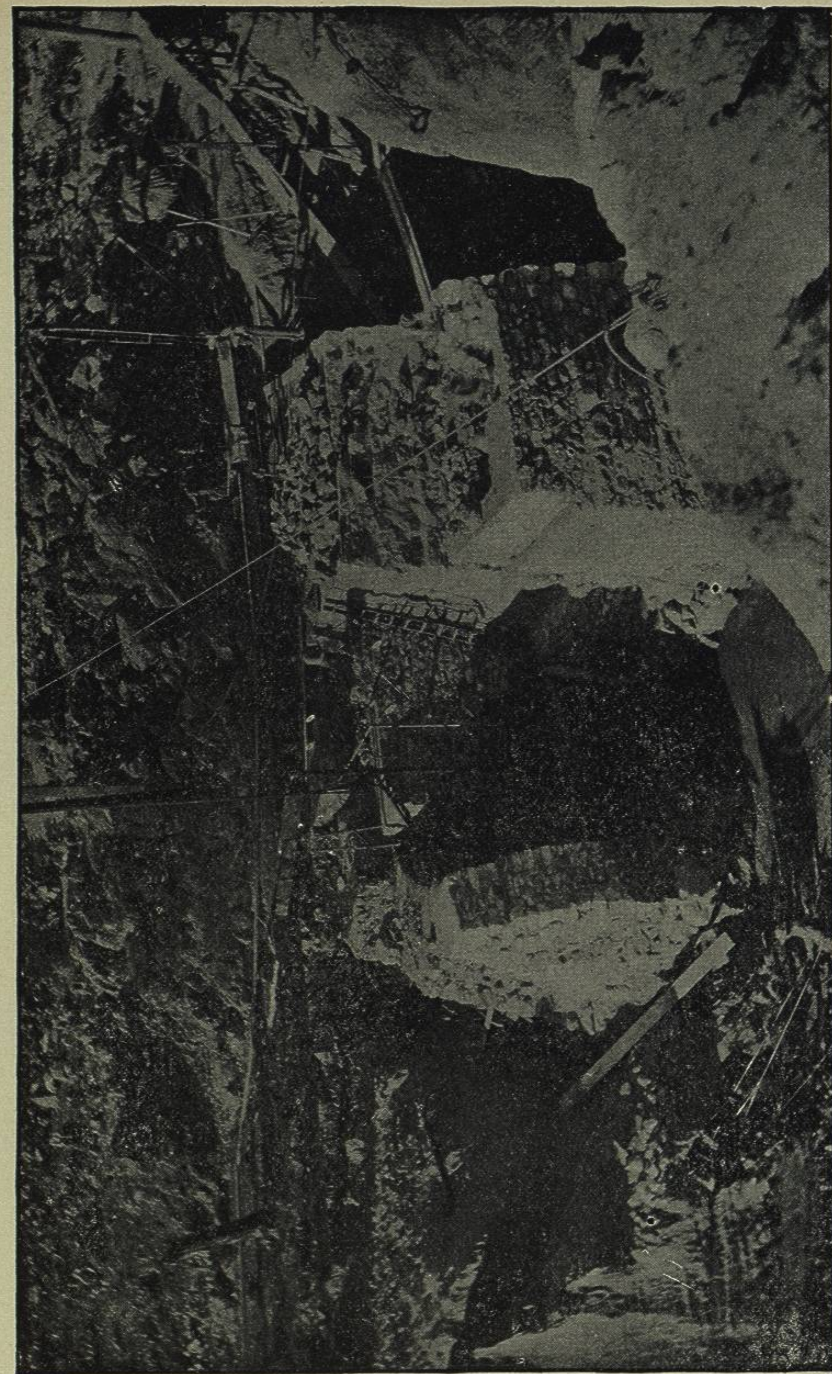

FIG. 200.—FOUNDATIONS OF WEST CHANNEL OF AGUA FRIA DIVERTING-DAM.

rate of flow established by the discharge of 15 inches (0.3 second-foot) would be precisely one mile per annum, a velocity which coincides with the observations of several authorities on the rate of flow through sand of that character. It may be noted in this connection that the volume of underflow in sandy rivers is generally vastly smaller than the popular conception of it, and for this reason submerged dams for raising this underflow are usually commercial failures, except where the material of the stream-bed is a coarse gravel, with little or no fine sand intermingled.

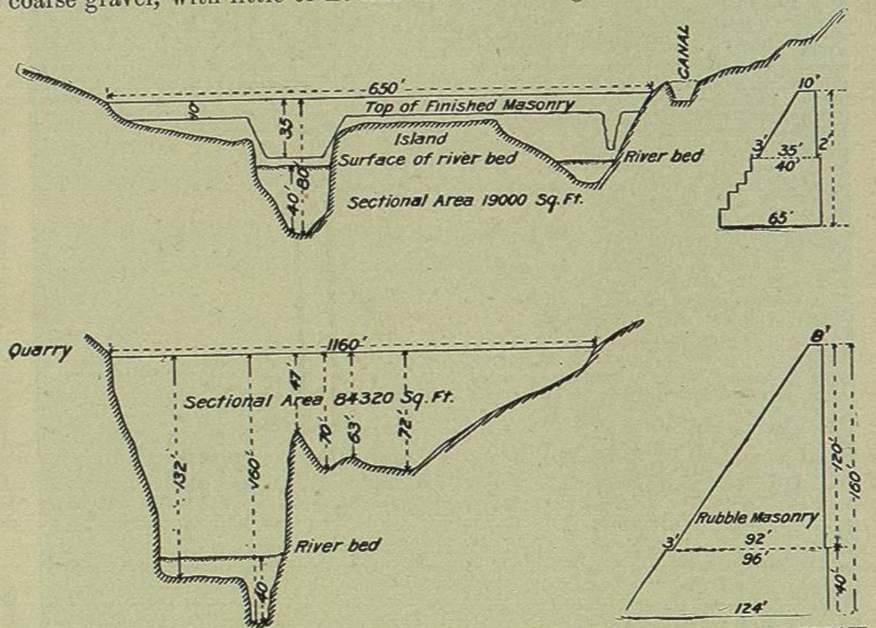

Fig. 201.—Cross-sections of Agua Fria Diverting-dam and Storage-reservoir Dam, Arizona.

The masonry used in the diverting-dam is a rough rubble, faced with coursed ashlar, mostly laid in a mortar of hydraulic lime of good quality, burned about 20 miles from the dam. (See Figs. 200 and 202.) For a portion of the work a small amount of Portland cement, made in Colton, California, was used. The rock was handled by a Lidgerwood cableway, with a span of 700 feet. The excavation of foundations, amounting to about 12,000 cubic yards, was accomplished by teams and scrapers, the water being handled by centrifugal pumps.

In October, 1895, a flood came which poured over the fresh masonry for several hours to the depth of 8 feet, and finally carried away a section 100 feet long, 12 feet deep, near the west end. The partial failure of the wall is accounted for by the fact that in laying the masonry each course was leveled off smoothly with mortar, in the fashion to which brick-masons are addicted in laying up house-walls. There was thus little bond between the courses, which is so essential in dam-work. A view of the dam, taken from

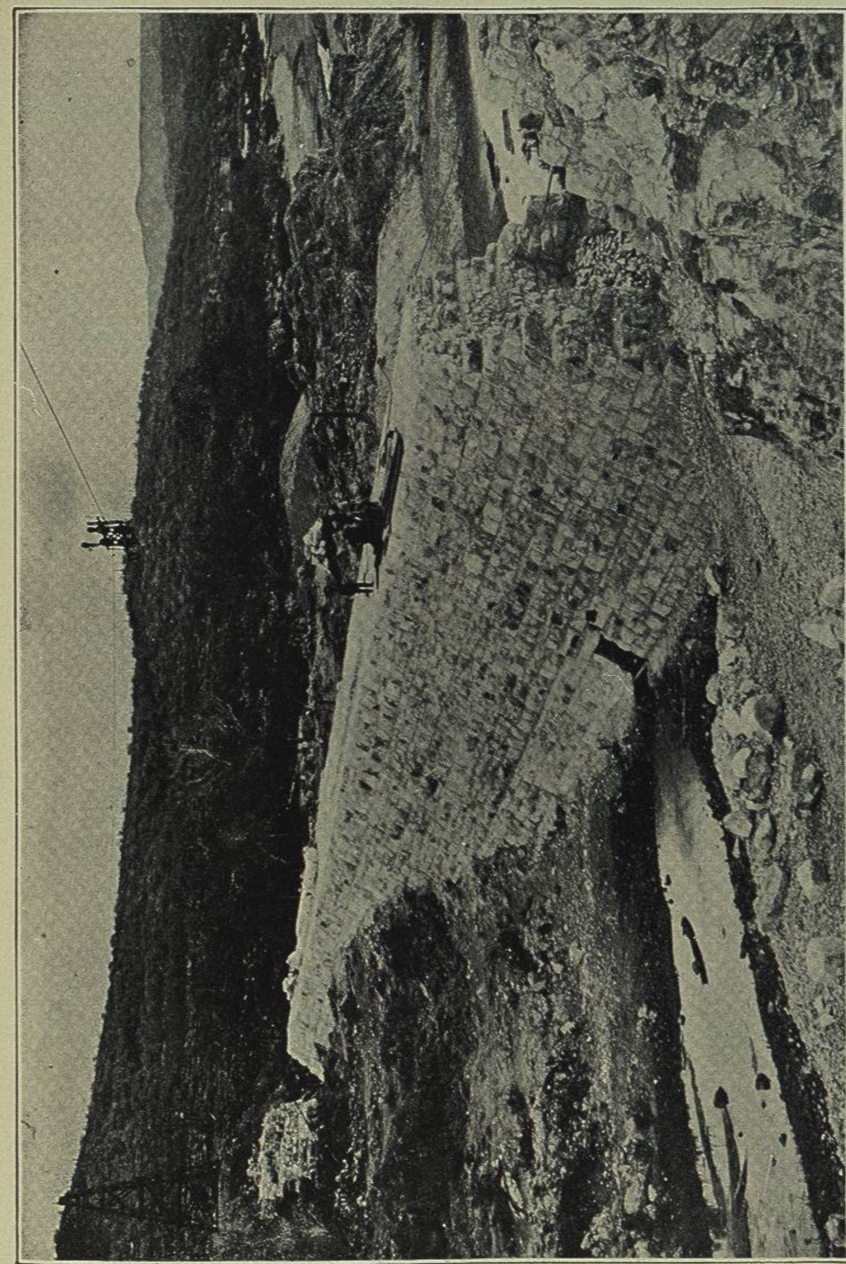

Fig. 202.—Diverting-dam on the Agua Fria.

the canal bank, is shown in Fig. 202, reproduced by permission from a paper entitled "Irrigation near Phœnix, Arizona," by Arthur P. Davis, C.E., Hydrographer, U. S. Geological Survey, being No. 2 of the series of "Water-supply and Irrigation Papers," from which some of the data for the foregoing description are derived.

In addition to the Frog Tanks reservoir-site the company have a second location, 8 miles higher up the river, where the gorge is but 262 feet wide at the river-bed, in solid rock, and but 500 feet wide at a height of 200 feet. This basin is said to have a capacity of 150,000 acre-feet, with a dam 150 feet high. The watershed, which drains the east slopes of the Bradshaw Mountains, reaches summit elevations of 6000 to 8000 feet. A reasonable estimate of rainfall and run-off from this shed is a precipitation of 16 inches and an annual run-off of 15%, which would yield 142,300 acre-feet.

Storage-reservoirs for Water-Supply Along the Line of the Santa Fé Pacific Railway in Arizona.—The northern portion of Arizona, traversed by the Santa Fé Pacific Railway, is an elevated plateau draining into the Colorado Canyon on the north, the Colorado River on the west, and the Verde, Salt, and Gila rivers on the south. This region has a maximum elevation of over 7000 feet along the railway and receives a greater precipitation than the lower altitudes in the southern part of the territory, but it is largely capped with volcanic lava and indurated ash, through which the water from rain and melted snow rapidly sinks and disappears. Living springs and streams are therefore infrequent, and the water-supply for railway purposes is so unevenly distributed as to necessitate the impounding of flood-waters in artificial reservoirs. This necessity is chiefly due to the general absence, in the valleys of that region, of beds of coarse sand and gravel, which constitute nature's storage-basins. The railway company, to avoid hauling water from point to point over this section of the road, has constructed several substantial dams for storage purposes at convenient points near the line of the railway, all of an interesting character in their construction from an engineering standpoint, although unimportant in the volume of water stored compared with works located in more favorable localities. These reservoirs are the following:

Locality.	Volume Stored.		Height of Dam. Feet.	Character of Dam.	Elevation above Sea-level.
	Cubic Feet.	Acre-ft.			
Kingman	....	....	16	Masonry, submerged	5384
Seligman	39,651,000	703	68	Masonry	5445
Ash Fork	4,950,000	113.6	46	Steel	7000
Williams	14,700,000	338	46	Masonry	6282
Walnut Canyon	20,798,000	488	70.4	Masonry	

The Kingman Submerged Dam.—About one mile west of Kingman the railway company have a well sunk in the gravelly bed of Railroad Canyon, from which they pump water for filling their tank at Kingman to supply the town, as well as the locomotives of the railway. To increase this supply and to furnish water by gravity to another tank 4 miles below, a masonry dam was built on bed-rock to intercept the underflow of the stream and store water in the gravel bed above the dam. The dam consisted of a slender masonry wall, 2 feet thick at top, 6 feet thick at base, and 16 feet high, crossing the canyon from side to side and reaching up nearly to the surface of the stream-bed. A trench was excavated in a straight line, the dam was built, and the gravel restored to its natural position, so that floods pass over its top unobstructed. The dam is thus entirely concealed from view. At the northerly end of the dam it was

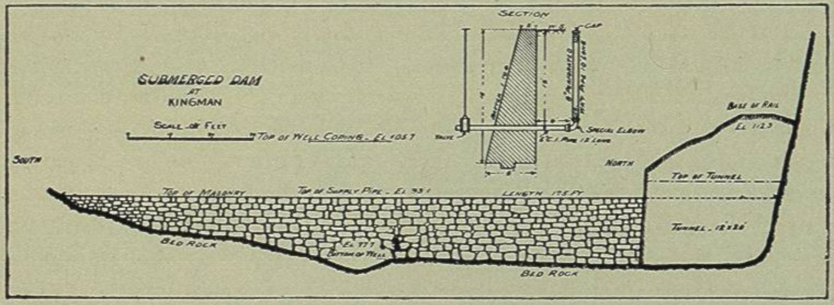

FIG. 203.—SUBMERGED STORAGE- AND DIVERTING-DAM, NEAR KINGMAN, ARIZONA.

necessary to tunnel some distance under the railway in gravelly formation in order to carry the masonry to the bed-rock wall of the canyon on that side. This tunnel was made 12 feet wide, 20 feet high, and about 30 feet long, the top of the tunnel being 16 feet below the rails. A 6-inch cast-iron outlet-pipe is built through the dam 12 feet below the top, at one side. Four feet above the dam an elbow is placed, upturned vertically, and an 8-inch wrought-iron stand-pipe 10 feet long is inserted in the elbow. This stand-pipe is perforated with ⅜-inch holes, placed ½ inch apart, for straining the water, the top being capped. The gravel reservoir is kept filled to the top of the dam by the natural underflow, and thus the town well is supplied and the lower tank automatically filled by gravity, the discharge being controlled by a float. No shortage of water has been experienced since the dam was built in 1897. The dam is 173 feet long on top, and contains 320 cubic yards of masonry. (See Fig. 203.)

The Seligman Dam.—This structure was begun June 25, 1897, and completed Feb. 28, 1898. It is the largest and most expensive of all the structures of its class built by the railroad company. It is located three miles southeast of the town of Seligman, an important division terminal