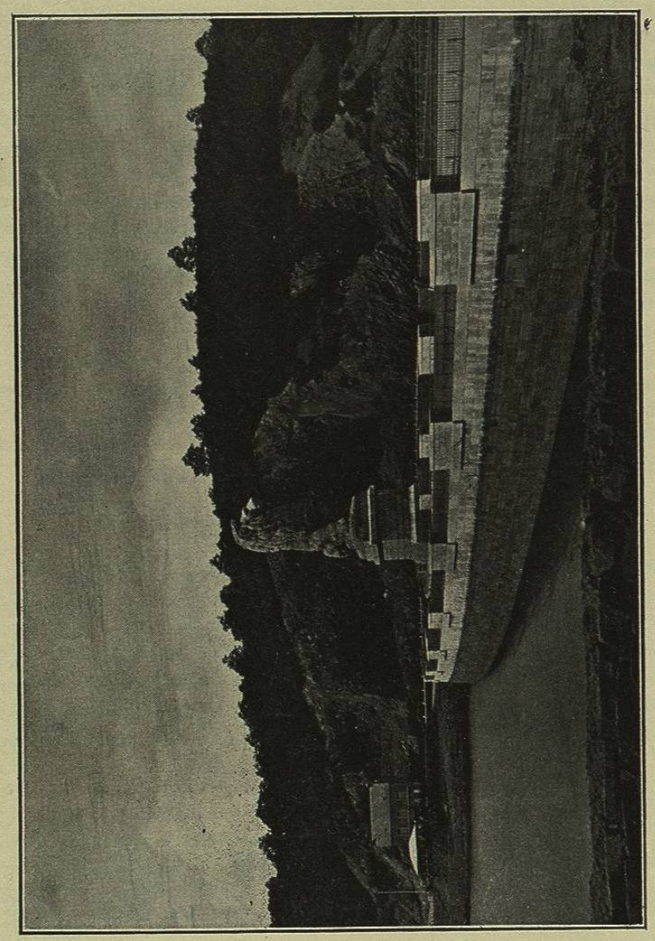

FIG. 273.—GILEPPE DAM, VERVIERS, BELGIUM. 400

feet, or just one-third the maximum depth. The capacity of the reservoir is about one-half the average annual run-off from 15.4 square miles of watershed.

The masonry is rough rubble throughout, of sandstone quarried on the spot. The dam is surmounted by a cyclopean statue of a lion sitting on a pedestal. An ample carriageway is provided across the dam.

Considering the great thickness of the wall and the care taken in its construction, it was a great disappointment to find on filling the reservoir that it leaked quite considerably. This leakage gradually diminished and is of no importance as affecting the stability of the dam.

The entire cost of the dam was $874,000, or $89.83 per acre-foot of storage capacity.

DAMS IN GREAT BRITAIN.

The Vyrnwy Dam, Wales.—Since July 14, 1892, the city of Liverpool, England, has been chiefly supplied by water from a large storage-reservoir in the mountains of Wales, 77 miles distant, formed by a monumental dam of masonry erected across the Vyrnwy valley, in 1882 to 1889. The dam has a top length of 1172 feet, is straight in plan, and has a maximum height of 161 feet from foundation to parapet. It is used as an overflow-weir over its entire length, and its profile was designed to offer additional resistance over that presented by water-pressure alone. An elevated roadway is carried across the dam on piers and arches, above the level of flood-water, which adds greatly to the architectural effect and ornamentation of the imposing mass of masonry. The great wall is composed of cut stone. The base width of the dam is 117.75 feet. The back-water level below the dam is 45 feet above its base.

The total volume of masonry in the dam is 260,000 cubic yards, which was laid with such extraordinary care that its average cost was nearly $10 per cubic yard, in a country where materials and labor are of the cheapest.

The base of the dam is founded on a hard slate rock, and one end of the masonry is built into the solid wall of bed-rock on the side of the valley. At the other end, however, the rock was so deeply overlaid with a deposit of bowlder clay that the masonry was connected with this material by a puddle-wall of clay recessed into the masonry.

The general dimensions of the dam are as follows:

Total length on top	1172 feet.
Maximum height on top of roadway parapet	161 "
Height, river-bed to parapet	101 "
Height, river-bed to overflow-level	84 "
Greatest width of base	120 "
Batter of water-face	1 to 7.27 "

The cost of the dam is given as follows:

Borings and preliminary work	$34,600
Excavating 220,820 cu. yds. and backfilling 79,501 cu. yds	287,600
Puddle-wall, including excavation	16,800
Masonry and brickwork	2,532,000
Regulating and gauging plant	46,000
Basin and other work below dam	40,000
Total for dam proper	$2,957,000

In addition to this the removal of a village in the basin, the building of roads around the lake, culverts, fencing, planting, dressing slopes, and erection of superintendent's house cost $377,000, or a total of $3,334,000.

The reservoir formed by the dam covers a surface area of 1121 acres, and impounds 12,131,000,000 Imperial gallons, or 44,690 acre-feet. This gives a mean depth of 39.87 feet, or 47.5% of the maximum. The water-shed area is 29 square miles, upon which the minimum recorded rainfall is 49.63 inches, and the maximum 118.51 inches.

The average cost of the dam per acre-foot of storage capacity formed by it was $74.61.

The dam was planned and constructed by Geo. F. Deacon, Chief Engineer, Liverpool Water-works. Messrs. Thos. Hawkesley and J. F. Bateman were consulting engineers.

Tests made by Kirkaldy of large blocks of the concrete and masonry taken from the dam showed a compressive strength of 300 tons per square foot, while the maximum strains to be borne by it are but 9 tons per square foot, an excess of strength which has been considerably criticised.

The Blackbrook Dam, England.—A dam of considerable importance was built in 1900 to 1905 across the valley of the Blackburn, to form a reservoir of 80,960,000 cubic feet capacity (1860 acre-feet) as storage for the domestic supply of the city of Loughborough (population in 1891, 18,200). The dam is 108 feet in maximum height, 525 feet long on the crest, 65 feet thick at base, and 14 feet at top, carrying a maximum depth of 65 feet of water. The foundations extend down 30 feet below the original stream level, and a cut-off trench goes down 25 feet still deeper. The dam has a spillway over the crest for a length of 150 feet, which is spanned with six arches of 25 feet each, carrying a 9-foot roadway over the top of the dam. A water-cushion or tail pond is provided at the down-stream toe of the structure to prevent scouring during heavy floods. Water is drawn from the reservoir through valves placed at various levels in a valve tower above the dam.

The work was carried out under direction of Messrs. George and F. W. Hodson, M. M. Inst. C. E.

The Swansea Dam, Wales.—The waterworks of Swansea, Wales (population in 1891, 90,400), were supplemented in 1905 by a storage reservoir formed by a dam of cyclopean rubble masonry, faced with brick, having a maximum height of 144 feet, and a crest length of 1250 feet. The structure was carried down into the rock a depth of 37 feet below the river bed, and is 7 feet higher than the overflow level, leaving an available depth of 100 feet of water in the reservoir.

The up-stream face is vertical from the top down for 70 feet, then batters 1:20 to the bottom. The thickness at the river bed level, 107 feet below the crest, is 75 feet. For the heart of the dam the large stones were bedded in 1:2:5 concrete, but in the lower part of the base and the upper six feet of the water face a richer mixture was used, consisting of 1 of cement, 2 of sand and 3.4 of fine crushed rock.

The brick facing on both up-stream and down-stream sides of the dam is uniformly 18 inches thick, tied into the body of the masonry, and laid in 1.3 cement mortar. The brick used were blue Staffordshire brick, hard burned, with hard pressed brick for the exterior facing courses.

The dam was designed and constructed by Mr. R. H. Wyrill, M. Inst. C. E., Borough and waterworks engineer for the city of Swansea.

The use of brick for the facing of a masonry dam is confined to three principal structures in the world, as far as recorded in technical literature: the Renscheid dam, with one face so covered, and the Ithaca dam, with both faces of brick, being the other two examples, aside from the Swansea dam.

The Burrator Dam, England.—The city of Plymouth (population in 1891, 84,200), a port in the south of England, began the construction of the Burrator reservoir, on the river Meavy, 10.5 miles from the city, in 1893, by the erection of a masonry structure called the Burrator dam, and an earth embankment called the Sheepstor dam, both notable structures. The works were described by Edward Sandeman, M. Inst. C. E., in a paper contributed to the Institution of Civil Engineers, and published in October, 1901, from which the following description has been compiled. Mr. Sandeman was hydraulic engineer for the city, and constructed the works under the advice of James Mansergh, F.R.S., President Inst. C. E., acting throughout as consulting engineer.

The Burrator dam has a total height of 145.5 feet from base of foundation to the coping of the parapet wall, is straight in plan, 361 feet in length, with a thickness of 62.8 feet at the level of the river bed, 77 feet below the overflow level, and is battered on the up-stream face 7.5%, and on the lower face 61%. It carries a roadway 18 feet wide on top, supported over a central spillway of 125 feet total length by five segmental arches of 28 feet span. The maximum depth of excavation to granite bedrock was 40 feet.

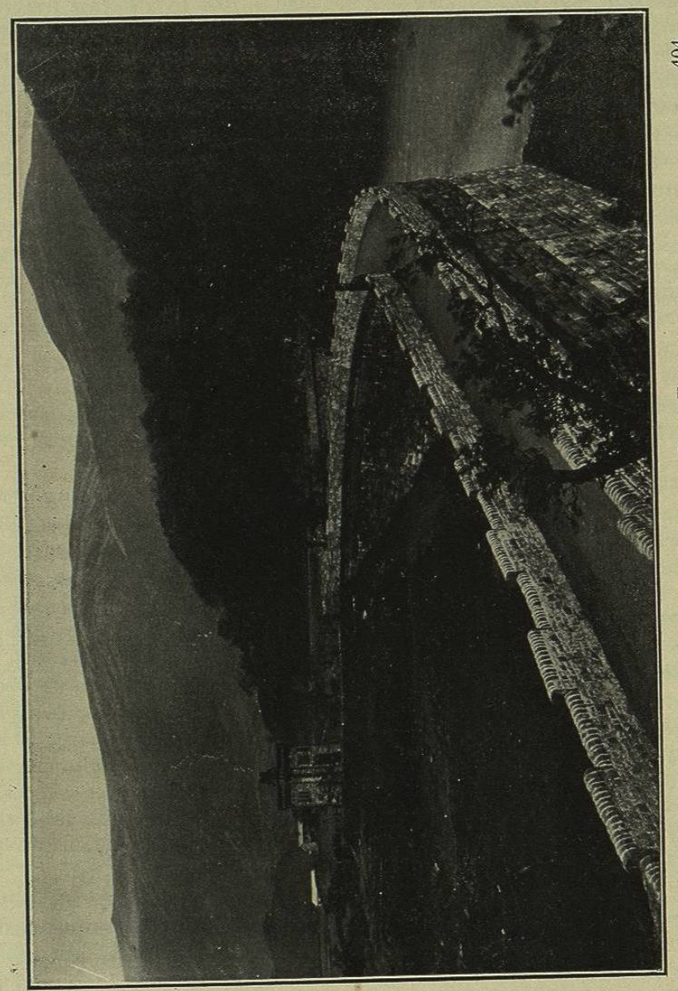

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FIG. 274.—THIRLMERE DAM, ENGLAND.

Blocks of granite, roughly dressed on the bed and weighing from a few hundred pounds to 7 tons, were embedded in rich concrete, while the facings were composed of large stones having an average thickness of 30 inches, with beds and joints carefully dressed, but left rough on the exterior, and laid in cement mortar, the joints being pointed and calked with neat cement mortar.

The cost of the masonry dam was $495,700, while the cost of the earth dam was $106,600, a total of $602,300. The reservoir has a capacity of 105,120,000 cubic feet, or 2410 acre-feet. The average cost, therefore was $250 per acre-foot of reservoir capacity.

The earth dam is a remarkable structure on account of the extraordinary depth of excavation required to reach bedrock with the concrete core-wall, whose lowest level is 91 feet below the surface. This was built up to within 22 feet of the water-line throughout, 5 to 6 feet thick, on top of which clay puddle 8.5 feet thick at bottom, 6 feet at top, was extended nearly to the crest of the embankment. The maximum depth of water against this embankment is but 17 feet. Its length is 470 feet, crest width 12 feet, slopes 3 on 1 and 2 on 1.

Thirlmere Dam, England (Fig. 272).—A part of the water supply of Manchester is furnished from a reservoir at Thirlmere lake, formed by a masonry dam, built in 1886-1893. The dam has a maximum height of 62 feet, and is 18.5 feet wide on top, forming a roadway with masonry parapets on each side. The width of the dam at the base is 51.8 feet. The up-stream face has a batter of 12.5%, while on the down-stream side is a vertical curve with a radius of 100 feet.

The dam has a gravity section, and is built on a reverse curve, in order to follow the alinement of highest bedrock across the valley. The crest of the roadway of the dam is 6.2 feet higher than the high water level of the reservoir.

The dam was built by Mr. George H. Hill, engineer in charge.

Craig Goch Dam, Wales.—The city of Birmingham, England, has been engaged for many years past in extensive works of water storage to obtain an additional supply from the mountains of Wales, to be brought to the city by an aqueduct 74 miles long, 8 feet high inside, by 7.5 feet wide, with a capacity of 129 cubic feet per second. A total storage capacity of 66,000 acre-feet is being created by the erection of five high masonry dams, one of which, the Craig Goch dam, is illustrated by two photographs, Figs. 275 and 276, taken from *Engineering Record*, January 30, 1904. Other dams on the same stream are the Caban Goch and Pen-y-Gareg dams, which are straight in plan. The Careg-Dhu dam and one other masonry structure are located on the Clarewen river.

The total cost of the dams and aqueduct are estimated at over

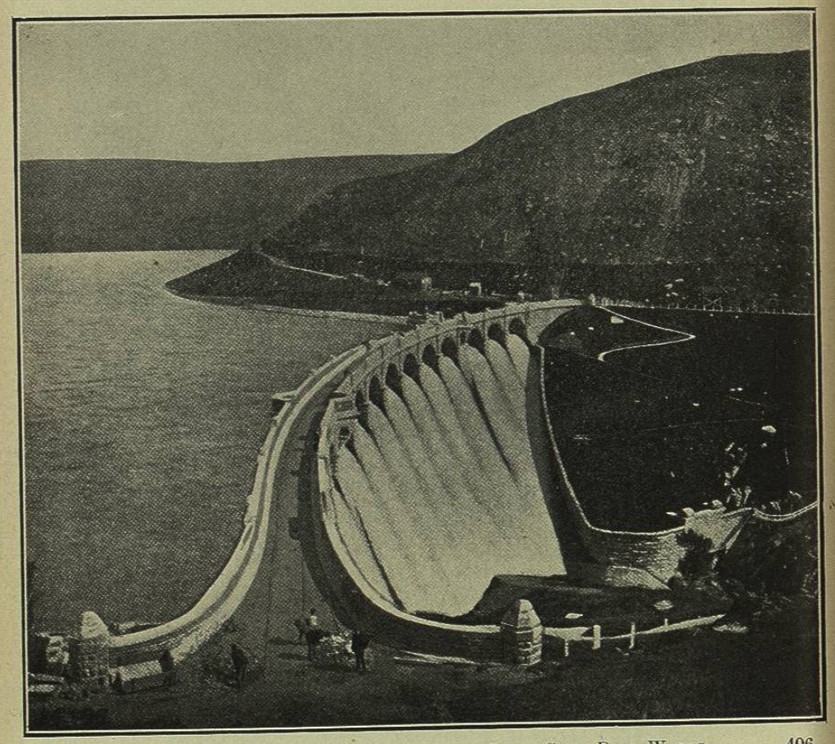

Fig. 275.—Showing Overpour on the Craig Goch Dam, Wales.

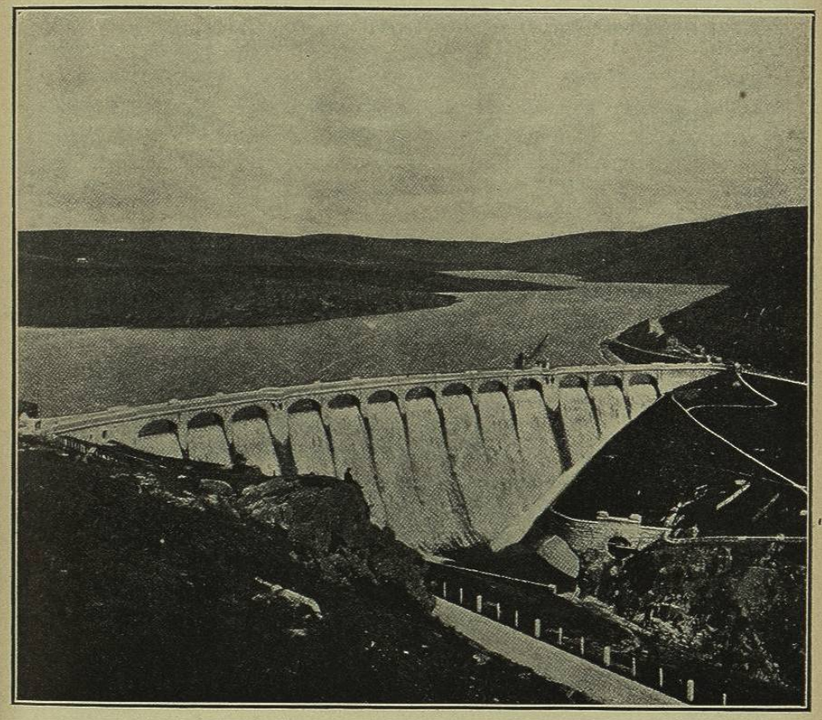

Fig. 276.—Craig Goch Dam and Reservoir, Radnorshire, Wales, for Birmingham Water-supply.

$29,000,000. All dams are built of cyclopean rubble laid in a matrix of high class Portland cement. The dams were designed and built under the direction of James Mansergh, F.R.S., M. Inst. C. E.

Derwent Valley Dams, England.—Five large masonry dams for the storage of water to supply the cities of Leicester, Derby, Sheffield, and Nottingham have been under construction since 1904, under one combined project controlled by an organization called the Derwent Valley Water Board. These dams are of the following general dimensions:

Name.	Length. Feet.	Maximum Height above Valley Level.
Howden dam	1080	118
Derwent dam	1070	115
Haglee dam	980	136
Ashop dam	840	103
Bamford dam	2500	95

In excavating for the Howden dam it has been necessary to sink to a depth of 67 feet below the river bed to reach bedrock, and a trench 20 feet deeper has to be cut into the rock to reach water-tight strata. In making the excavations a cableway for carrying away the spoil has been used.

The dam is to be 160 feet thick at the base, 9 feet at crest, and be built of cyclopean rubble masonry. It will have a long spillway over the crest.

It is estimated that the works will cost entire about $35,000,000, and serve about 2,000,000 people. The work will occupy twenty years in construction before the entire system is completed, although they will be in partial service at a much earlier date. The main aqueduct will be 55 miles long.

Dams in South America.

The Rio das Lages Dam, Brazil.—The Rio de Janeiro Tramway, Light and Power Co., in 1905-07, built a rubble masonry dam 135 feet in height, on the Rio das Lages, 50 miles from the city of Rio de Janeiro, to form a regulating reservoir for the development of power. The dam is of gravity type, with all lines of pressure well within the middle third, the main portion of which is curved on an arc of short radius, best fitting the bedrock, with tangential extensions into the banks at either end. Five hundred feet below the dam the river plunges over a vertical fall of 200 feet over a hard ledge of granite, in a gorge filled with rank tropical foliage, forming a scene of great beauty and grandeur.

The dam creates an enormous reservoir, 16 miles long, with many tortuous windings and arms, giving a total capacity of 7,780,000,000 cubic feet, or 178,000 acre-feet.

The writer examined and reported upon the site before the plans were definitely decided upon, at which time the quantity of masonry required was estimated at about 63,000 cubic yards.

From the dam to the power house a total fall of 1030 feet is utilized for the development of over 50,000 H. P. in the primary installation, transmitted to Rio de Janeiro at 80,000 volts.

The works have been designed and built by Mr. Chas. H. Kearney, chief engineer, under direction of F. S. Pearson, M. Am. Soc. C. E., as consulting engineer, and vice-president of the company.

Parnahyba Dam, Brazil.—In 1900 the Sao Paulo Tramway, Light and Power Co. built a masonry dam across the Tieté river, 22 miles below the city of Sao Paulo, near the village of Parnahyba, for the development of power. The dam is 850 feet long on the crest, straight in plan, 37 feet in height, with a base width of 30 feet. A rollway section for overflow is located in the central portion of the dam, 325 feet in length, the end sections being 5 feet higher. The dam rests throughout on solid granite, and is formed of rough rubble masonry, with cut-stone facings on the down-stream portion of the rollway and crest.

The water from the dam is conveyed to a small penstock reservoir, 200 feet from the power-house, through two $\frac{3}{8}$-inch steel feeder pipes, 12 feet diameter, 2223 feet long, resting on steel saddles, placed 10 feet apart, on masonry piers. The secondary dam is constructed of concrete, resting on rock, is about 45 feet high, 255 feet long, 24 feet thick at the base, with a batter of 35% on the down-stream side. The crest width is about 8 feet at a height of about 10 feet above the water line.

The constructing engineer was Mr. Hugh L. Cooper, with F. S. Pearson, Dr. Sc., M. Am. Soc. C. E., acting as consulting engineer.

Reservoirs in Peru.

The only storage reservoir dams of importance in Peru are situated on the headwaters of the Santa Eulalia river, the main tributary of the Rimac river, and are probably the highest in altitude of any dams in the world, as well as possessing many other unique conditons.

In the years 1874-75 the Peruvian Government undertook the work of developing a water supply for irrigation in the Rimac valley by the building of masonry dams and outlet cuts in a group of lakes known as the "Lagunas Huarochiri," situated at elevations of 14,000 to 16,000 feet above sea level in the Andes mountains at the head of the Rimac river. There are some 65 or 70 of these lakes, nine of which were converted into storage reservoirs, having an aggregate capacity of 37,212 acre-feet, although the maximum quantity ever stored since they were put in service has been

but 28,100 acre-feet. The lakes are about 80 miles away from the land irrigated; the loss by evaporation and seepage in transit by the natural stream channels in this distance is estimated at 50%, and the net results accomplished by the water of these reservoirs is stated to be the reclamation of only 1940 acres, at an average cost of $506.70 per acre! The works are nevertheless of an interesting and instructive character, and the writer is indebted to Mr. W. T. Turner, chief of the Hydrographic Commission, Department of Lima, for the accompanying photographs, illustrating their construction and the data concerning them, from which the following description has been compiled.

Lake Carpa Dam.—Lake Carpa is situated near the head of the Huasca river, a small tributary of the Santa Eulalia, having a limited drainage

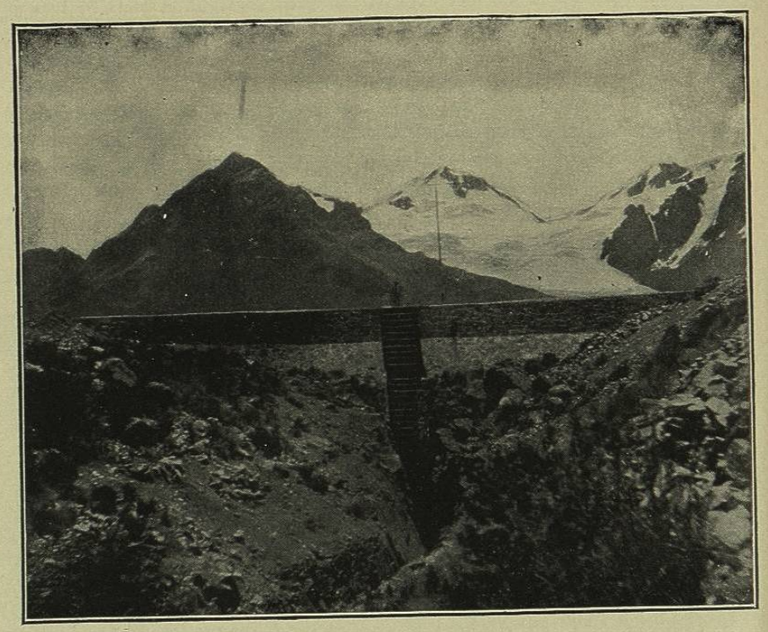

FIG. 277.—CARPA DAM, PERU, SHOWING TYPICAL OUTLET CUT, FILLED WITH STEEL BULKHEAD, GLACIER IN BACKGROUND.

area and principally fed by the melting of a glacier. A cut through gravel and solid rock, about two meters wide, was first made to a depth of 11.7 meters (38.4 feet) to drain the lake, and a masonry dam was built about the top of the cut to a total height of 4.30 meters (14.1 feet) making a total

depth of reservoir of 16 meters (53.5 feet). The dam is vertical on the up-stream face, has a crest width of 1.5 meters, and is vertical on the lower face for a depth of two meters below the top, thence slopes 0.5:1 to the bottom. The length of the dam on the crest is 58 meters (190 feet) and it is curved with a radius of 60 meters. It contains a total of 907 cubic meters (1190 cubic yards) of masonry, the contract cost of which was $65.00 per cubic meter. Excavation in rock, 2978 cubic meters at $20.00 per cubic meter, and in gravel 1857 cubic meters at $12.00 per cubic meter, brought up the total cost of the work, exclusive of gates, to $140,800. The storage capacity when filled is 16,921 acre-feet, but as the lake has never filled above the foot of the masonry in this dam, the maximum storage has been but 10,190 acre-feet.

Fig. 277 shows the dam from the down-stream side and the outlet cut from near the bottom to the top of the masonry, which is divided by the cut in two halves, the space being filled with a bulkhead composed of I-beams and steel plates. Water is released at the bottom of the cut through gates in the bulkhead that are raised by screw-stems reaching to the top.

Lake Quisha Dam.—About a mile above lake Carpa reservoir and 300 feet higher in elevation, is lake Quisha which has been converted into a storage reservoir by a dam quite similar in construction to the works at lake Carpa. The cut to drain the lake is 10.6 meters deep and the dam 6 meters high, a total of 16.6 meters (54.5 feet). The dam has the same section as the Carpa dam with a crest length of 48 meters and a volume of 887 cubic meters of masonry. It is also curved up-stream, with a radius of 66 meters. The water-shed tributary to the lake is but 3 square miles, and the annual run-off is so much less than the reservoir capacity that the water has never reached within 5 meters of the top of the dam. The capacity of the lake is 8035 acre-feet, while the maximum amount stored has been 5654 acre-feet. As this dam is on the same water-shed as the Carpa dam, and the total annual run-off of the tributaries of both is less than the capacity of Carpa lake reservoir, it is evident that the Quisha dam was not required, and its cost—over $125,000—was a useless expenditure. The elevation of the lake is 15,400 feet above sea level. Fig. 278 shows the entire dam and a portion of the lake. Incidentally it conveys an idea of the scenic grandeur with which the lake is surrounded.

The Sacsa Dam.—Sacsa lake is 1000 feet lower in elevation than Quisha lake, and is located near the head of the Sacsa river, but, unlike the two reservoirs just described, has a water supply greatly in excess of its capacity, which is but 4172 acre-feet. The outlet cut was made to a depth of 5 meters, and gates were erected with the evident purpose of building a dam 7.5 meters in height above the bottom of the cut. This dam, however, was never completed, although it would have added 50%