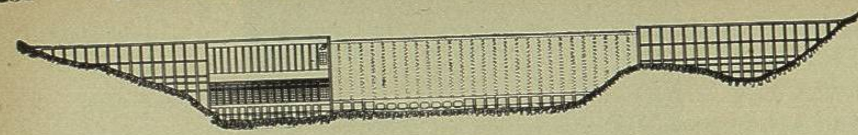


FIG. 327.

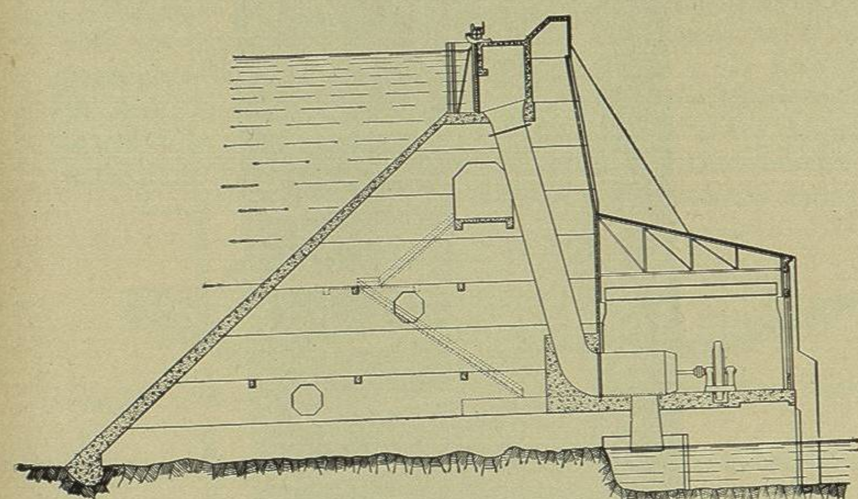


FIG. 328.—SECTION OF DAM 115 FEET HIGH, WITH POWER-HOUSE.

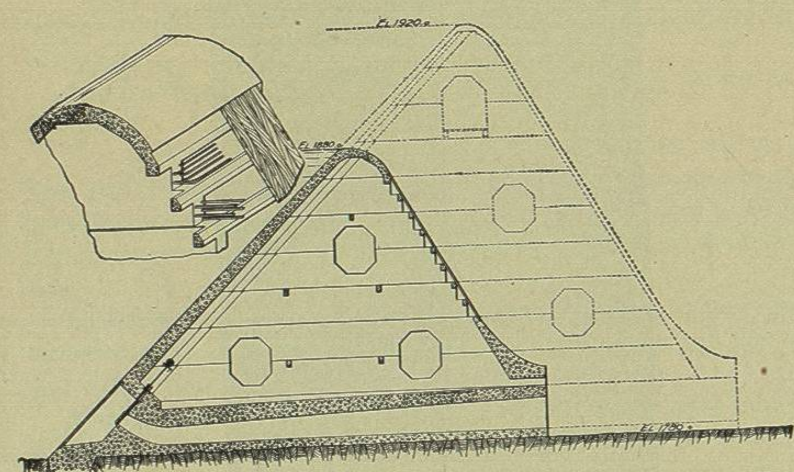


FIG. 329.—SECTION OF HIGH DAM, PLANNED FOR INCREASE OF HEIGHT IN FUTURE.

CHAPTER VII.

NATURAL RESERVOIRS.

ON the great plains east of the Rocky Mountains there are thousands of natural basins which have no outlets and which gather the storm-water run-off from a few hundred acres of surrounding territory, and hold it in shallow ponds until it is lost by evaporation. Many of these depressions have been utilized as storage-reservoirs by carrying water to them from adjacent streams, and by providing them with outlets, either by tunnels or cuts; and many more have been selected for future utilization. They are often at the proper elevation to command large areas of arable land, and can usually be converted into safe storage-reservoirs at small expense. Such natural basins appear to be invariably water-tight, and in every way suitable to the purpose, except in occasional instances where they contain deep beds of alkali.

In the mountains, too, many natural basins are to be found, which have been formed by land slides, but more frequently by glacial moraine deposit, often of great depth and width, forming natural dikes of enormous magnitude. These basins are usually occupied by lakes, which can be converted into storage-reservoirs, either by restoring a portion of the originally higher dike which has been worn down by the channel of the outlet of the lake, and thus increase the capacity of the lake basin, or by the deepening of this channel by artificial cut, or by both these methods. Frequently these lakes are of very great depth, held back by dams built by Nature's hydraulic-fill methods, and suggesting the limitless heights to which such dams can be built, provided they be made of adequate dimensions. The author has seen a natural dam on a branch of the Umpqua river in Oregon, over 300 feet high, formed by a landslide from the adjacent sandstone cliff. The base of this dam was not over 3000 to 4000 feet. Floods of several thousand second-feet pass over the top of it every year, and it is practically water-tight, as it holds back a good sized lake. This is a natural rock-fill dam, composed of enormous blocks of stone, whose voids are filled with smaller stone and rock dust ground up in the process of falling.

Lake Como, in the Bitter Root valley, Montana, is an instance of a very deep natural lake basin formed by a terminal moraine of fine and coarse gravel, sand and glacial flour. This lake is to be converted into a reservoir for irrigation storage by the building of a hydraulic-fill dam across the outlet channel.

Twin Lakes Reservoir, Colorado.—Almost identical in geographical formation and glacial origin to that of Lake Como, Montana, are the Twin Lakes on the fork of the Arkansas river which heads in Mt. Massive, near Leadville. This was one of the reservoir-sites segregated and surveyed by the United States Government in 1892, as shown by the map (Fig. 330).

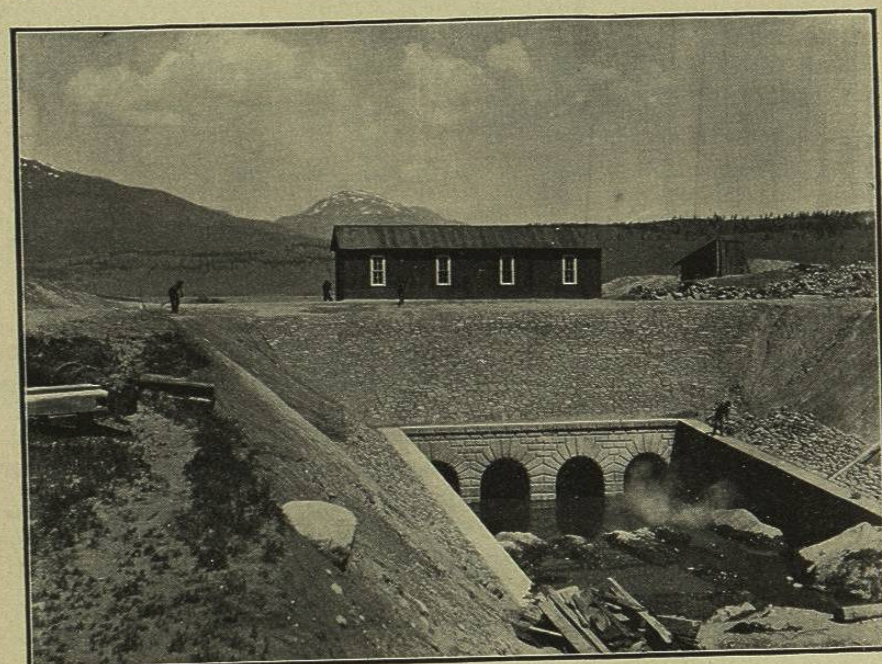
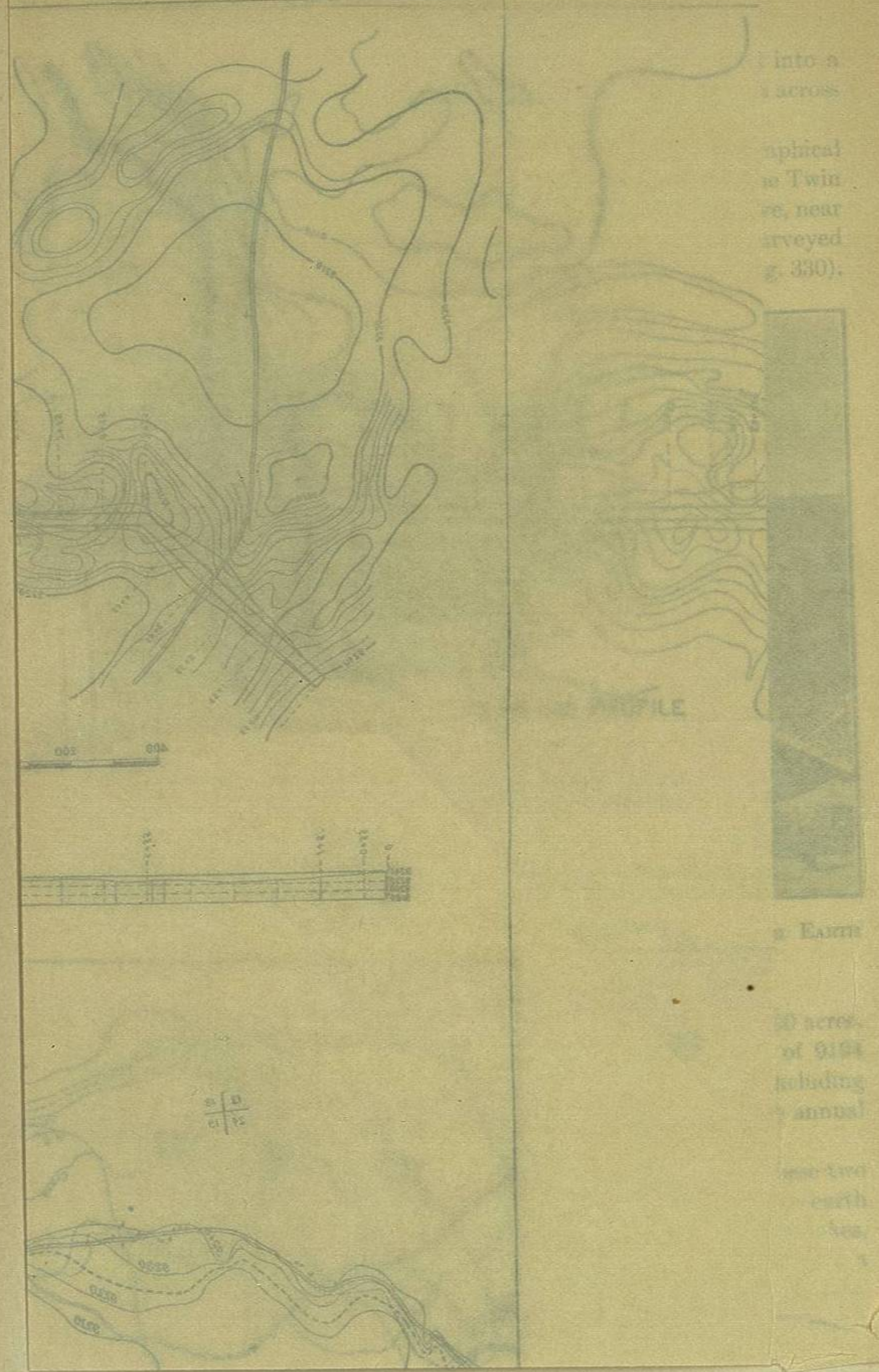


FIG. 331.—TWIN LAKES, COLORADO, MASONRY DAM OVER OUTLET, WITH EARTH BACKING, GATE-HOUSE, AND OUTLET CULVERTS.

These lakes cover an area, at normal stage of water, of about 1900 acres, and have a depth of more than 80 feet. They are at an altitude of 9194 feet, and receive the drainage from 387 square miles of watershed, including within this area some of the highest mountains of Colorado. The annual run-off from this area is from 40,000 to 100,000 acre-feet.

The plan proposed by the government engineers for utilizing these two lakes and converting them into one large reservoir was to erect an earth dam, with a maximum height of 73 feet, across the valley below the lakes, and thus increase their surface area to 3475 acres. This would give a reservoir capacity above the normal lake surface of 103,500 acre-feet. To fill the reservoir it was designed to supplement the run-off of the streams

Fig. 350
[To face page 484.



directly tributary by diverting water from the main Arkansas river, by a canal leaving the river a short distance below Leadville.

Some years after this survey was made a private corporation, called the Twin Lakes Reservoir Company, was organized by Buffalo capitalists to carry out the work on a modified plan. This company acquired sufficient land around the margins of the lakes to control them, and began work in the summer of 1898. The plan adopted by them contemplated works that would enable them to draw off the lakes to 16 feet below their normal level, and in addition build a low dam that would store 9 feet in depth above that level,—thus commanding a total depth of 25 feet and a total volume of 48,000 acre-feet. Of this volume, two-thirds, or 32,000 acre-feet, is below the normal lake-level. In pursuance of this plan they excavated a canal at one side of the outlet-stream, 2000 feet long, from the edge of the lower lake to the point of its intersection with Lake Creek. This canal is 40 feet wide on bottom, and has a maximum depth of 37 feet. The excavation was in sand, bowlders, and silt, or "glacial flour," and was chiefly made with a steam-shovel. At the point where the excavation was deepest, some 200 feet from the lake margin, they prepared to erect head-gates of iron, on a heavy base of concrete, with abutment-walls of cut stone laid in cement mortar. The structure was to have been 32 feet in height. The gates were twelve in number, each 2 feet $8\frac{1}{2}$ inches wide, 5 feet high, made of $\frac{1}{2}$-inch boiler-plate, and carrying iron flashboards, loosely resting one above another, on top of the gate, and reaching up to above high-water mark. The gates were to slide vertically between 12-inch I beams. These beams were to be embedded in the concrete floor. The foundations for this floor were made by driving piles, upon which the abutment-walls and center pier rest. (Fig. 332.)

The concrete base of the gate structure was planned and built 72 feet long, with a width of 69 feet to the outer lines of the abutment-walls. It was made 5 feet in thickness, with double grillage of T rails, encased in the concrete. Three lines of apron or curtain walls extended down 5 feet below the bottom of the concrete, across the line of the canal.

In the spring of 1899 this structure was partially completed, the floor was finished, and one of the abutment-walls was built 12 feet high, when work was stopped by threats of injunction made by officials of the Denver and Rio Grande and the Colorado Midland railways, whose tracks through the canyon of the river below would have been endangered by any failure of the proposed reservoir. At this juncture Mr. O. O. McReynolds was appointed Chief Engineer, and the writer was employed as Consulting Engineer to prepare plans to make the work secure and allay apprehensions of its safety. The modifications which were made in the plan are shown in Fig. 332, and the work has since been completed in compliance

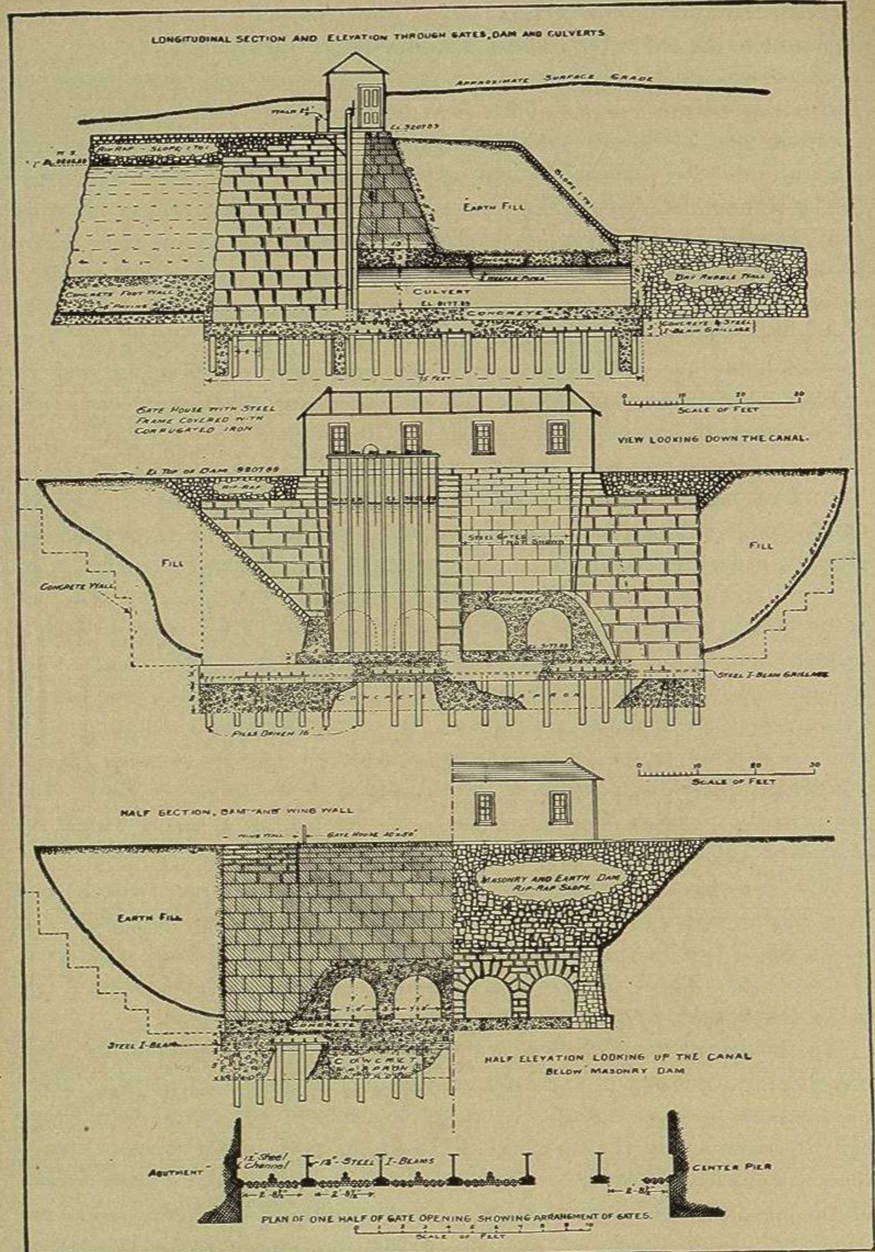


FIG. 332.—DETAILS OF OUTLETS FOR TWIN LAKES, COLO. DESIGNED FOR THE TWIN LAKES RESERVOIR CO. BY J. D. SCHUYLER, CONS. ENGR., AND BUILT BY O. O. McREYNOLDS, CHIEF ENGINEER.

with the new design. The changes were made in such manner as to adapt them to the part already completed and to utilize materials already on the ground. These were the following: A series of four culverts were built on top of the completed floor, extending from the line of gates to the lower edge of the concrete platform, a distance of 47 feet. These culverts are each 7 feet 11 inches wide and 7 feet high, with a semicircular arch over them. They are built of concrete, the thickness of the arch being 2 feet. On top of these culverts a masonry dam is built across the canal, reaching to a height of 30 feet above the floor of the structure. This wall is of sandstone ashlar, laid in large blocks with Portland-cement mortar. Its base width is 15 feet, top 4 feet; down-stream batter 5 : 12. Extending well into the banks on each side, in line with the dam, is a concrete wall, 2 feet thick, designed to cut off seepage through the earth filling on the sides that would tend to pass around the dam. Against the masonry dam on the lower side is an embankment of earth over the top of the culverts, forming a driveway over the canal, 22 feet wide on top. The outer slope terminates against a low wall forming a façade for the culvert-portals. The slope is paved with stone. For 50 feet above and 75 feet below the concrete platform the canal is paved with concrete on the bottom, and the sides protected from erosion by substantial walls of concrete above the dry rubble below the headworks. The gates built for the original design were used, but the hoisting-device was improved, and a substantial gate-house built over the gates.

Spillway.—A space is left between the gates and the masonry which will admit of a maximum discharge of 600 second-feet over the top of the flashboards, without raising the gates. Whenever any water thus passes over the top of the flashboards it can escape freely through the culverts and down the canal. This provision for sudden floods in the possible absence of attendants to open the gates is considered an ample spillway allowance. The culverts have a combined capacity of over 2000 second-feet.

Fishway.—To provide for a free passage of migratory fish over the dam, in compliance with the State law, it is proposed to erect a fish-ladder of approved design, supplying it with water piped from a neighboring stream. The lakes abound in trout.

The entire cost of the improvements, including the purchase of valuable villa sites on the lake margins, will be about $200,000. The works were finished during the current year (1900).

"*Glacial Flour.*"—An interesting feature of these improvements is the peculiar character of the material through which the canal has been excavated and upon which the head-works have been built. The lakes are located between two great lateral moraines, hundreds of feet in height, while the barrier across the valley, forming the natural dam inclosing the lower lake, is a terminal moraine deposit, consisting largely of rock dust, or almost pure silica ground to an impalpable powder, known to geologists as "glacial flour." This material is so fine in texture as to resist percolation through any considerable mass of it, and hence it becomes practically impervious as an embankment of ordinary dimensions. It is neither quicksand nor clay, and has none of the characteristics of these elements.

The natural channel through which the lakes overflowed into the Arkansas river was closed by an embankment of this glacial flour, well riprapped with stone on both sides.

Larimer and Weld Reservoir.—One of the natural basins, located 1½ miles north of Fort Collins, Colorado, has been made to hold an important auxiliary supply to the Larimer and Weld canal, feeding into the latter 2 miles below the head of the canal. When filled to the rim it holds a maximum depth of 25 feet, and has a storage capacity of 7700 acre-feet at that level. This capacity was increased in 1895 to 11,550 acre-feet by constructing a low levee or bank about 2000 feet long at the lowest part of the rim of the basin. This added 5 feet to the depth of water in the lake.

The cost of the improvements was $21,796, but land and water rights, attorneys and court fees, and miscellaneous expenses swelled the entire cost to $64,782. On the same canal system are two other natural basins, utilized as reservoirs, the larger of which, called the Windsor reservoir, is 25 miles below the head of the canal. It carries a maximum depth of 28 feet of water, and cost $52,000, of which $25,000 was for the land and attorneys' fees. To increase the depth to 40 feet, an embankment is to be built which is estimated to cost $23,000 additional. The reservoir will then have a capacity of 23,000 acre-feet.

The Larimer County Canal utilizes six of these basins on the plains, as storage-reservoirs, which have a combined capacity of 10,560 acre-feet.

All of these basins above described derive their water-supply from the Cache la Poudre River.

Marston Lake.—Another one of these natural basins, situated at an elevation to command the city of Denver, has been utilized by the Denver Union Water Company as a storage-reservoir of 5,000,000,000 gallons capacity. It is fed by a canal from Bear Creek, and is provided with two outlet-tunnels which connect with the main conduits leading to the city of Denver, 10 miles distant.

Loveland Reservoir-site.—One of the largest of the natural-basin reservoirs that has been projected for use in Colorado is located 3 miles northeast of Loveland, Colorado, at Boyd Lakes. These are two basins adjacent, each containing small lakes, on the high ground between the Cache la Poudre and Big Thompson rivers. The basin will require no dam, and when filled will have a maximum depth of 44 feet, and a surface area of 1920 acres, the capacity of which will be 45,740 acre-feet.

The method proposed for its conversion into a reservoir is to make an open cut, 10 feet wide at the bottom, on a grade of 1.5 feet per mile. At the deepest point in the cut a masonry wall is proposed to be built across the cut, with six 3-foot, cast-iron pipes passing through the wall. The reservoir would be fed by two canals from the rivers on each side of it. The entire cost of the improvement is estimated by Capt. H. M. Chittenden * at $262,106.34, or $5.73 per acre-foot of storage capacity.

The Laramie Natural Reservoir-site, Wyoming.—Capt. Chittenden's able report † on reservoir-sites in Wyoming and Colorado describes a natural basin that could be made available for storing the surplus water of the Laramie and Little Laramie rivers, which is one of colossal magnitude. Its maximum depth is 170 feet, covering an area of 13,651 acres, and having a capacity of 937,038 acre-feet. This is greatly in excess of the supply available from the two streams mentioned, which is estimated at 70,000 acre-feet annually, although this could be increased by gathering the supply from more distant sources.

When filled to the 100-foot level, the annual loss by evaporation would be 24,000 acre-feet, leaving a supply of 46,000 acre-feet for irrigation. The estimated cost of the canals, reservoir-outlets, rights of way, etc., for utilizing the basin on the basis of storing only the waters of the two Laramie rivers, was $416,254, or $9.05 per acre-foot of average supply.

Lake De Smet Reservoir-site, Wyoming.—Among the reservoir-sites examined and reported upon by Capt. Chittenden, in the report quoted above, was a natural depression without outlet, called Lake De Smet. This basin is 3 miles long, 1 mile wide, and covers an area of 1965 acres. The improvement of this basin which he recommended was to construct a feeder-canal, 3¼ miles long, with a capacity of 727 second-feet, and construct two outlets, one at each end of the basin, discharging into Box Elder Creek on one side and into Piney Creek on the other, each to have a capacity of 425 second-feet. This would convert the basin into a reservoir by the addition of 30 feet in depth, bringing the level of the lake up to the rim of the basin, increasing its surface area to 2400 acres, and affording an available storage of 67,627 acre-feet of water. The entire cost of the improvement was estimated at $113,360, or $1.67 per acre-foot of storage capacity.

* Report of Capt. Hiram M. Chittenden, Corps of Engineers, U. S. A., upon examination of Reservoir-sites in Wyoming and Colorado, under the provisions of Act of Congress of June 3, 1896. House Document No. 141, 55th Congress, 2d Session.

† *Ibid.*