employ two "drivers" to patrol the portion of the flume where the grade was lightest, to keep all such stones in continuous motion. On the heavier grade, however, no such attention was necessary.

In the summer of 1894 the railway company made a similar fill of 66,000 cubic yards, at the crossing of a stream called Chapman Creek, the average cost of which was 7.5 cents per cubic yard, of which 3.2 cents was for plant. The actual work of sluicing was but 1.78 cents per cubic yard. In this case also, it was necessary to use explosives to loosen the gravel and prepare it for washing.

In 1897–98 the same company made a similar fill at the crossing of Mountain Creek, in the Selkirk Mountains, requiring 400,000 cubic yards. (See Fig. 141.) The total length was 10,086 feet over all, with extreme depth of 154 feet. The fill was carried up on a slope of 1½ to 1. Between Aug. 10 and Nov. 1, 1897, over 65,000 cubic yards were sluiced in place, at the following cost:

Mattresses	$1370.79
Sluicing labor	1195.96
Maintenance and repairs	678.90
Superintendence and tools	385.05
Total	$3630.70

This gives the average cost of the first 65,000 cubic yards at 5.59 cents per yard. Including a proportion of the plant, the average was less than 8 cents per cubic yard of embankment. The work was done in about 60 working days of 10 hours each, and the average was nearly 1100 cubic yards per day. The water was delivered to the nozzle of the monitor under a head of 160 feet, the diameter of nozzle being 5.5 inches. The volume was therefore 15.75 second-feet, or 787 miner's inches. The ratio of water to gravel was as 19 to 1 and the duty of the water was nearly 4.2 cubic yards per 24-hour inch under 6-inch pressure. The sluice-boxes had a grade of 8%. The water-supply was brought in a flume, 4 feet wide, 2 feet high, 2 miles long, built on a grade of 20 feet per mile. The entire plant, including roads, camp, stables, flume, pipe-line 1200 feet long, sluice-boxes 600 feet in length, etc., cost $10,038.40. Considerable expense was caused by snow and land-slides, which damaged the plant.

The trestles were filled beginning at the banks of the stream and working back each way. On the made bank thus formed masonry piers were constructed, and a steel bridge of five spans was built over the main stream between them.

The work has been planned and executed under direction of H. J. Cambie, Chief Engineer Pacific Division, Canadian Pacific Railway, and his Chief Assistant Engineer, Edmund Duchesnay, of Vancouver, B. C., by whose courtesy the data concerning the work have been supplied.

The class of work done on the Canadian Pacific Railway described in the foregoing pages is identical with that which is required in dam-construction with similar materials, and the processes employed will be recognized by engineers as distinctly applicable in a treatise on the subject of hydraulic dam-building, the only difference being that in railway fills no attention is paid to such a distribution of materials as will secure the water-tightness of the bank and free drainage of percolating waters on its exterior surface.

Hydraulic Fills on the Northern Pacific Railway.—The cheap and effective transportation of earth, gravel, rock, and sand and their deposit in embankment by water at a cost far below all other feasible methods, is the main principle involved, and this principle has been given further demonstration on a large scale on the Northern Pacific Railway, in the State of Washington, during the years 1895–96–97. No less than fifteen high and dangerous trestles on the Cascade Mountain division have been replaced by hydraulic-made embankments of earth, gravel, and loose rock, washed from the adjacent mountainsides. The total amount of material thus moved aggregates 606,750 cubic yards, the average cost of which was 6.39 cents per cubic yard; or 5.82 cents for labor and 0.57 cents for materials. The lowest cost of any of the fills was 3.38 cents per cubic yard, everything included.

The average cost of 377,000 cubic yards was 4.79 cents per yard, of which the detailed cost per cubic yard was as follows, figures which may be of special interest to those contemplating similar undertakings:

Sluicing and building side levees	3.89	cents per yard.
Hay used in side levees	0.09	" " "
Tools	0.08	" " "
Lumber and nails	0.22	" " "
Labor building flumes	0.44	" " "
Engineering and superintendence	0.11	" " "
Total	4.79	" " "

This work was done in the midst of a dense forest, where the ground to be sluiced had to be cleared, and stumps and roots necessarily interfered with the loosening of the material. All of the 377,000 yards were carried and deposited by water brought to the pits by gravity. In one case, however, that of bridge 191, the water was supplied by pumping and 42,250 cubic yards were moved by water thus lifted at an average cost of 13.5 cents per cubic yard, the dêtail of which was as follows:

Sluicing and building levees	10.81	cents per yard.
Hay used in side levees	0.21	" " "
Tools	0.14	" " "
Lumber and nails	0.12	" " "
Labor building flumes	0.14	" " "
Coal used in pumping	1.87	" " "
Engineering and superintendence	0.20	" " "
Total	13.50	" " "

Fig. 140.—Hydraulic Sluicing, Canadian Pacific Railway. View of Pit, and Hydraulic Giant at Work

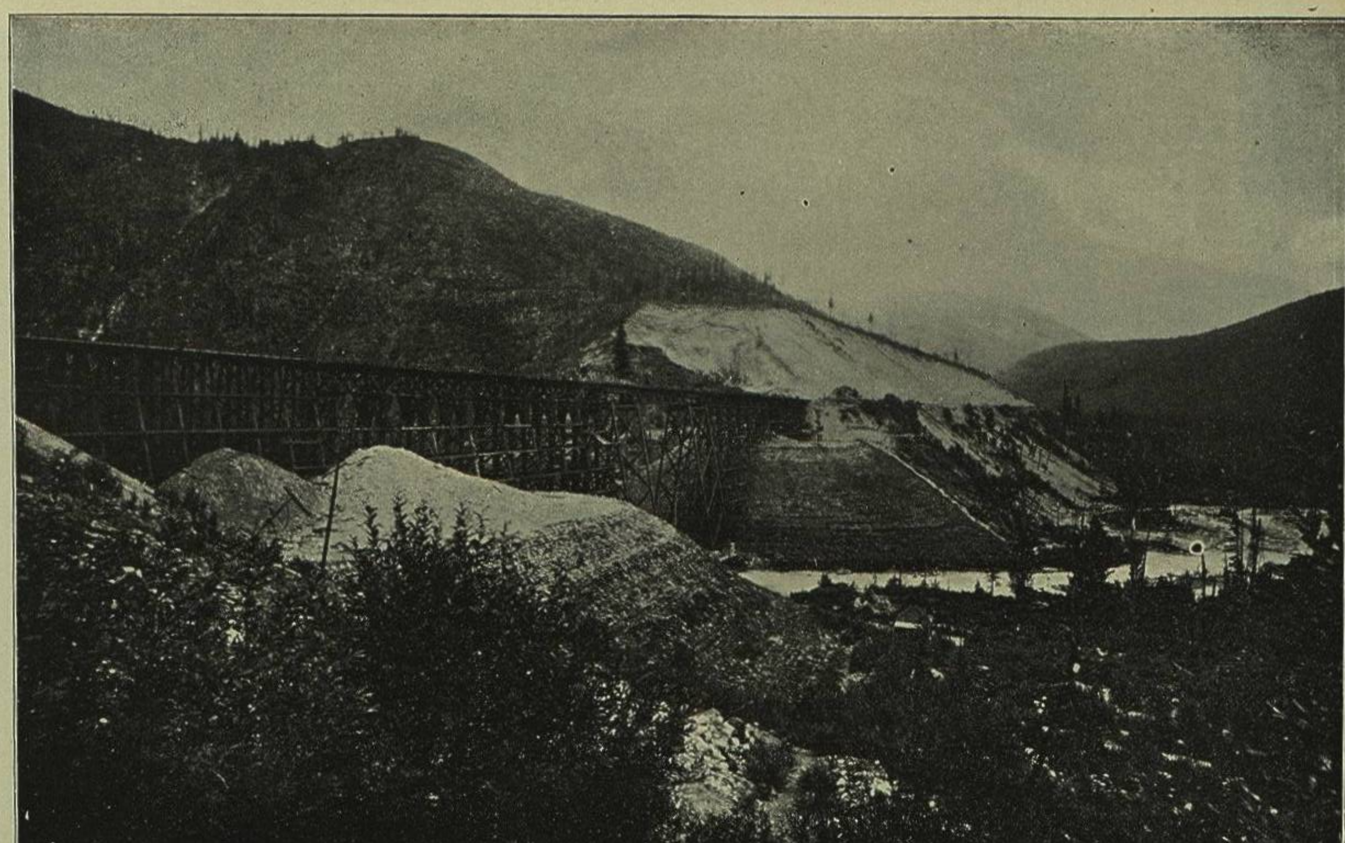

Fig. 141.—Hydraulic Fills, partially completed, at Mountain Creek, B. C., Canadian Pacific Railway.

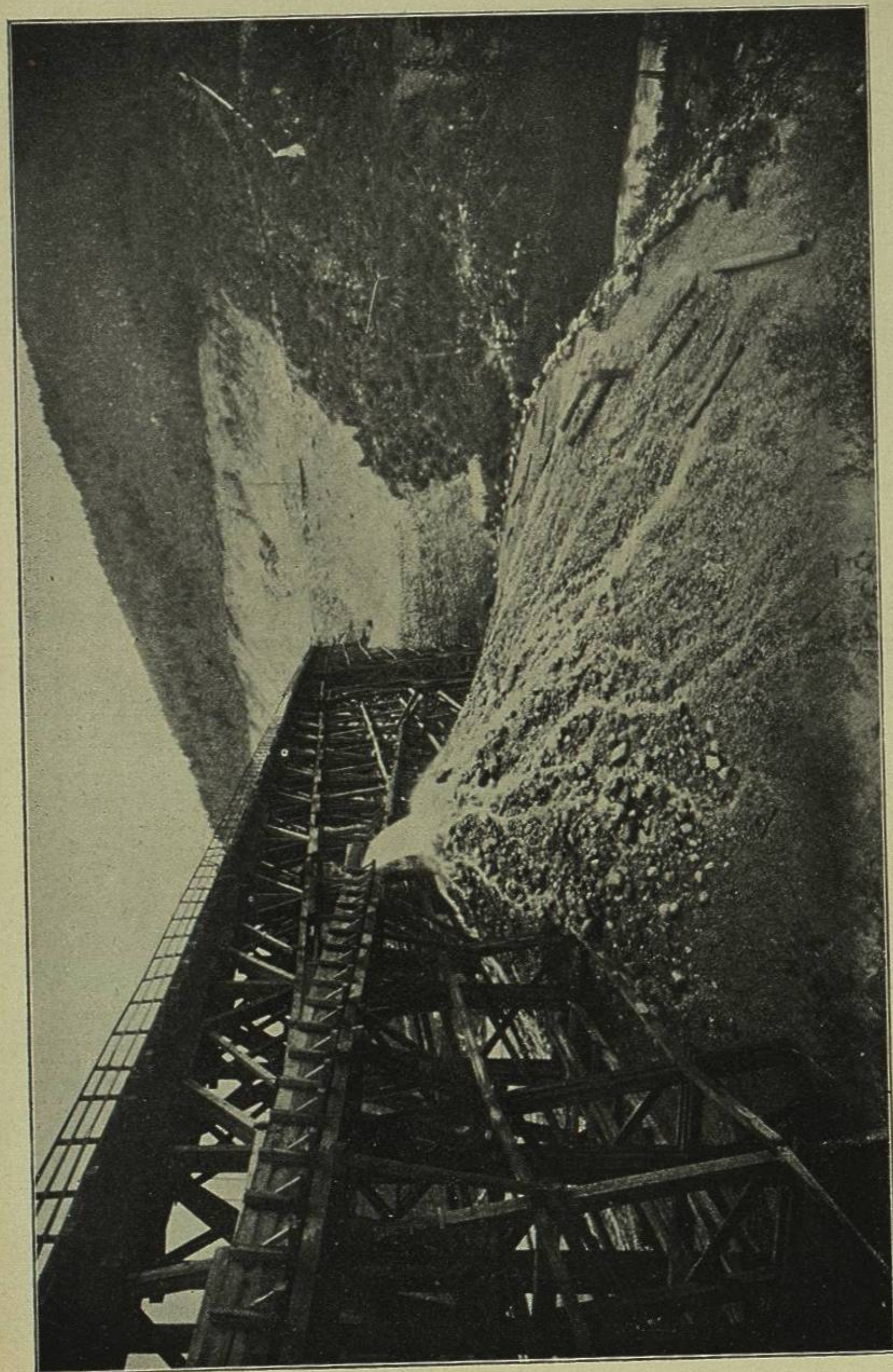

FIG. 142.—HYDRAULIC FILLING OF HIGH TRESTLE AT MOUNTAIN CREEK, B. C., ON CANADIAN PACIFIC RAILWAY, NEAR VIEW OF DUMP.

The plan adopted on this work for disposal of the water after it had accomplished its duty was practically the same as that used at the La Mesa dam. A waste-box (or a number of them if the fill was a large one) was taken up through the body of the embankment, and built up a little at a time, as the filling increased in height. The top of the boxes was always kept lower than the side levees, so that the water could escape without overflowing the sides as in the case of the Canadian Pacific fills. Hay or straw was used for the side levees instead of brush or logs, which would

FIG. 143.—NORTHERN PACIFIC RAILWAY. BRIDGE 190.

have cost considerably more. In order to prevent the rapid wearing out of the bottom of the flumes a paving of square timbers was used, cut into 3-inch blocks, so that the end would be presented as wearing surface.

It was found that grades of 7% and preferably 8% were most advantageous for the sluicing-flumes to carry material containing considerable gravel and rock, to prevent frequent blocking of the flumes.

By courtesy of E. H. McHenry, Chief Engineer, and Charles S. Bihler, Division Engineer, Northern Pacific Railway, the writer has been furnished with the interesting photographs of the work (Figs. 143, 144, 145, and 146), which illustrate the process of hydraulic filling very clearly in all its phases, and demonstrate with what precision embankments can thus be formed. The following general description of the work from the pen of Mr. Bihler is appended:

"The results have been very gratifying, both as to cost and character of the fills made. We are using, or trying to obtain, about 100 inches of water for each nozzle, as with a less quantity the rocky character of the material moved does not give good results. In some cases we have been able to obtain water at the bridge, without the necessity of building any considerable length of flumes. In other cases we had to construct several miles of flumes for the water-supply. These flumes are constructed in the

Fig. 144.—Northern Pacific Railway. Bridge 189, Cascade Mountains.

most temporary manner, of inch-and-a-quarter lumber, 16 to 18 inches square. Where the locality would permit we have carried the dirt to the bridges to be filled a distance of over half a mile. The manner of building up the fill is very clearly shown in the photographs. We use hay for keeping up a levee on the outside, and wooden frames or baffle-boards which are easily moved, to deflect the main current from the levees. The waste-water is taken off through a waste-box which is taken up through the body of the fill and built up as the filling increases in height. By adjusting the height of the waste-gate a larger or smaller amount of fine material can be retained in the fill, as desired. In building up the fill naturally a separation of the

materials takes place. The coarser material is deposited right under the end of the sluice-boxes, while the finer material is carried along toward the waste-boxes, the finest particles of each being deposited in the vicinity of the waste-gate in the shape of mud. For large embankments it is therefore necessary to have several waste-gates, so that coarse material may be deposited, from time to time, at those places, and the accumulation of too much of the fine material at any one point may be avoided.

"The plant required for the work is rather inexpensive. According to locality, one nozzle would require from 300 to 1000 feet of light sheet-iron

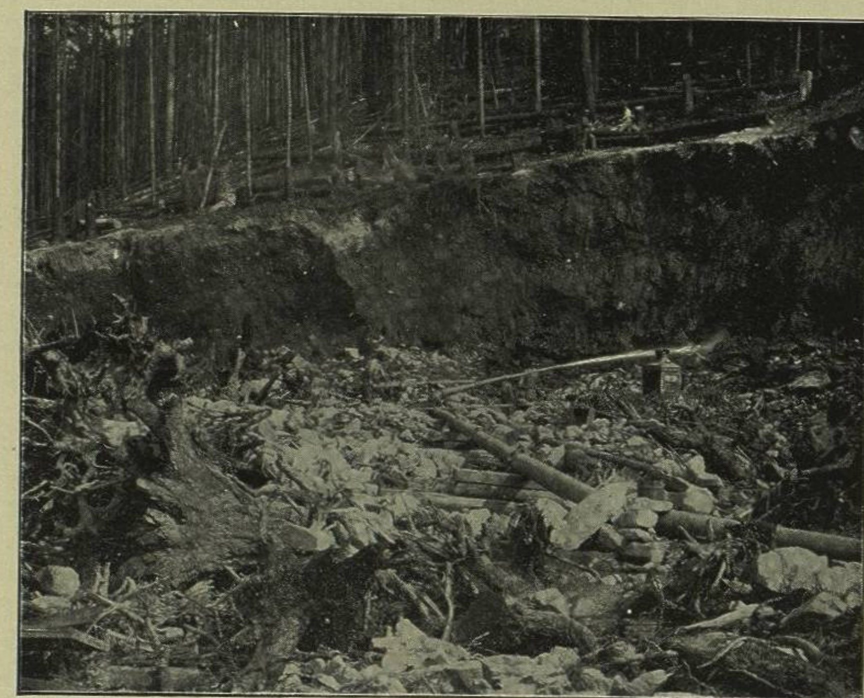

Fig. 145.—Northern Pacific Railway, Hydraulic-fill Construction. View in Pit showing Hydraulic Giant in Action.

pipe, costing about 27.5 cents per foot, and a No. 2 Giant, costing $95. Outside of this nothing is required except picks, shovels, hoes, and axes.

"The character of the material that we have available is not very favorable. The pits are very rocky, and the banks overlying bed-rock which can be loosened by the water-jet are not deep. The cost given for sluicing and building levee includes all costs of clearing. From five to six men are required with each nozzle, to build the levee, move sluice-boxes, and do everything else connected with the work."

Following is a summary of the volume and cost of hydraulic filling as reported on the Northern Pacific Railway:

			Average Cost per Yard.
Bridge	164	18,300 cubic yards.	8.21 cents.
"	165	6,200 " "	16.58 "
"	167	24,500 " "	14.00 "
"	170	30,800 " "	8.75 "
"	172	4,300 " "	10 55 "
"	173	9,700 " "	6 23 "
"	178	2,100 " "	13.25 "
"	179	19,800 " "	9.31 "
"	182	53,600 " "	3.80 "
"	184	96,650 " "	4.34 "
"	185	800 " "	30 24 "
"	186	51,600 " "	7.02 "
"	189	158,100 " "	5.19 "
"	190	128,800 " "	6.11 "
"	191	42,250 " "	13.50 "

FIG. 146.—NORTHERN PACIFIC RAILWAY, BRIDGE 184. HYDRAULIC FILLING IN PROGRESS.

The distinctive advantage recognized in favor of hydraulic filling of trestles on railways is that it can be carried on without interruption to the traffic and without endangering the trestle, either by falling rocks or unequal settlement, and when it is completed no further settlement of the embankment can occur. The latter advantage applies with special force to dam-construction, and is one whose importance can scarcely be overestimated. Where the materials available consist of large and small stones, either angular or rounded with small gravel, sand, and silt, the ease with which these materials may be graded and assorted so as to permit the outer portion of the embankment to be built of the coarser rock where it will afford ready drainage, while the finer particles may be assembled in the center and inside where they will best resist percolation, constitutes a further advantage, which may well be considered as an efficient substitute for the ordinary puddle-wall of earth dams built in the usual manner.

OTHER HYDRAULIC CONSTRUCTION.

Seattle, Washington.—Except in the manner of loosening the materials and putting them in motion, the methods of hydraulic construction of embankment described in the foregoing pages are quite similar to those employed in the reclamation work done by the Seattle and Lake Washington Waterway Co., at the city of Seattle, Washington.

This work, however, has a totally different object, namely, the opening of navigable tidal channels by dredging and the reclamation of valuable tide-lands adjacent to the business center of the city, by filling them with the fine black sand dredged from the channels. Two powerful suction-dredges were used, each with a capacity of removing 6000 to 7000 cubic yards of solids per 24 hours, which was pumped from the bottom of the channel through 18-inch pipes, a distance of 2000 to 4000 feet, and deposited to a depth of 18 or 20 feet over the area to be reclaimed. Some 36,000,000 cubic yards are to be handled in this way, and 1500 acres filled in solidly to a height of 2 feet above high tide. The actual cost of this class of work does not exceed two cents per cubic yard.

The mean velocity maintained in the delivery-pipes was 13.5 feet per second, and the discharge was 24 second-feet, so that when the work was at a maximum the percentage of solids carried by the water was 9%, although tests have shown as high as 20%. The bulkhead along the channels which hold the sand in place is made of brush mattresses, while the temporary cross-levees are effectively formed by the use of coarse hay, straw, or swamp-grass, precisely as used on the Northern Pacific fills.

Tacoma, Washington.—Hydraulic filling was done on a very large scale a few years since, at Tacoma, Washington, with salt water pumped from Puget Sound. The wharves in front of the city were located near the foot of a high bluff of glacial drift, and it was desired to fill a large area of lowland approaching the wharves, and substitute a portion of the wharves with an embankment of solid ground. To do this work the pumped water was piped against the bank, which was undermined, and the material carried to the place of deposit by the water. The cost of the work is represented to have been very low, not exceeding six cents per cubic yard, and the object sought was attained with entire success.

Holyoke Dam, Massachusetts.—The Holyoke dam, across the Connecticut River, was built as a timber-crib structure 1017 feet long and 30 feet high. In 1885 the dam was reconstructed and filled with a mass of puddle-gravel, washed in and puddled by hydraulic streams, under direction of Mr. Clemens Herschel, M. Am. Soc. C. E., of which he writes:* "No part of the work gave less anxiety and more satisfaction than this from the day it was started." Referring to similar work Mr. Herschel again writes: † "Pure gravel, just as it comes from the gravel-pit, will make a water-tight stop, when used between planks, or in any other position for which puddle is used, as far as my experience goes, better than clay or a clay mixture ever did."

Mr. Herschel further describes gravel as "a natural mixture of earth and pebbles; of various attributes and consistencies, some of which are good for building dams and some not. The best for that purpose is gravel that will puddle or 'binding gravel.' To tell whether any given gravel would puddle and to judge of its fitness for use in a dam, it should be mixed with water in a pail to the consistency of moist earth, about to be used in a dam or before rolling. If on turning the pail upside down the gravel remained in the pail it was fit for use, but if it dropped out it should be discarded." ‡

Utah Experiments.—The experiments made by Prof. S. Fortier, of the Utah Agricultural College Experiment Station, on the mixture of various aggregates for use in construction of earthen dams, shows that gravel, sand, and clay will occupy less space and become more compact when poured into water, mixed therewith, and allowed to drain and settle, than by any process of tamping either moist or dry. §

* Trans. Am. Soc. Civil Eng., vol. xv. p. 568.

† *Ibid.*, vol. xxvi. p. 684.

‡ *Engineering News*, Sept. 6, 1905.

§ Earthen Dams, by Samuel Fortier; Bulletin Utah Agricultural College, No. 46, Nov. 1896.

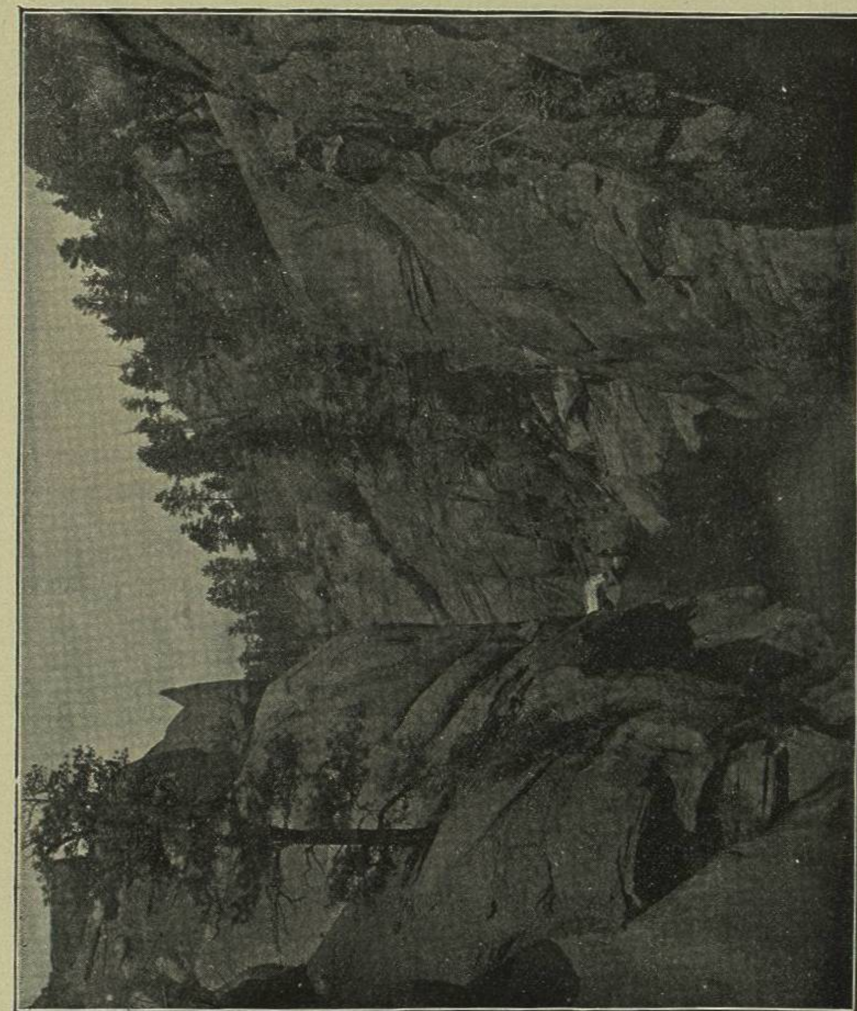

Fig. 147.—Site of Cheesman Dam, looking Down-stream.