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.*

Such natural basins as those described in the foregoing pages, which can be filled by controllable canals, present advantages as storage-reservoirs which are certainly ideal. The great thickness of the natural ridges which surround them renders them absolutely safe against bursting, provided their outlets are properly designed and well constructed; they are generally quite free from loss by percolation, and the volume of silt deposited in them is in direct ratio to their capacity, as no more silt-laden water need be put into them than is drawn out of them for use, in addition to evaporation, whereas a reservoir located in the channel of a river may often have to receive the silt from a volume of water many times the reservoir capacity. The only disadvantage they possess is that the surface area exposed may be greater per unit of volume stored than in deep reservoirs formed by high dams, and consequently the ratio of loss by evaporation may be somewhat greater.

This disadvantage is, however, amply offset by the many superior features they possess when compared with the average stream-bed reservoir.

**Natural Reservoirs of the Arkansas Valley, Colo.**—The most extensive enterprise for the storage of flood waters for irrigation in natural-basin reservoirs yet undertaken in the West was recently completed by The Great Plains Water Company in the Arkansas Valley in Eastern Colorado, and the reservoirs were partially filled and used for the first time during the irrigation season of 1900. The reservoirs are five in number, lying in a group closely adjacent to each other, and have the following capacities:

| * Name of Reservoir. | Area. Acres. | Total Capacity. Acre-feet. | Volume below Outlet Level and Unavailable. Acre-feet. | Volume Available for Use. Acre-feet. |
|---|---|---|---|---|
| Nee Sopah | 3,600 | 34,372 | 10.908 | 23.464 |
| Nee Gronda | 3,490 | 97,069 | 39,860 | 57,209 |
| Nee Noshe | 3.770 | 82,121 | 21,485 | 60,636 |
| Nee Skah | 1,930 | 32,985 | 9,939 | 23,046 |
| King | 1,331 | 18,279 | .......... | 18,279 |
| Totals | 14,121 | 264.826 | 82,192 | 182,635 |

* The names of the reservoirs are from the Osage Indian language, and have the following interpretations: Nee Sopah, Black-water; Nee Gronda, Big-water; Nee Noshe, Standing-water; Nee Skah, White-water.

The reservoirs are located 12 to 18 miles north of the town of Lamar, and are fed by a canal from the Arkansas river, which heads near La Junta, Colo., and has a maximum capacity of 2096 second-feet. The company, whose name has been changed to that of The Arkansas Valley Sugar Beet and Irrigated Land Company, has built various other canals, as shown by the following table:



| Name of Canal. | Length in Miles. | Capacity in Sec-ft. |
|---|---|---|
| Fort Lyon | 113.00 | 2096 |
| Kicking Bird | 36.50 | 1000 |
| Satanta | 12.50 | 300 |
| Comanche | 16.78 | 400 |
| Pawnee | 6.34 | 200 |
| Amity | 110.00 | 870 |
| Buffalo | 16.10 | 192 |

The company has invested about $2,250,000 in its irrigation works and lands, the area of its holdings being about 100,000 acres. The manager of the company is Mr. W. H. Wiley, of New York, now residing at Holly, Colo.

The three reservoirs described in the foregoing table are so connected that they can be drawn upon by one outlet. This has been formed by a deep cut through the rim of the basin, in which the gates are placed in substantial headworks of cut-stone masonry. The outlet to Nee Skah is of a similar plan. The King reservoir as yet has no outlet provided for it.

**Oregon Basin Reservoir, Wyoming.**—One of the most capacious natural basin reservoirs in the West is that created by the Big Horn Basin Development Company near the town of Wiley, Wyo., for the irrigation of lands lying between the Shoshone and Grey Bull rivers. The reservoir is to be fed by a canal taking water from the south fork of the Shoshone river, about 15 miles above the Shoshone dam.

The reservoir has an area of 5106 acres, at an elevation of 5213 feet above the level of the sea. It is nearly circular, is 4 miles long, nearly 12 miles in circumference, and 100 feet in depth. Its capacity is 400,000 acre-feet.

The outlet is through a tunnel 4000 feet long between approaches, the water being controlled by gates at the bottom of a shaft 60 feet deep, located 250 feet below the head of the tunnel. A dike is required at the outlet gap over the tunnel 150 feet long, with 15 feet maximum depth of water against it. Mr. G. W. Zorn is chief engineer of the company, to whom the author is indebted for the information.

**The Douglas Lake Reservoir, Colorado.**—An earth dam across a natural depression on Dry Creek, five miles northwest of Fort Collins, Col., was built in 1902, an illustration of which is shown in Fig. 333.

The great cracks in the dam are the conspicuous feature of the picture, and are evidence of the lack of proper care and supervision in important works of this character. The dam contains about 150,000 cubic yards of earth, and forms a reservoir of 10,600 acre-feet capacity, sufficient to create great havoc in the country below it if it were suddenly released. The reservoir is filled by a ditch from the North Poudre river.

**The Fossil Creek Reservoir, Colorado.**—A part of the same system of reservoirs for irrigation storage is one built the same year, requiring an earth dam, 60 feet high, half a mile long, and containing 300,000 cubic yards. It forms a reservoir covering 750 acres, with a capacity of 12,600 acre-feet. Its estimated cost was $170,000. The feeder ditch from Cache la Poudre river is 4.5 miles long, with a capacity of 400 second-feet.

FIG. 333.—DOUGLAS LAKE DAM; COLORADO, SHOWING DANGEROUS SETTLEMENT CRACKS, DUE TO IMPROPER METHOD OF CONSTRUCTION.

**Natural Gravel-bed Storage-reservoirs.**—It may be said that all the soil of the earth is a storage-reservoir, which receives a large proportion of the precipitation from the clouds and gives it off slowly to feed the natural springs by which the normal flow of the streams is maintained. These natural reservoirs are increased in capacity and useful function by a maintenance of the forests, which shade the ground, lessen the force of the winds, increase the humidity of the air, diminish evaporation, and knit the soil together with a network of roots and so enable it to resist erosion.

In many parts of the country the storm-waters from the mountains flow over great beds of coarse gravel, extending from the foot-hills out into the valleys, for many miles. These gravel beds constitute natural storage-reservoirs of enormous capacity, and if, at some lower point, a contraction occurs in the stream-channel, or some natural barrier intercepts the flow, the water is again forced to appear on the surface and feeds the stream by



a constant outpouring from the gravel reservoir, long after the feeders of the reservoir have gone dry.

In southern California there are a number of such natural reservoirs, one of the most notable of which is in the San Fernando Valley, north of Los Angeles, and supplies, by its natural overflow, the Los Angeles River. The San Fernando Valley has an area of 182 square miles, about one-fourth of which is a deep bed of coarse gravel, constituting a natural storage-reservoir. The valley is surrounded by mountains, of which about 300 square miles in the area drains into the valley. At its outlet the valley narrows down to a width of about 2 miles, and at this first contraction the Los Angeles River begins to appear, growing by rapid accretions in the space of a mile or more, at the rate of 10 to 25 miner's inches per 100 feet of channel. All the streams flowing into the valley are intermittent, and for months at a time have practically no surface-flow. The overflow of the gravel reservoir, however, is practically constant through all seasons, wet and dry, maintaining a discharge of from 70 to 90 second-feet. Even after three seasons of drouth the river at the present writing shows a diminution of but about 15% from the normal.

**The Upper San Gabriel Valley,** some 15 miles east of Los Angeles, constitutes another natural reservoir, of somewhat greater discharge than that of the Los Angeles River. The passage of the stream through the coast range of hills is but one mile in width, and contracts the basin sufficiently to cause the reservoir to overflow at the surface, producing a never-failing water-supply for irrigation in the valley below. Near the outlet of the upper valley a number of artesian wells have been bored which pierce strata of impervious clay and add considerably to the natural output of the reservoir.

**The San Bernardino Valley** is another interesting example of nature's storage-reservoirs, whose overflow at the narrows below yields a large and unfailing supply to the adjacent irrigated districts. This valley also produces a large artesian flow to augment the supply which naturally seeks outlet to the surface, as the overflow of the gravel reservoir.

Only second in importance to these natural reservoirs which retain water and let it out to the surface at a uniform rate, where it may be diverted by gravity to the lands, are the great artesian basins fed by underground streams, which require to be tapped by the boring of wells, and the more numerous and widespread subterranean basins from which water in wells may be pumped in practically immeasurable quantities.

**Lost Canyon Natural Dam, Colorado.**—The region of Lost Park and Lost Canyon, on Goose Creek, Colorado, a tributary of South Platte River, is one of rugged grandeur, characterized by scenery of the wildest imaginable description, abounding in high cliffs and rock-masses of fantastic shapes and colors and of Titanic dimensions. Nature has here made an effort at rock-fill dam-construction on a grand scale by filling in the canyon to a maximum depth of 250 feet with an aggregation of enormous bowlders thrown from the neighboring cliffs. This remarkable rock-fill is

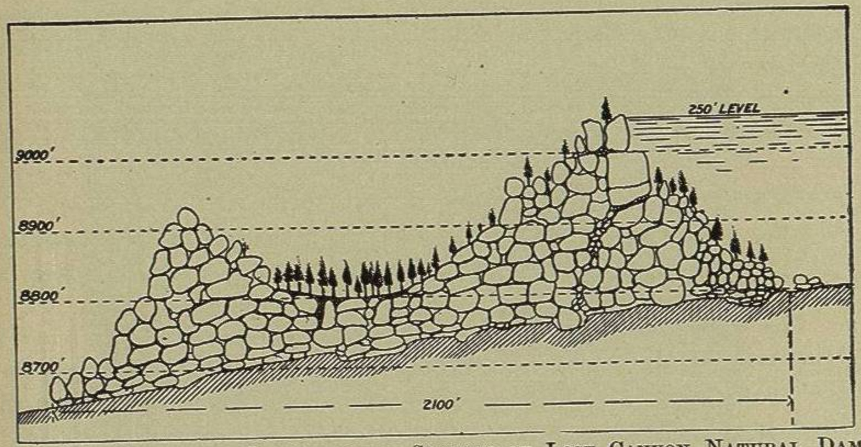

FIG. 334.—SKETCH OF LONGITUDINAL SECTION OF LOST CANYON NATURAL DAM

2100 feet in length, and is fairly well represented in a general way by the longitudinal and cross sections shown in Figs. 334 and 335. The maximum height above the upper toe is, as stated, 250 feet; but as the bed of the canyon falls 150 feet in the length of the dam, the height of the crest is 400 feet above the lower toe, where the stream emerges from underneath the bowlders. The extreme width on top is 400 feet, although the bulk of the fill is less than 100 feet in width, and at the bottom the canyon width between well-polished walls is but 20 to 25 feet, at such places as it is possible to go underneath and inspect it.

Some of the bowlders that form the embankment are as large as an ordinary two-story dwelling-house, and the stream finds its way through them with little apparent obstruction, although the presence of a pile of driftwood at the mouth of a cave on the upper face, 150 feet above the bottom, is an indication that occasionally the volume is too great to find exit in the lower passages and is forced to rise to this higher outlet. It is possible to descend in this cave, by means of ladders and ropes, into the interior of the dam almost to the water-level. The crest of the solid mass of the dam proper is at the 200-foot level, although a chain of huge bowlders, 25 to 50 feet high, lying near together, extends across the canyon



from side to side. The entire surface of the natural embankment is dotted over with large fir-trees, growing in the soil that has lodged in the crevices. As the stream emerges from the foot of the dam it has the appearance of a spring flowing out from beneath an old glacial moraine.

Surveys of the site have developed the fact that a reservoir with a capacity of 24,000 acre-feet can be made available for storage and use by making nature's dam water-tight. This may readily be done by filling

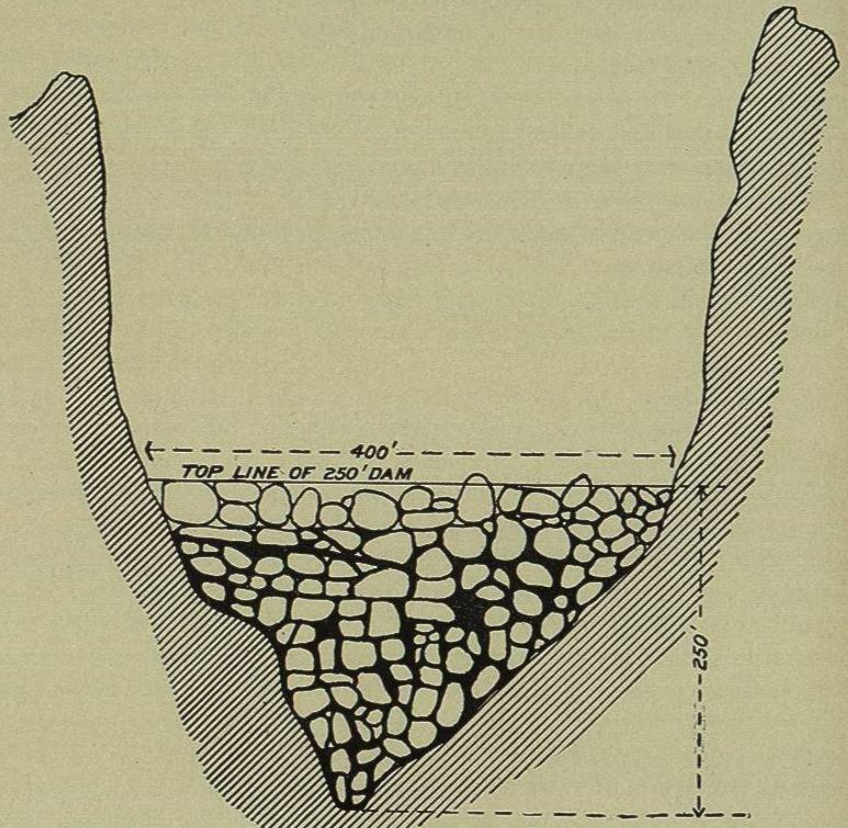

FIG. 335.—SKETCH OF CROSS-SECTION AT UPPER END OF LOST CANYON NATURAL DAM.

the crevices and cavities on the upper face with concrete and providing a proper outlet for the water by means of a tunnel.

The latter has been projected on the 75-foot level, and will require to be 1200 feet long to reach a neighboring canyon. The cost of this work has been estimated at $104,000, or $4.35 per acre-foot of storage capacity in the reservoir. An addition of 20 feet to the top of the dam would increase this capacity to 27,700 acre-feet, and the cost to $144,000, the work to be done in Portland-cement masonry. The reservoir has been in contemplation for some years as a storage for irrigation and domestic supply in and around Denver, from which city it is some sixty miles distant.

## ACKNOWLEDGMENTS.

Throughout the text of this work the author has endeavored to make due acknowledgment for information furnished and courtesies extended, in connection with each of the subjects treated. If any omissions have been made, their subsequent discovery will cause him sincere regret and mortification. To cover any such omissions in the first edition he begs to make a broad and general expression of gratitude for all aid extended in making the work more complete.

Special acknowledgments are due the Director of the U. S. Geological Survey, for the use of many of the cuts and illustrations which embellish the foregoing pages, and are indispensable to the proper understanding of the text.

# CHAPTER VIII.

## MISCELLANEOUS.

After completing the proof-reading of the revised edition presented in the foregoing chapters, a number of photographs were received which had been intended to be incorporated in the body of the work had they been available. As these illustrations, mostly of new or little known types, are particularly valuable and instructive, adding much to the illumination of the subject, they have been assembled in a concluding chapter of miscellany.

The author takes pleasure in acknowledging his indebtedness for these photographs and notes descriptive of them, as follows:

To Mr. Samuel Storrow, M. Am. Soc. C. E., for thirteen recent photographs of the Bowman Lake, the English, the Weaver Lake, and the Eureka Lake rock-fill dams in the mining regions of Northern California, referred to in the text; also a view of the Faucherie timber frame, triangular dam—a very old structure still in service—and a late picture of the Lake Frances hydraulic-fill dam, as it appears after completion. Many of these dams are remotely situated in the Sierra Nevada mountains and not readily visited or photographed. The views supplied by Mr. Storrow have been taken in the course of his professional work, and his notes upon the construction of these curious old dams of the mining-day type of temporary structure, have been kindly placed at the author's disposal. The obligation is still further increased by the fourteen pictures of four Mexican masonry dams, most of which are quite new to the world at large, but one of them having been illustrated in the first edition. These fourteen pictures were taken by Mr. Storrow on a tour of Mexico with a party of mining engineers in November, 1901.

The author is under obligations to Messrs. Wiley & Lewis, contractors, for the interesting pictures of the hydraulic-sluicing operations which are transforming the topography of the city of Seattle, Washington, by deep excavations and high embankments.