

main-line track to be revised to a total of 18.6 miles. The maximum change in elevation of grade would occur at a point about 12 miles east of dam site and would amount to 34 feet. Revisions on branch lines of this company in Wallula area would add 9.3 miles, bringing the total of Union Pacific line to be revised to approximately 28 miles. On the Washington and Columbia River and Pendleton branches of the Northern Pacific Railroad Co. 3.4 miles of track immediately north of Wallula would be raised. The revision of the Spokane, Portland & Seattle Railway Co.'s track would begin at a point 6 miles west of the dam site and terminate at Hover, Wash., a total of about 30 miles. The maximum change of elevation would be at the dam site and would total 43 feet.

693. There is at this time no modern highway on either bank of the Columbia from Umatilla dam site through Wallula Gap. A poor road which may be traveled at extremely low speed makes it possible to pass through the gap on the Oregon side. Only the railroad extends through the gap on Washington side. About 3 miles of highway in the open country immediately north of Wallula would have to be relocated. The tabulation below shows in brief what would be required in the way of revising railroads and highways.

Railroads and highways	Miles		
	Relocate	Raise	Revise
Union Pacific system:			
Main line.....	17.6	1.0	18.6
Branch line.....	0	9.3	9.3
Northern Pacific R. R. Co., branch line.....	0	3.4	3.4
Spokane, Portland & Seattle Ry. Co., main line.....	28.4	1.8	30.2
Inland Empire Highway.....	3.1	0	3.1
Total.....	49.1	15.5	64.6

694. *General data.*—The principal facts relative to development at Umatilla with pool elevation 330 follow:

Drainage area.....	square miles	214, 000
Area of pool.....	acres	27, 000
Length of pool.....	miles	47
Natural mean low water elevation.....		253
Length of dam (including powerhouse section).....	feet	7, 400
Height of dam (maximum section, foundation to walkway).....	do	125
Average static head.....	do	64. 9
Proposed hydraulic capacity.....	second-feet	184, 000
Power capacity.....	horsepower	348, 000
Plant capacity factor.....	percent	68
Firm power (99.3 percent of time).....	kilowatts	250, 000
Firm output.....	kilowatt-hours	2, 190, 000, 000
Secondary power:		
90 percent of time.....	kilowatts	86, 000
80 percent of time.....	do	128, 000
70 percent of time.....	do	180, 000

Head, tailwater and power curves, hydrographs and powergraphs, output in kilowatt-hours for firm, secondary, and potential power are shown graphically on plates² 56, 57, and 58.

Cost in mills per kilowatt-hour for load factors from 50 to 100 per cent for 4 and 6 percent money, and for 50 and 100 percent power-market factors are shown graphically on plate 95.²

² Not printed.

TABLE 22.—*Umatilla development*

ESTIMATE OF COST

I. Preliminary expense.....	\$1,000,000
II. Railroads, roads, and bridges (for construction purposes only).....	400,000
III. Reservoir and damages.....	8,230,000
IV. Dam and diversion.....	10,100,000
V. Conduits (including forebay).....	-----
VI. Intake and equipment (including gates, racks, cranes, etc.).....	5,100,000
VII. Powerhouse substructure.....	3,750,000
VIII. Powerhouse superstructure.....	2,380,000
IX. Hydraulic equipment (including governors and auxiliary equipment).....	5,110,000
X. Electrical equipment (including generators and all electrical equipment between generators and low tension side of transformers).....	6,300,000
XI. Powerhouse cranes and miscellaneous auxiliary equipment.....	300,000
XII. Tailrace (included in VII).....	-----
XIII. Fishways.....	500,000
XIV. Switching station (structural only).....	560,000
XV. Operators village and permanent improvements.....	210,000
XVI. Contingencies, 10 percent.....	4,394,000
XVII. Overhead (engineering, supervision, clerical, legal, insurance, etc.), 12½ percent.....	6,042,000
XVIII. Interest during construction (2½ years to build) 4 percent money.....	2,714,000
XIX. Carrying charges, 50 percent power-market factor and 4 percent money.....	2,970,000
Total estimated cost, chargeable to power.....	60,060,000
Cost of navigation locks.....	4,000,000

ANNUAL CHARGES

Item	4 percent money	6 percent money
Interest on investment.....	\$2,402,400	\$3,800,000
Depreciation.....	560,600	403,300
Taxes.....	-----	945,000
Amortization.....	630,600	-----
Operating charges.....	280,000	250,000
Total annual charge.....	3,873,600	5,428,300

695. The tabulation below shows the cost in mills per kilowatt-hour, dollars per kilowatt-year for power at site, and at Portland, Oreg., for both public and private development, financed with 4 and 6 percent money, respectively, and based on a load factor of 55 percent. Costs were selected from the graphs shown on plate 95.²

Point	Mills per kilowatt-hour (55 percent load factor)		Dollars per kilowatt-year (55 percent load factor)	
	4 percent money	6 percent money	4 percent money	6 percent money
At site.....	1.72	2.41	15.10	21.10
At Portland.....	2.34	3.20	20.50	28.00

² Not printed.

696. *e. Umatilla to Canoe Encampment Rapids.*—From Umatilla dam site to the town of Umatilla, a distance of about 3 miles, the Columbia flows between low rolling hills, lying some distance from the river on the south, and somewhat higher hills rising from near the water's edge on north. At Umatilla, however, the hills on the Washington shore give way to rolling country, and on Oregon side to a stretch of ground extending inland for a distance of 10 to 15 miles so gently undulating that it may be considered almost a plain. This may be taken as descriptive of the country flanking the Columbia from Umatilla to Canoe Encampment Rapids, 28 miles down stream from Umatilla Rapids dam site.

697. The river, along the greater portion of this stretch, flows with a generally even current over a sand, or sand and gravel bottom, and between sand and gravel banks. From Umatilla dam site to Canoe Encampment Rapids no practicable dam sites occur although rock outcroppings appear in the river at Devils Bend Rapids and at Island No. 19, 7 and 15 miles, respectively, from the Umatilla site.

698. *f. Canoe Encampment Rapids site—Location.*—Canoe Encampment Rapids is 264 miles from the mouth of the Columbia, 160 miles from Portland by line of Union Pacific Railroad, and 168 miles by the Columbia Highway, both on south bank, and 168 miles from Portland by line of Spokane, Portland & Seattle Railway on north bank, though the latter line is about 1 mile north of the river at this point. The elevation of water surface at low water is 210 and at record flood about 248. The bank on the Oregon shore rises to a height of about 30 feet above mean low water and shows rock outcroppings. From the top of the bank to the south the ascent is very gradual. Rock shows on north bank and the ground rises steeply to a much higher level than on the south, but descends again to elevation about 250 in the depression through which the Spokane, Portland & Seattle Railway passes. Rock shows also at a number of points in river channel. A map of this site and exploration drilling are shown on plate 59.²

699. *Geology and test borings.*—James Gilluly, geologist, United States Geological Survey, made an examination of Canoe Encampment site in fall of 1929. His report is quoted as follows:

Depth to bedrock which is adequate though not as good as that at sites 2, 3, and 4 (i. e. at The Dalles, Biggs and Four O'Clock sites) is probably small here. Rock is found at about the elevation of the water at many places on the Oregon side. Little anticipation of the discovery of large deep potholes need be felt due to the great width of the river here. However, there is no indication of the bedrock rising in a short distance on the Oregon side and a cut-off wall may have to be carried several hundred feet from the present shore to insure watertightness as the alluvium now exposed on this bank is very porous. The depth to bedrock should be tested by drilling on the Oregon shore 200 feet from the river and at intervals till the elevation of bedrock found is equal to that of the flow line of the proposed dam.

A minor matter which may have to be evaluated is the possible damage to farm lands on the Oregon side if the dam flow line is maintained at 250 feet. This will raise the ground water table and perhaps cause the loss of some farm lands through alkali accumulation.

700. Two exploratory holes were drilled at Canoe Encampment site. Hole no. 1 was started in exposed bedrock at elevation 214, near water's edge on south bank. The upper 28 feet was in dense, hard

² Not printed.

jointed basalt and lower 17 feet through what is probably a scoriaceous bouldery phase of the lava with ash or clay filling, from which little core was obtained. Hole no. 2 was started in exposed bedrock near water's edge on north bank, at elevation 216. It was drilled to a depth of 27 feet, the upper 14 feet in hard basalt and lower 13 feet in porous scoria-like material similar to that penetrated in hole no. 1. The drill water was lost in the bottom porous material in both of these holes.

701. The poor material encountered in drilling in the low ground to the south of the river and that which is exposed in the draw on the north, through which the Spokane, Portland & Seattle Railway passes, marks Canoe Encampment Rapids as a site for a power dam much inferior to sites above and below.

702. *g. Canoe Encampment Rapids to Arlington.*—Below Canoe Encampment Rapids the river again flows with an even current over a sand and gravel bottom and between sand and gravel banks for a distance of about 20 miles, to a point about 3 miles upstream from Arlington, Oreg. Though the banks gradually become higher and outcroppings of rock or short sections of rim-rock appear at many points some distance from the river on the Oregon side, and the hills gradually gain in height and approach nearer the river on the Washington side, the absence of rock in the river itself and general unfavorable conditions in comparison with those prevailing along other sections eliminates the entire 20-mile stretch from further consideration as affording a site for constructing a power dam.

703. *h. Arlington power site—Location.*—The Arlington power site at which test borings were made is about $1\frac{1}{2}$ miles upstream from the town of Arlington, Oreg., and about one half mile above the town of Roosevelt on the Washington shore. It is 242.5 miles from the mouth of Columbia River, 140 miles from Portland by the line of Union Pacific Railroad and 148 miles by the Columbia Highway, both on the Oregon shore, and 147 miles from Portland by Spokane, Portland & Seattle Railway on the Washington side. The elevation of low-water surface at the dam site is 184, and of high water about 226. It is possible that further exploration might show the most favorable site for building a dam in the vicinity of Arlington to be about 1 mile downstream, or a short distance above the Union Pacific station. The width of the river between low-water lines at Arlington site is 1,650 feet. The distance between Union Pacific system on the south and Spokane, Portland & Seattle Railway on the north, is 4,000 feet; between 260-foot contours, 6,000 feet. A map of this site is shown on plate 61.² The exploration drilling is given on plate 60.²

704. *Geology and test borings.*—The town of Arlington, Oreg., is situated at the outlet of a ravine designated as Alkali Canyon. For a number of miles downstream from this canyon a vertical cliff, or series of cliffs, parallels the river at or near water's edge. Upstream from the mouth of this canyon a similar formation is exposed for a distance of several hundred feet. Beyond the end of this cliff the rolling sagebrush-covered hills extend down to water's edge for several miles. Low rimrocks or ledge outcroppings at some distance from the river indicate that the conditions for a distance upstream with respect to rock are, in general, similar to those at Arlington, except that the cliffs are farther from the river and that fine material, deposited by different agencies, has evened the steps in the cliff formation. It is

² Not printed.

thought probable that further drilling on the Oregon side at the site 1 mile above Arlington will prove the existence, within a few hundred feet of water's edge, of a cliff similar to those above and below outlet of Alkali Canyon.

705. On the Washington shore excellent lava rock is exposed at water's edge and at a number of points on the wide flat on which the town of Roosevelt is located. The conditions at the Arlington-Roosevelt site, as shown by surface examination and by a study of the results of the test drilling, seem favorable for constructing a dam which would raise the water up to the elevation 330.

706. Two exploratory holes were drilled at the Arlington power site. Hole no. 1, at elevation 187, is at water's edge on Oregon shore, and drilled to a depth of 57 feet. The upper 11 feet is sand, gravel, and boulders; the lower 46 feet is coarsely cellular to dense hard jointed basalt. Hole no. 2 was drilled at a point in the river 480 feet from Oregon shore, the water surface at the time standing at elevation 183. The total depth from water surface was 105 feet, as follows:

0 to 13, water.

13 to 40, sand, gravel, and boulder overburden.

40 to 92, coarse to finely cellular and dense basalt, somewhat scamed and jointed. Probably parts of two lava flows with contact at about elevation 67.0.

707. *Plans for development.*—Two plans for development have been considered. One would create a pool with water surface at elevation 258, which would extend to the foot of Umatilla development and give a low water head of 73 feet. The other would form a pool with water surface at elevation 330, extending 15 miles above the mouth of Snake, and producing a low water head of 145 feet.

708. *a'. Arlington development to elevation 258—Dam.*—The dam would be a gravity type concrete structure. The spillway section would be located across the main channel of the river and extend a few hundred feet on the Washington shore. It would be 2,180 feet in length. Fifteen roller gates 130 feet long by 30 feet high would control the pool level. A non-overflow, concrete gravity abutment section would extend northerly from the end of the spillway section to make connection with bedrock at elevation 268. This section would be about 1,700 feet long.

709. *Power house and equipment.*—The power house would be located on the Oregon shore and parallel to the river channel. The upstream end would connect to the spillway section of the dam. It would be about 1,700 feet in length. There would be installed 18 units, rated at 65,000 kilowatts at a head of 68 feet. This installation would carry a peak load of 500,000 kilowatts at 50 percent load factor. The turbines would be of the adjustable blade propeller type.

710. The substation equipment would be installed on the roof of the power house.

711. *Navigation locks.*—The navigation locks would be located next to the downstream end of the power house and on the Oregon shore.

712. *Fishways.*—Two fishways would be installed, one along the locks on the Oregon side and another on the Washington shore at the end of the spillway.

713. *General property damage.*—The pool created by the dam would extend upstream a distance of 49.5 miles to the Umatilla site and would have a surface area of 38,000 acres. The area of tillable and

pasture land submerged would total about 3,000 acres, all but a very small percent on Blalock Island.

714. *Revision of railroads and highways.*—Construction of a dam at the Arlington site with pool level at elevation 258 would necessitate the revision of 65 miles of railroad, assuming that the profile grades be maintained at an elevation 10 feet above water surface in the pool. Two miles of these revisions may be accomplished by raising the tracks in places, and 63 miles would involve relocation. The revision of the main line of the Union Pacific Railroad would begin at a point about 2 miles west of the damsite and terminate at a point about 2 miles east of Messner, Oreg., a distance of 29 miles. One summit in this distance would reduce the main line track to be revised to a total of 27.3 miles. The maximum change in elevation of grade would occur at the damsite and would amount to 49 feet. Revisions on branch lines of this company would add 1.2 miles, bringing the total of Union Pacific line to be revised to 28.5 miles. The revision of the tracks of the Spokane, Portland & Seattle Railway Co. would begin at a point about 4 miles west of the damsite and terminate at a point about 1 mile west of Paterson, Wash., a distance of 36 miles. The maximum change in elevation of grade would occur at the damsite and would amount to 35 feet.

715. Revision of 20 miles of the Columbia River Highway would be necessary, assuming that profile grade be maintained at an elevation not less than 10 feet above water surface in the pool. This revision would involve relocation of portions that are below the proposed grade or within the right of way of the relocated Union Pacific tracks. The revision would begin at a point about 2 miles west of the damsite and would terminate at a point about two miles east of Messner, Oreg., a distance of 29 miles. There are no modern highways on the north bank of the Columbia that would be affected by construction of a dam at the Arlington site with pool level at elevation 258.

716. The tabulation below shows the mileage of required revision of railroads and highways.

Railroads and highways	Miles		
	Relocate	Raise	Revise
Union Pacific System:			
Main line.....	27.3	-----	27.3
Branch line.....	1.2	-----	1.2
Spokane, Portland & Seattle Railway Co., main line.....	34.3	1.9	36.2
Columbia River Highway.....	20.6	-----	20.6
Total.....	83.4	1.9	85.3

717. *General data.*—The principal facts relative to development at Arlington with pool elevation 258 follow:

Drainage area.....	square miles.....	219,000
Area of pool.....	acres.....	38,000
Length of pool.....	miles.....	49.5
Natural mean low-water elevation.....		184
Length of dam.....	feet.....	4,200
Height of dam (maximum section, foundation to walkway).....	do.....	135
Maximum effective head.....	do.....	73
Minimum effective head (at record flood).....	do.....	32

Firm power (99.3 percent of time).....	kilowatts.....	250, 000
Firm output.....	kilowatt-hours.....	2, 190, 000, 000
Construction cost including carrying charges, and based on 50 percent load factor and 4 percent money.....		\$71, 500, 000

Cost in mills per kilowatt-hour for load factors from 50 to 100 percent, for 4 and 6 percent money, and for 50 and 100 percent power market factors are shown graphically on plate 96.²

718. *b'. Arlington development to elevation 330.*—The plan for developing the Arlington site by a dam with pool at elevation 330 would require a different arrangement to that proposed for dam with pool at elevation 258.

719. The total length of dam and power house would be about 10,300 feet. The spillway section is divided in two parts, one with nine roller gates 130 by 30 feet extending directly across the main channel, and the other with six similar gates on the Washington shore. The power house would be built in two sections, each 1,600 feet long extending downstream, parallel with the channel, from the ends of the main spillway section. A short gravity abutment section together with the navigation locks would connect the downstream end of the power house with high ground on the Oregon shore. On the Washington shore the short spillway section with gravity abutment would extend from the downstream end of the power house to the high ground on this side. This abutment would be about 3,900 feet long. The fall, 146 feet at low water, is too great for salmon to ascend in the usual type of fishway, but advantage might be taken of the extended rock formation on the Washington side to blast out a series of pools which would give a ladder approaching, in general, the conditions prevailing in an ordinary mountain stream, as has been done past the 42-foot natural fall in Willamette River at Oregon City, Oreg.

720. *General property damage.*—The pool created by the dam would have a length of 96.5 miles and a surface area of 162 square miles. This lake would have a maximum width of some 5 miles at a point about 2 miles below Irrigon, Oreg. There would be submerged, in addition to the area flooded by Umatilla Dam (par. 691) about 7,000 acres of land now under irrigation between the Arlington and Umatilla Rapids sites. This is distributed as follows:

	<i>Acres</i>
Umatilla, west extension.....	4, 200
Blalock Island.....	700
Paterson area.....	800
Artesian Well area.....	700
Miscellaneous areas.....	600

On these areas are located the towns of Paterson, Alderdale, Boardman, Irrigon, and Umatilla.

721. *Revision of railroads and highways.*—Constructing a dam at the Arlington site with pool level at elevation 330 would make necessary the revision of 176 miles of railroad, assuming that profile grade of railroad be maintained at 10-foot elevation above water surface in pool. In places, revision may be accomplished by raising the track, but the major part of the work would involve relocation.

722. The revision of the main line of the Union Pacific Railroad would begin at a point 5 miles west of dam site and terminate at a point about 2 miles east of Wallula, a distance of 77 miles. Two summits in this distance reduce the main-line track to be revised to a total of 69.7 miles. The maximum change in elevation of grade would occur

² Not printed.

at dam site and would amount to 121 feet. Revisions of branch lines of this company would add 17.6 miles, bringing the total of Union Pacific line to be revised up to approximately 87 miles. On the Washington and Columbia River and Pendleton branches of the Northern Pacific Railroad 3.4 miles of track immediately north of Wallula would be raised.

723. The revision of the track of the Spokane, Portland & Seattle Railway Co. would begin at a point about 13 miles west of the dam site and terminate at Hlover, Wash., a distance of 85 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 107 feet.

724. Revision of 31 miles of the Columbia River Highway and 3 miles of highway immediately north of Wallula would be necessary, assuming that profile grade be maintained at an elevation not less than 10 feet above water surface in the pool. This revision would involve relocation of portions that are below the proposed grade or within the right of way of the relocated railroad tracks. The revision of Columbia River Highway would begin about 5 miles west of the dam site and terminate about 3 miles southeast of Umatilla, Oreg., a distance of 51 miles. There are no modern highways on the north bank of the Columbia that would be affected by construction of a dam at the Arlington site with pool level at elevation 330.

725. The tabulation below shows the mileage of railroads and highways requiring revision.

Railroads and highways	Miles		
	Relocate	Raise	Revise
Union Pacific System:			
Main line.....	68.7	1.0	69.7
Branch line.....	8.3	9.3	17.6
Northern Pacific R. R. Co. branch line.....		3.4	3.4
Spokane, Portland & Seattle Ry. Co. main line.....	83.2	1.8	85.0
Columbia River Highway.....	30.9		30.9
Inland Empire Highway.....	3.1		3.1
Total.....	194.2	15.5	209.7

726. *General data.*—The principal facts relative to development at Arlington with pool elevation 330 follows:

Drainage area.....	square miles	219, 000
Area of pool.....	acres	104, 000
Length of pool.....	miles	96. 5
Maximum draw-down.....	feet	30
Storage available.....	acre-feet	2, 715, 000
Natural mean low-water elevation.....		184
Length of dam (including power-house section).....	feet	10, 300
Height of dam (maximum section, foundation to walkway).....	do	205
Maximum effective head.....	do	146
Minimum effective head (at record flood).....	do	104
Firm power (99.3 percent of time).....	kilowatts	685, 000
Firm output.....	kilowatt-hours	6, 000, 000, 000
Construction cost, including carrying charges, and based on 50 percent load factor and 4 percent money.....		\$178, 100, 000

Cost in mills per kilowatt-hour for load factors from 50 to 100 percent, for 4- and 6-percent money, and for 50- and 100-percent power market factors are shown graphically on plate 97.²

² Not printed.

727. *v. Arlington to Celilo.*—From Arlington to Celilo the river flows through a rocky gorge with rock in evidence almost continuously on both banks and outcropping at many points in the channel in the form of reefs and small rock islands. The entire 41.5-mile stretch may be considered as containing a succession of dam sites, adequate for supporting a dam up to several hundred feet in height.

728. Exploration drilling was done in this stretch at following points, named in order downstream:

Blalock Rapids.
Four O'Clock Rapids.
Squally Hook Rapids.
John Day Rapids.
Biggs Rapids.

729. *a'. Blalock Rapids site—Location.*—Blalock Rapids is 234 miles from mouth of the Columbia, 1 mile east of Blalock station on line of Union Pacific Railroad on south bank, and 139 miles from Portland by lines of Spokane, Portland & Seattle Railroad on north bank. This site was investigated after a drill hole put down at water's edge on the Oregon shore at Four O'Clock Rapids, 2 miles downstream, had shown the existence at that point of a blind channel upwards of 100 feet deep. The elevation of water surface at mean low water is 171, and at extreme flood about 213. A map of this site together with the exploration drilling is shown on plate 62.²

730. *Test borings.*—Two holes were put down in the river at the margins of two small islands. The river surface during the drilling stood at mean elevation about 169 feet. Hole no. 1 was started in sand and gravel at elevation 164 and drilled to a depth of 136 feet, the upper 6 feet in overburden and lower 130 feet in good basalt. Hole no. 2, near Washington shore, at elevation 161 was drilled to a depth of 46 feet, 19 feet in sand and gravel overburden and 27 feet in hard blue-gray basalt.

731. *b'. Four O'Clock Rapids site—Location.*—Four O'Clock Rapids is 232 miles from mouth of Columbia and 1 mile downstream from Blalock, Oreg., a station on the Union Pacific Railroad. It is 129 miles from Portland by rail and 137 miles by Columbia River Highway. The distance from Portland by line of Spokane, Portland & Seattle Railway on north bank of Columbia is 137 miles. The elevation of water surface at Four O'Clock at mean low water is 167, and at time of record flood about 210. A map of this site together with the exploration drilling is shown on plate 62.²

732. *Geology and test borings.*—This site was examined by James Gilluly, geologist, of United States Geological Survey, in fall of 1929. His report is quoted as follows:

Bedrock, when found, will prove to be basalt, and competent to sustain any projected structure. No channels deeper than those shown by recent soundings are to be anticipated. However, there is a possibility of one or more such channels being concealed beneath the gravel bar on the Oregon side of the river and considerable care should be taken to verify their presence or absence. Also the dam or cut-off wall may have to be carried a considerable distance to the south on the Oregon side as the surface is covered with gravel and sand, and bedrock may not rise to the elevation of flow line of the dam for some distance in this direction.

² Not printed.

733. One hole was drilled at water's edge on Oregon shore, starting at elevation 175 and going to a depth of 97.5 feet in sand and gravel without reaching bedrock, evidently penetrating one of the deep channels which the geologist anticipated might be found on the Oregon side of the river at this point. Acting on the information gained by the drilling, this site was abandoned and the drill moved to Blalock Rapids, 2 miles upstream.

734. *c'. Squally Hook rapids site—Location.*—Squally Hook rapids is 222.5 miles from mouth of the Columbia, 120 miles from Portland by line of Union Pacific Railroad, 127 miles by Columbia River Highway, both on south bank, and 128 miles by line of Spokane, Portland & Seattle Railway on north bank. The elevation of water surface at foot of rapids at low water is 152, at time of record flood about 191. A map of this site together with the exploration drilling is shown on plate 63.²

735. *Geology and test borings.*—Good basalt rock is exposed at water's edge on Oregon shore, appears as islands or reefs above low water surface at several points in the stream, and probably forms the river bottom over much of the distance between banks.

736. Two diamond drill holes were put down at the site. Hole no. 1 was started at elevation 166.5 in exposed bedrock close to water's edge on Oregon shore and penetrated excellent hard basalt to a depth of 69.5 feet. Hole no. 2, started at elevation 184.9 in an old railroad borrow pit about 300 feet back from low-water line on Washington shore, was drilled to a depth of 75 feet, 37 feet in sand and gravel and 38 feet in excellent hard coarsely cellular basalt.

737. *d'. John Day Rapids site—Location.*—Upper, Middle, and Lower John Day Rapids extend from the mouth of John Day River for a distance of about 2½ miles downstream. The site selected for investigation is at Middle Rapid. It is 216 miles from the mouth of the Columbia, 114 miles from Portland by line of Union Pacific Railroad, and 121 miles by Columbia River Highway, both on south bank. It is 122 miles from Portland by Spokane, Portland & Seattle Railway on north bank. The river at low water stands at elevation 145, and at record flood of 1894 it stood at about 182. The main channel next to the Oregon shore has a width at low water of about 550 feet. To the north of this channel are two islands. The first, or the one next to the main channel, is bare basalt and measures about 400 feet in width by 1,600 feet long. The second, with bare basalt rock forming its southern rim, is 1,500 feet wide by about 1 mile in length. It is covered with an overburden consisting mostly of sand and gravel. The smaller island is completely submerged at ordinary high water and the larger at times of extreme flood. A map of this site together with the exploration drilling is shown on plate 64.¹

738. *Geology and test borings.*—The rock exposed along the shore and on the islands at John Day site is similar to that in evidence at Blalock site, 18 miles above, and at Biggs site 9 miles downstream, and is adequate for the support of a dam of height proposed in paragraphs following. The test borings indicate the advisability of carrying cut-off walls to considerable depth and of tightening the formation by drilling and grouting to insure against excessive loss of water by seepage. Two exploration holes were drilled. Hole no. 1,

² Not printed.

located on the small rock island just to north of the main channel, was started in exposed dense hard jointed basalt at elevation 153 and continued in this type of rock to a depth of 151 feet. The material penetrated, though varying from solid to agglomeratic and some checked and broken basalt, as the cores are interpreted, is about average for this formation in this region. Three flows were apparently penetrated, with contact horizons at depths 31-36 and 95 feet. The fact that the drill water was returned at all depths in this hole indicates that no fissures or open seams of consequence were encountered.

739. Hole no. 2 at elevation 159.2 on the larger island, penetrated sand and gravel to a depth of 14 feet and basalt for 208 feet additional. Here, also, at least three separate flows were crossed by the drill, with recognizable contact horizons at 96, and 196-206 feet of depth. The cores do not show as good rock on the average as do those from hole no. 1. The loss of the drill water at a depth of 29 feet (15 feet in basalt) and the necessity of cementing the hole to prevent continual caving, though it shows the presence of a certain degree of openness of jointing or seaminess, is not unusual in this type of lava, particularly when as in this instance a hole is put down near the channel which is deeply cut into the same basalt layers.

740. *Plans for development.*—Three plans have been considered for making a power development at John Day site, (1) to elevation 185, which would backwater to Arlington site and give a low water head of 33 feet; (2) to elevation 258, which would produce a pool extending to Umatilla site and a low-water head of 106 feet; and (3) to elevation 330 which would backwater to point 15 miles above the mouth of Snake and give a low-water head of 178 feet. These heads result from assuming the backwater from The Dalles site as at elevation 152. Since a dam with pool to elevation 185 would give little or no power at time of flood, it is not given further consideration. The plans for development to elevations 258 and 330 are set forth in some detail.

741. *a'. John Day development to elevation 258--Dam.*—The distance across river between low-water lines at John Day site is 2,800 feet; between Union Pacific Railroad on south and Spokane, Portland & Seattle Railway on north 3,200 feet, and between contours 260 on opposite sides, 3,800 feet. The dam as planned would be a gravity concrete structure. The spillway section would be next to the Washington shore, with rollway at elevation 228 and with piers, roller gates, and operating bridge as specified for Umatilla development (par. 684). Short concrete, nonoverflow abutment sections on both Oregon and Washington sides complete the dam. Plan of dam is shown on plate 65.

742. *Power house and equipment.*—The power house, as shown on plate 65, would extend from the southern end of the spillway section for a distance of about 2,000 feet and would connect with the main Oregon shore. There would be installed 27 units, rated at 40,000 kilowatts at a head of 100 feet. This installation would carry a peak load of 770,000 kilowatts at 50 percent load factor. The turbines would be of the vertical reaction type with steel scroll case.

743. The substation equipment would be installed on the roof of the power house.

744. *Navigation locks.*—The navigation locks would be located in the bulkhead section of the dam on the Oregon shore.

745. *Fishways*.—The elevation to be overcome, approximately 100 feet at time salmon would be coming up the river to spawn, exceeds the ascent which authorities believe the fish will pass in a ladder of conventional type. Further study may show it feasible to construct either a ladder in two flights with a fairly long pool between, or a conveyance of the escalator type.

746. *General property damage*.—The pool for John Day development to elevation 258 would have a length of 76 miles and a surface area of 49,000 acres. Due to the fact that the river flows through a canyon or gorge from Arlington to John Day site, the area of tillable land submerged would not differ greatly from that above dam at Arlington with crest at elevation 258 (par. 713). A small portion of the town of Arlington and all of Roosevelt, Wash., however, would lie below pool level and would have to be moved to higher ground.

747. *Revision of railroads and highways*.—Construction of a dam at the John Day site with pool level at elevation 258 would necessitate the revision of 124 miles of railroad, assuming that the profile grade be maintained at an elevation 10 feet above water surface in the pool. A portion of this revision may be accomplished by raising the tracks in place, but the remainder would involve relocation.

748. The revision of the main line of the Union Pacific Railroad would begin at a point about 3 miles west of the dam site and terminate at a point about 2 miles east of Messner, Oreg., a distance of 57 miles. One summit in this distance reduces the main line track to be revised to a total of 54.9 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 84 feet. Revisions of branch lines of this company would add 2.8 miles, bringing the total of Union Pacific line to be revised to approximately 58 miles.

749. The revision of the tracks of the Spokane, Portland & Seattle Railway Co. would begin at a point about 9 miles west of the dam site and terminate at a point about 1 mile west of Paterson, Wash., a distance of 66 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 74 feet.

750. Revision of 42 miles of Columbia River Highway would be necessary, assuming that profile grade be maintained at an elevation not less than 10 feet above water surface in the pool. This revision would involve relocation of portions that are below the proposed grade or within the right-of-way of the proposed Union Pacific tracks. The revision would begin at a point about 3 miles west of the dam site and would terminate at a point about 2 miles east of Messner, Oreg., a distance of 57 miles. There are no modern highways on the north bank of the Columbia that would be affected by construction of a dam at the John Day site with pool level at elevation 258.

751. The tabulation below shows the mileage of required revision of railroads and highways:

Railroads and highways	Miles		
	Relocate	Raise	Revise
Union Pacific system:			
Main line.....	54.9	0.0	54.9
Branch line.....	2.8	.0	2.8
Spokane, Portland & Seattle Ry. Co., main line.....	64.6	1.9	66.5
Columbia River Highway.....	41.8	.0	41.8
Total.....	164.1	1.9	166.0

752. *General data.*—The principal facts relative to development at John Day with pool elevation 258 follow:

Drainage area.....	square miles..	227, 230
Area of pool.....	acres.....	49, 000
Length of pool.....	miles.....	76
Natural mean low-water elevation.....		145
Length of dam (including power-house section).....	feet.....	5, 300
Height of dam (maximum section, foundation to walk-way).....	feet.....	180
Average static head.....	do.....	102. 5
Proposed hydraulic capacity.....	second-feet.....	186, 500
Power capacity.....	horsepower.....	549, 000
Plant capacity factor.....	percent.....	79
Firm power (99.3 percent of time).....	kilowatts.....	385, 000
Firm output.....	kilowatt-hours..	3, 372, 600, 000
Secondary power:		
90 percent of time.....	kilowatts.....	120, 000
80 percent of time.....	do.....	200, 000
70 percent of time.....	do.....	280, 000

Head, tailwater and power curves, hydrographs and powergraphs, output in kilowatt-hours for firm, secondary, and potential power are shown graphically on plates ² 66, 67, and 68.

Cost in mills per kilowatt-hour for load factors from 50 to 100 per cent, for 4 and 6 percent money, and for 50 and 100 percent power market factors are shown graphically on plate 95.²

TABLE 23.—*John Day development to elevation 258*

ESTIMATE OF COST		
I. Preliminary expense.....		\$850, 000
II. Railroads, roads and bridges (for construction purposes only).....		150, 000
III. Reservoir and damages.....		21, 200, 000
IV. Dam and diversion.....		11, 360, 000
V. Conduits (including forebay).....		
VI. Intake and equipment (including gates, racks, cranes, etc.)..		7, 540, 000
VII. Power-house substructure.....		9, 355, 000
VIII. Power-house superstructure.....		3, 230, 000
IX. Hydraulic equipment (including governors and auxilliary equipment).....		10, 260, 000
X. Electrical equipment (including generators and all electrical equipment between generators and low-tension side of transformers).....		12, 150, 000
XI. Power-house cranes and miscellaneous auxilliary equipment.....		300, 000
XII. Tailrace (included in VII).....		
XIII. Fishways.....		500, 000
XIV. Switching station (structural only).....		1, 080, 000
XV. Operators village and permanent improvements.....		405, 000
XVI. Contingencies, 10 percent.....		7, 838, 000
XVII. Overhead (engineering, supervision, clerical, legal, insurance, etc.), 12½ percent.....		10, 772, 000
XVIII. Interest during construction (3 years to build) 4 percent money.....		5, 810, 000
XIX. Carrying charges, 50 percent power market factor and 4 percent money.....		7, 060, 000
Total estimated cost, chargeable to power.....		109, 860, 000
Cost of navigation locks.....		5, 400, 000

² Not printed.

ANNUAL CHARGES

Item	4 percent money	6 percent money
Interest on investment.....	\$4,394,500	\$6,996,000
Depreciation.....	1,048,000	763,000
Taxes.....		1,749,000
Amortization.....	1,153,500	
Operating charges.....	540,000	540,000
Total annual charge.....	7,136,000	10,048,000

753. The tabulation below shows the cost in mills per kilowatt-hour, dollars per kilowatt-year for power at site, and at Portland, Oreg., for both public and private development, financed with 4 and 6 percent money, respectively, and based on a load factor of 55 percent. Costs were selected from the graphs shown on plate 95.²

Point	Mills per kilowatt-hour 55 percent load factor		Dollars per kilowatt-year 55 percent load factor	
	4 percent money	6 percent money	4 percent money	6 percent money
At site.....	2.02	2.87	\$17.70	\$25.15
At Portland.....	2.42	3.39	21.20	29.70

754. *b''*. *John Day development to elevation 330*.—The general features of the John Day development to pool elevation 330 would be similar to those already described for the development with pool elevation 258. The general property damage, in addition to the towns and irrigated areas submerged by dam to elevation 330 at Arlington site (par. 720), would include the greater part of the business portion of Arlington.

755. *Revision of railroads and highways*.—Construction of a dam at the John Day site with pool level at elevation 330 would necessitate the revision of 234 miles of railroad, assuming that the profile grade be maintained at an elevation of 10 feet above water surface in the pool. A small part of this revision may be accomplished by raising the tracks in place, but the major portion involves relocation.

756. Revision of the main line of the Union Pacific Railroad would begin at a point about 7 miles west of the dam site and terminate at a point about 2 miles east of Wallula, Wash., a distance of 105 miles. Two summits in this distance reduce the main-line track to be revised to a total of 98.1 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 156 feet. Revisions on branch lines of this company would add 17.6 miles, bringing the total of Union Pacific line to be revised to approximately 116 miles. On the Washington & Columbia River and Pendleton branches of the Northern Pacific Railroad Co. 3.4 miles of track immediately north of Wallula would be raised.

757. The revision of the Spokane, Portland & Seattle Railway Co.'s track would begin at a point about 18 miles west of the dam site and terminate at Hover, Wash., a distance of 115 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 146 feet.

² Not printed.

758. Revision of 50 miles of Columbia River Highway would be necessary, assuming that profile grade be maintained at an elevation not less than 10 feet above water surface in the pool. This revision would involve relocation of portions that are below the proposed grade or within the right-of-way of the proposed Union Pacific tracks. The revision would begin at a point about 7 miles west of the dam site and terminate about 2 miles east of Umatilla, Oreg., a distance of 78 miles.

759. About 3 miles of highway immediately north of Wallula would have to be relocated. There are no modern highways on the north bank of the Columbia that would be affected by construction of a dam at the John Day site with pool level at elevation 330.

760. The tabulation below shows the mileage of required revision of railroads and highways:

Railroads and highways	Miles		
	Relocate	Raise	Revise
Union Pacific System:			
Main line.....	97.1	1.0	98.1
Branch line.....	8.3	9.3	17.6
Northern Pacific Railroad Co.; branch line.....	.0	3.4	3.4
Spokane, Portland & Seattle Railway Co., main line.....	113.5	1.8	115.3
Columbia River Highway.....	50.0	.0	50.0
Inland Empire Highway.....	3.1	.0	3.1
Total.....	272.0	15.5	287.5

761. *General data.*—The principal facts relative to development at John Day with pool elevation 330 follow:

Drainage area.....	square miles..	227, 230
Area of pool.....	acres.....	120, 000
Length of pool.....	miles.....	123
Maximum draw-down.....	feet.....	35
Storage available.....	acre-feet.....	3, 347, 500
Natural mean low-water elevation.....	feet.....	145
Length of dam (including power-house section).....	feet.....	6, 800
Height of dam (maximum section, foundation to walk way).....	feet.....	255
Maximum effective head.....	do.....	185
Minimum effective head.....	do.....	148
Firm power (99.3 percent of time).....	kilowatts.....	875, 000
Firm output.....	kilowatt-hours.....	7, 666, 000, 000
Construction cost, including carrying charges, and based on 50 percent load factor and 4 percent money.....		\$197, 000, 000

Cost in mills per kilowatt-hour for load factors from 50 to 100 percent, for 4 and 6 percent money, and for 50 and 100 percent power market factors are shown graphically on plate 99.²

762. *c'. Biggs Rapids site—Location.*—Biggs Rapids near the village of Biggs, Oreg., is 207 miles from mouth of Columbia, 104 miles from Portland by line of Union Pacific Railway and 111 miles by Columbia Highway. The distance from Vancouver, Wash., by the line of Spokane, Portland & Seattle Railway is 102 miles. This site is mentioned in paragraph 651, as a site for a 35-foot dam in the series of five dams proposed to secure slack-water navigation from

² Not printed.

Celilo to mouth of Snake River. A map of this site together with exploration drilling is shown on plate 69.²

763. *Geology and test borings.*—An examination of the site was made in fall of 1929, as a part of the present investigation, by James J. Gilluly. His report relative to Biggs Rapids dam site is quoted as follows:

The rock here is basalt and suitable for support of any projected structure. The sand bars on the south shore and the island near the Washington shore may possibly conceal some buried deep channels and should be drilled rather than the main part of the river where bedrock is almost surely present at depths very close to those given by soundings.

764. One test hole was put down near water edge on Oregon shore with diamond drill during winter of 1929–30. The hole starting at elevation 148.8 had a depth of 103 feet, the upper 59 feet churn drilled through sand, gravel, and boulders, and the lower 44 feet with diamond core drill through basaltic rock with occasional clay seams. The latter is probably a scoriaceous and agglomeratic phase of the lava in which there is a filling of ashy and clayey materials among the harder parts.

(C) SECTION 2. CELILO TO THE DALLES

765. *General.*—Celilo, 201 miles from mouth of Columbia, and the foot of Three Mile Rapids, 190 miles from mouth, and 1½ miles above the city of The Dalles, mark the upper and lower limits of what may be considered as The Dalles-Celilo power site. This 11-mile stretch is one of the remarkable river sections of America. It includes Celilo Falls, which at low water has a vertical drop of 20 feet, Ten Mile Rapids, Five Mile Rapids, Big Eddy, and Three Mile Rapids. Through Ten Mile Rapids for a distance of about one half mile, and through Five Mile Rapids for a distance of 1½ miles, the entire volume of the Columbia at low and ordinary stages flows with great velocity in a basaltic channel with vertical sides 180 to 300 feet apart and of such depth that it is often spoken of as a "river on edge." Soundings which were taken show, at low water, depths of from 150 to more than 200 feet. A map of this stretch of the river is shown on plate 70.

766. *Natural fall.*—The water surface at head of Celilo Falls at mean low water is at elevation 127, and a foot of Three Mile Rapids at elevation 45, giving between these points a natural fall of 82 feet. With increased flow the river rises more slowly at the head of Celilo Falls than at the foot of Three Mile Rapids and as a result the fall becomes less. The natural fall for various stages is given in the tabulation below:

Discharge in second-feet:	Fall in feet
40,000.....	84
60,000.....	82
200,000.....	75
500,000.....	66
800,000.....	61
1,200,000.....	55

767. *Natural flow.*—The flow available for The Dalles-Celilo section is increased over that for section above by the inflow of the

² Not printed.

Deschutes River. For discharge relations in this section of Columbia River see paragraph 570.

768. *Geology and test borings.*—Columbia River basalt, with no overburden, occurs along the margin of the river for much of the distance between upper and lower limits of The Dalles-Celilo section, and from the head of Five Mile Rapids to foot of Three Mile Rapids, its irregular surface is exposed in a continuous stretch from the Union Pacific Railroad on south to Spokane, Portland & Seattle Railway on the north side of the river channel.

769. Eight exploratory holes were drilled along this stretch of the river in connection with this investigation. Three were put down at or near Three Mile Rapids, four at outlet of Big Eddy and along north side of channel extending from Big Eddy to Three Mile Rapids, and one on the rolling bench about $1\frac{1}{2}$ miles to north of Three Mile Rapids. (See plate 71.)²

770. At the head of Three Mile Rapids, two holes were started in exposed bedrock, one on south and the other on north side of channel. Hole no. 1 on the south side at elevation 63 was drilled to a depth of 207.1 feet. Hole no. 3 on the north at elevation 57 went to a depth of 183.3 feet. A third hole, no. 2, at a point about one half mile south of head of Three Mile Rapids, was started at elevation 76 and drilled to a total depth of 85.1 feet, 10.8 feet in sand and gravel overburden and 74.3 feet in rock. Two relatively thin layers of the lava were penetrated in this hole, with tuff contact horizons at 41–42 feet and at about 60 feet of depth.

771. Two holes were put down, one on south and one on north side of the upper end of the straight channel extending downstream from Big Eddy. Both were started in exposed basalt bedrock. The one on south hole no. 4 was drilled from elevation 71.33 to a depth of 262.2 feet, or about 90 to 100 feet below bottom of river channel at that point, through a succession of layers of hard, prevailingly jointed blue-gray basalt. Hole no. 1 on north was started at elevation 72.6 and drilled to a depth of 243 feet through the same series of heavy basalt flows. Two holes were drilled at the north side of the channel further downstream, hole no. 2 to a depth of 113 feet and the other, hole no. 3, 230 feet. These holes also penetrated typical Columbia River basalt, which yielded a good percentage of core, except when crossing contacts between flows. Drill water was lost in some instances in drilling these holes, in both the contact materials and the jointed basalt, but this is to be expected in holes drilled near to the vertical sides of the river channel. In some holes it was found expeditious to cement the formation in order to continue the drilling at point where loosened small pieces of the lava or of the fragmental material between lava flows tended to block the hole and retard progress. Neither the loss of water nor the tendency of parts of the formation to ravel reveals a condition to indicate other than satisfactory foundation. It is believed that a dam of any desired height could be constructed safely on this foundation and that it would be secure against losses of water when usual engineering precautions are taken.

² Not printed.

1. EARLIER INVESTIGATIONS

772. The United States Reclamation Service (now the United States Bureau of Reclamation) in cooperation with the State of Oregon, made an investigation of The Dalles-Celilo power site in 1914-15 and published its findings as a report entitled "Columbia River Power Project." L. F. Harza, consulting engineer, made the investigation and prepared the report; E. G. Hopson, supervising engineer, represented the United States Reclamation Service, and J. H. Lewis, State engineer, represented the State of Oregon.

773. The plan of development proposed a dam up to elevation 151 at the head of Five Mile Rapids and a canal about 1½ miles long on the Washington shore to a power house located on the margin of Big Eddy. The canal would have a maximum capacity of 145,000 second-feet and would be created in part by excavation and in part by construction of a wall on river side. The dam would be provided with regulating gates and head would vary from maximum of 105 feet at low water to a minimum of about 25 feet at time of record flood (that of 1894). However, a study of flood stages for the past 50 years shows that the minimum head of 25 feet would have occurred only once and that in only 1 year in 7 the head would fall below 45 feet. The power output was estimated at 480,000 horsepower continuous, 600,000 horsepower for 11 months, 700,000 horsepower for 10 months, and 800,000 horsepower for 8 months of an average year. The cost, estimated as for 1914 prices, was placed at \$50,000,000, without substation and transmission line. The report, in addition to setting forth plans for the development, gives a great deal of information relative to the use of power in electrochemical and electrometallurgical industries.

2. PRESENT INVESTIGATION

774. *Plans for development.*—Consideration was given to a number of alternate plans for developing power in The Dalles-Celilo section. The sites given special study, named in order downstream, are Five Mile Rapids; Big Eddy; Three Mile Rapids.

The investigation having shown Big Eddy to be the most favorable site, plans for development at that point will be presented last.

775. *a. Five Mile Rapids Plan.*—This plan proposes a dam at head of Five Mile Rapids to elevation 150 and a canal down north bank to a power house along margin of Big Eddy. It is in all essentials the plan proposed in the cooperative report by the United States Reclamation Service and State of Oregon, and for that reason it is not necessary to describe it in detail here. For general location see plate 70.

776. The Five Mile Rapids plan offers two advantages over a plan involving the construction of a dam at either Big Eddy or Three Mile Rapids. One of these is that the present lock canal below the dam would be left intact and, with additional lock constructed at the dam to gain pool elevation, would serve the future needs of navigation. The other is that, being farther up the river than the Big Eddy and Three Mile Rapids sites, there would be, for a dam to given elevation, less cost for revising or protecting railway and highway along south bank. However, estimates of cost show that these favorable factors are more than offset by others favoring the Big Eddy site. The essential features of height of dam, head, stream flow, and power

output for this site and the Big Eddy development (par. 782) are so similar that a separate tabulation for this site is not set up here.

777. *b. Three Mile Rapids plan.*—The Three Mile Rapids site is about 1½ miles upstream from the center of the business section of the city of The Dalles, Oreg., and 190 miles from mouth of the Columbia River. The general location is shown on plate 70.

778. The elevation of water surface ranges from 45 for mean low water to about 106 at peak of record flood in 1894. The proximity to The Dalles, especially to the Union Pacific Railroad yards, limits a development to approximate elevation 135.

779. The dam across the channel would be located in the narrow throat at head of Three Mile Rapids. The width is about 300 feet and the water at low stages has a depth of about 140 feet. This portion of the dam would be a concrete arch structure. Its building would involve the same problems as those to be met in building at Big Eddy and the method of construction described for that site would have to be employed here (par. 786). The power house would be located along Oregon side of the main channel. The spillway, equipped with roller type control gates, would have one section to the north of the main channel. The other section would extend from downstream end of power house and connect with the high ground on the Oregon side. It would be necessary to construct a wall to protect the railroad yards at The Dalles from water discharged through this latter section of spillway.

780. The effective head at mean low water, with a development to elevation 54 in vicinity of Cascades Rapids, would be about 79 feet, with no development at Cascades Rapids, 88 feet. At peak of record flood the head would be reduced to about 25 feet, with or without a dam to elevation 54 at Cascades Rapids.

781. On account of the great fluctuation in head and the fact that a development to elevation 135 at this point does not fit in with a favorable plan for utilizing the entire head between mouth of Snake and tide water, no tabulation of output, etc., for development at Three Mile Rapids will be given.

782. *c. Big Eddy plan—a'. The Dalles development to elevation 150—Location.*—The Big Eddy plan, hereafter referred to as The Dalles development, proposes a dam in the narrow channel between the Oregon shore and Big Eddy Island at a point about 600 feet downstream from the foot of The Dalles-Celilo Canal, and a power house along north side of the channel, extending from end of overfall section of the dam well down toward head of Three Mile Rapids. The plan of development is shown on plate 72.

783. *Dam.*—The dam may be considered as being divided into six parts:

(a) A concrete arch overfall section in the river channel, with concrete thrust blocks at each end. The crest would be at elevation 135, and crest length about 600 feet. It would be fitted with 24 tainter type regulating gates 20 feet long by 15 feet deep. (b) A concrete gravity overfall section approximately 1,700 feet long, extending from westerly end of arch dam to upstream end of power house, with spillway crest at elevation 120, and topped with 11 roller type gates 130 feet long by 30 feet deep. (c) A nonoverflow concrete section 2,580 feet long, flanking the power house, and with top at elevation 160. (d) A concrete overflow section 430 feet long, extending northerly from lower end of power house and with spillway crest at elevation 120. This would be topped with three roller type gates 130 feet long by 30 feet deep. (e) A multiple arch section 800 feet long, continuing from

end of spillway section north to navigation locks. And (f), concrete abutment sections to close the gaps between navigation canal and high ground at the north, and between the end of arch dam and the high ground to the south. See plate 72 for locations.

784. The main arch structure would have a maximum height of 260 feet from foundation in bottom of the river channel to walkway; the gravity spillway sections and gravity nonoverflow sections along power house, a maximum height of 80 feet, except across the temporary diversion channel where the height would be 120 feet; and the multiple arch section a maximum height of 70 feet. Of these several parts only the main arch dam involves an unwatering problem, all other portions being located above water level, except at time of extreme flood.

785. The steps proposed for diverting the flow of the river and constructing a dam in the natural deep river channel follow:

(a) Excavate a diversion channel from Big Eddy diagonally in southwest direction to connection with river a short distance below Big Eddy Island. This channel would have a width of 600 feet and the bottom would be at approximate elevation 40. It would involve about 900,000 cubic yards of rock excavation and would pass about 200,000 second-feet at a velocity of 13 feet per second with a water surface at elevation 67 in Big Eddy. As a flow of 200,000 second-feet or more prevails for only about 30 percent of the time, a working season of not less than 8 months would be secured.

(b) Place a loose rock fill, composed entirely of large rocks, in the main river channel in the narrow section just north of the lower entrance to The Dalles-Celilo Canal. This fill would require approximately 1,000,000 cubic yards of loose rock. Its object would be to reduce current velocities in the main stream while working on unwatering for the permanent dam between Big Eddy Island and the Oregon shore.

(c) Construct two temporary concrete arch dams in the river channel between Big Eddy Island and the Oregon shore to serve as cofferdams during the construction of the permanent arch dam. Locate one arch upstream and the other downstream from the site of the permanent arch, with sufficient space between for the necessary construction work. Build the upstream temporary arch dam first.

(d) Pump out the area between the two temporary dams.

(e) Construct the permanent concrete arch dam in the dry within the space enclosed by the temporary arches.

(f) Construct the spillway sections of the dam located above low-water level on Big Eddy Island and on the Washington shore, leaving until later the section across the diversion channel. The work of placing concrete in these portions of the dam would be in progress while building the dam in the deep river channel. The portion of this spillway which is located on Big Eddy Island would be provided with temporary openings to be used in making final closure of the dam.

(g) Close the diversion channel by means of stop logs between steel guide posts, the posts being supported by a concrete sill at the bottom and a steel bridge at top. After dropping these stop logs the flow would be diverted through temporary openings provided in the spillway section on Big Eddy Island.

(h) Complete the spillway section across the diversion channel.

(i) Effect final closure by dropping concrete gates in front of the temporary openings in the spillway section on Big Eddy Island.

786. The building of a dam in the Columbia River at Big Eddy Island, or at any point in the stretch from foot of Three Mile Rapids to head of Five Mile Rapids, presents a problem involving special and unprecedented difficulties owing to the great depth of water and high velocities. Much study was given this problem in the Columbia River power project investigation (par. 772), and several suggested solutions are outlined in the report. The channel where the arch dam would be built has a maximum depth at low water of 150 feet. Soundings show the drop on north side of channel to be practically vertical, while on the south the slope is irregular, averaging about 1

vertical to 2 horizontal. The most difficult portion of the work would be the building of the two cofferdams in the river channel, between which the permanent arch would be constructed.

787. The plan which seems to offer the best solution for construction of the two temporary arches is here designated the "steel tower method". It was proposed, and the detail procedure worked out, by A. L. Alin, hydraulic engineer, Corps of Engineers, after making a detailed personal investigation of the Sand Island method developed by the engineers of the Southern Pacific Co. in building its Suisun Bay bridge near San Francisco in 1930. It contemplates the use of steel towers erected on rock at the bottom and sides of channel for the support of steel forms, in which the concrete for temporary arches would be placed in monolithic sections.

788. The general procedure in executing this plan would be as follows:

(a) Cut benches in the rock to secure foundations for the towers and cut back the rock walls between benches to a line as nearly vertical as possible. With the experience gained during construction of The Dalles-Celilo Canal, located nearby, no difficulties should be encountered in excavating vertical walls at this point. Deep-water rock excavation methods would be employed. It is realized that this excavation would be very expensive in unit cost, but the quantities to be removed are not great and the whole item is small compared to the total cost of the work.

(b) After the rock has been prepared, lower and erect in place structural-steel towers constructed in sections. It is expected that as much preparatory work on the towers as possible would be performed above water, leaving to the divers only the connecting together of the sections as erected. The temporary arch dam would be built in monoliths, each measuring 30 feet along the axis of the dam and with 25 feet clearance between. Each steel tower would cover one 30-foot monolith. The towers would be provided with guides so that steel forms could be let down to form the upstream, downstream, and radial faces of the arch sector to be built up within the tower.

(c) Divers would clean and inspect the foundation within the tower section.

(d) Tremie concrete would be placed within the tower section. The process of concreting each section would be continuous to an elevation above water line.

(e) After the completion of the tower sections steel forms would be lowered between them in guides provided for that purpose, and the intervening space would be filled with tremie concrete to an elevation above water level as was done for the tower sections.

With completion of the upstream temporary arch dam, the downstream arch would be constructed in a similar manner. Less difficulty should be experienced with the second arch, as the upstream arch would completely shut off the current. With the two temporary dams placed and water pumped out of the enclosed space, the permanent arch dam could be constructed in the approved manner employed for any ordinary dam.

789. Consideration was given to the possibility of using the method proposed for building the arches in building the dam proper and thus effect a considerable saving in cost. Comparative estimates, however, do not show any saving owing largely to the greater volume of tremie concrete. Even if a large expenditure is required, it is considered essential that the final arch dam be built in the dry between two cofferdams so as to insure proper and tight connection with foundation and abutment rock.

790. *Power house and equipment.*—The power house would be located on the Washington shore and parallel to the river, which in this section flows along a nearly straight line for about half a mile. For location see plate 72. The river bank is here almost vertical, and the low-water depth a short distance from the shore is 150 feet or more. The power house would be located as close to river's edge as possible

to avoid excessive tailrace excavation. The length of the power house would be about 2,600 feet.

791. The installation would be 30 units. The turbines would be of two types, 20 reaction wheels rated at 50,000 horsepower at a head of 92 feet and 10 adjustable-blade propeller type rated at 84,000 horsepower at a head of 66 feet. The loss in head at flood stages at this site is unusually large, the gross head being 95 feet at mean low water and only 47 feet for a flow of 800,000 second-feet. The reaction units which at low water would have an output of 37,500 kilowatts would develop only 14,000 kilowatts at 800,000 second-feet flow. Thus, if only reaction units were installed, 54 units would be required in order to carry the peak load at flood stage. For this site it has therefore been found advisable to propose two types of water wheels, reaction and propeller, in order to effect economy. For lower heads propeller wheels produce more power than reaction wheels as they are capable of handling a greater flow of water per unit. For the units proposed for The Dalles development the propeller units would be able to produce about three times as much power as the reaction units at a river flow of 800,000 second-feet. The total installation would carry a peak load of 750,000 kilowatts at 50 percent load factor. If this development is made in advance of one to elevation 54 farther downstream, the firm power due to added head would be increased about 10 percent. The substation equipment would be installed on the roof of the power house.

792. *Navigation locks.*—The navigation locks would be located directly at the head of Three Mile Rapids, the depth and dimensions of chambers being as specified in paragraph 618. The total maximum lift of 95 feet, assuming a development to elevation 54 in vicinity of Cascades Rapids, would be made in two lifts of 47.5 feet each. If The Dalles development precedes any development farther down the river, the greater lift would make necessary the construction of an additional lock.

793. *Fishways.*—The same conditions prevailing at John Day development to elevation 258 would also exist at The Dalles development to elevation 150. (See par. 745.)

794. *General property damage.*—The building of The Dalles Dam to elevation 150 would create a pool having a length of 24 miles, and a surface area of 16,000 acres. The item of cost covering general property damage with crest at elevation 150 would be small, as the river occupies practically the entire space between railroads for much of the distance. The Dalles-Celilo Canal and the buildings belonging to the United States and occupied or used by attendants at the locks would be submerged.

795. *Revision of railroads and highway.*—Construction of a dam at The Dalles site with pool level at elevation 150 would necessitate the revision of 18 miles of railroad, assuming that the profile grade be maintained at an elevation 10 feet above water surface in the pool. A portion of this revision may be accomplished by raising the tracks in place, but the greater part would involve relocation.

796. The revision of the main line of the Union Pacific Railroad would begin at a point about 3 miles west of the dam site and terminate at a point about 2 miles east of Dillon, Oreg., a distance of 10 miles. One summit in this distance reduces the main line track to be revised to a total of 6.2 miles. The maximum change in eleva-

tion of grade would occur at the dam site and would amount to 12 feet.

797. The revision of the tracks of the Spokane, Portland & Seattle Railway Co. would begin at a point about 6 miles west of the dam site and would terminate at a point about 1 mile west of Avery, Wash., a distance of 12 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 29 feet.

798. Revision of 7 miles of the Columbia River Highway would be necessary, assuming that profile grade be maintained at an elevation not less than 10 feet above water surface in the pool. This revision would involve relocation of portions that are below the proposed grade or within the right of way of the proposed Union Pacific tracks. The revision would begin about 2 miles west of the dam site and would terminate at a point about 2 miles east of Dillon, Oreg., a distance of 9 miles. There are no modern highways on the north bank of the Columbia that would be affected by construction of a dam at The Dalles site with pool level at elevation 150.

799. The tabulation below shows the mileage of required revision of railroads and highways.

Railroads and highways	Miles		
	Relocate	Raise	Revise
Union Pacific System: Main line.....	3.0	3.2	6.2
Spokane, Portland & Seattle Ry. Co.: Main line.....	11.3	1.0	12.3
Columbia River Highway.....	7.4	0	7.4
Total.....	21.7	4.2	25.9

800. *General data.*—The principal facts relative to development at The Dalles with pool elevation 150, as in series "A", follow:

Drainage area.....	square miles..	237, 000
Area of pool.....	acres..	16, 000
Length of pool.....	miles..	24
Natural mean low water elevation.....		45
Length of dam (including power-house section).....	feet..	6, 860
Height of dam (maximum section, foundation to walkway):		
River section.....	feet..	260
On shores.....	do..	120
Average static head.....	do..	86. 5
Proposed hydraulic capacity.....	second-feet..	266, 000
Power capacity.....	horsepower..	491, 000
Plant capacity factor.....	percent..	60
Firm power (99.3 percent of time).....	kilowatts..	375, 000
Firm output.....	kilowatt-hours..	3, 285, 000, 000
Secondary power:		
90 percent of time.....	kilowatts..	110, 000
80 percent of time.....	do..	175, 000
70 percent of time.....	do..	255, 000

Head, tailwater and power curves, hydrographs and powergraphs, output in kilowatt-hour for firm, secondary and potential power are shown graphically on plates² 73, 74, and 75.

Cost in mills per kilowatt-hour for load factors from 50 to 100 percent, for 4 and 6 percent money, and for 50 and 100 percent power market factors are shown graphically on plate 95.²

² Not printed.

TABLE 24.—*The Dalles development to elevation 150*

ESTIMATE OF COST	
I. Preliminary expense.....	\$1, 100, 000
II. Railroads, roads, and bridges (for construction purposes only).....	150, 000
III. Reservoir and damages.....	2, 620, 000
IV. Dam and diversion:	
River diversion and pumping.....	\$4, 930, 000
Dam complete.....	6, 150, 000
	11, 080, 000
V. Conduits (including forebay).....	1, 350, 000
VI. Intake and equipment (including gates, racks, cranes, etc.)..	6, 760, 000
VII. Power-house substructure.....	7, 900, 000
VIII. Power-house superstructure.....	3, 700, 000
IX. Hydraulic equipment (including governors and auxiliary equipment).....	11, 250, 000
X. Electrical equipment (including generators and all electrical equipment between generators and low-tension side of transformers).....	13, 500, 000
XI. Power-house cranes and miscellaneous auxiliary equipment..	300, 000
XII. Tailrace.....	2, 200, 000
XIII. Fishways.....	500, 000
XIV. Switching station (structural only).....	1, 200, 000
XV. Operators village and permanent improvements.....	450, 000
XVI. Contingencies, 10 percent.....	6, 410, 000
XVII. Overhead (engineering, supervision, clerical, legal, insurance, etc.), 12½ percent.....	8, 810, 000
XVIII. Interest during construction (3 years to build), 4 percent money.....	4, 760, 000
XIX. Carrying charges, 50 percent power market factor and 4 percent money.....	4, 490, 000
	88, 530, 000
Total estimated cost, chargeable to power.....	88, 530, 000
Cost of navigation locks.....	2, 100, 000

ANNUAL CHARGES

Item	4 percent money	6 percent money
Interest on investment.....	\$3, 541, 200	\$5, 600, 400
Depreciation.....	1, 148, 500	836, 300
Taxes.....		1, 400, 300
Amortization.....	929, 300	
Operating charges.....	600, 000	600, 000
Total.....	6, 219, 000	8, 437, 000

801. The tabulation below shows the cost in mills per kilowatt-hour, dollars per kilowatt-year for power at site, and at Portland, Oreg., for both public and private development, financed with 4 and 6 percent money, respectively, and based on a load factor of 55 percent. Costs were selected from the graphs shown on plate 95.²

Point	Mills per kilowatt-hour 55 percent load factor		Dollars per kilowatt-year 55 percent load factor	
	4 percent money	6 percent money	4 percent money	6 percent money
At site.....	1.80	2.42	\$15.80	\$21.20
At Portland.....	2.17	2.88	19.00	25.20

² Not printed.

802. *b'*. *The Dalles development to elevation 183.*—Between Arlington site and head of pool from The Dalles Dam to elevation 150, there is a drop of 34 feet. Owing to the exceptional advantages afforded for building a dam at the Arlington site, it seemed advisable to give some consideration to developing The Dalles site to 183, and so have a complete series which would include a development at Arlington. This would utilize the entire fall between the mouth of Snake River and tidewater without the necessity of constructing a dam at the John Day site, which would have available at low water a head of but 33 feet as mentioned in paragraph 740.

803. The location of dam, power house, and navigation locks in this development would be the same as already proposed for The Dalles to elevation 150 (par. 782). The river being confined to a rather narrow gorge, the item for general property damage would be small, not greatly exceeding the estimate for development to elevation 150. The damage to railways and highways, however, would become much greater.

804. *Revisions of railroads and highways.*—Construction of a dam at The Dalles site with pool level at elevation 183 would necessitate the revision of 74 to 83 miles of railroad, assuming that profile grade be maintained at an elevation 10 feet above water surface in the pool. A portion of this revision may be accomplished by raising the tracks in place, but a portion will involve relocation.

805. Two alternates have been considered for the revision of the Union Pacific Railroad:

A. Revision would begin at a point about one quarter mile west of the dam site. The principal feature would be a double track, concrete lined tunnel 3.2 miles long, the first 2.5 miles ascending eastward on a grade of 0.4 percent. About 2 miles of this portion would lie from about 35 to 0 feet below pool level. However, with tunnel located at some distance from margin of pool and with care taken to secure a tight lining and to provide adequate drains it is not believed that any particular trouble would be experienced from water. The revision would terminate at a point about 2 miles east of Hook, Oreg., a distance of 33 miles. The maximum change in elevation of grade would occur about 2 miles east of the dam site and would amount to 35 feet. Revisions on branch lines of this company would add 3.4 miles, bringing the total of Union Pacific line to be revised to approximately 36 miles.

B. Revision would begin at a point about 4 miles west of the dam site, ascending eastward on the high ground to the west of the existing line through The Dalles, Oreg., on a grade of 0.4 percent to the dam site, and would terminate at a point about 2 miles east of Hook, Oreg., a distance of 38 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 47 feet. Revisions on branch lines of this company would add 3.4 miles, bringing the total of Union Pacific line to be revised to approximately 41 miles.

806. Revision of the Great Southern Railroad, a short line extending south from The Dalles, would begin at The Dalles, Oreg., and would terminate at a point about 4 miles east of The Dalles.

807. Revision of the Spokane, Portland & Seattle Railway would begin at a point about 11 miles west of the dam site and would terminate at a point about 3 miles west of Towal, Wash., a distance of 37 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 63 feet. Revisions on branch lines of this company would add 1 mile, bringing the total of Spokane, Portland & Seattle line to be revised to approximately 38 miles.

808. Revision of 12 miles of the Columbia River Highway would be necessary, assuming that profile grade be maintained at an elevation not less than 10 feet above water surface in the pool. This revision

would involve relocation of portions that are below the proposed grade or within the right-of-way of the proposed Union Pacific tracks. The revision would begin at a point about one quarter mile west of the dam site and terminate at Sherman, Oreg., a distance of 14 miles. There are no modern highways on the north bank of Columbia River that would be affected by construction of a dam at The Dalles site with pool level at elevation 183.

809. The tabulation below shows the mileage of required revision of railroads and highways:

ALTERNATE A

Railroads and highways	Miles		
	Relocate	Raise	Revise
Union Pacific System:			
Main line.....	29.0	3.9	32.9
Branch line.....	3.4	.0	3.4
Spokane, Portland & Seattle Ry. Co.:			
Main line.....	36.0	1.0	37.0
Branch line.....	1.0	.0	1.0
Columbia River Highway.....	12.0	.0	12.0
Total.....	81.4	4.9	86.3

ALTERNATE B

Railroads and highways	Miles		
	Relocate	Raise	Revise
Union Pacific System:			
Main line.....	33.7	3.9	37.6
Branch line.....	3.4	.0	3.4
Great Southern R. R. Co., main line.....	3.7	.0	3.7
Spokane, Portland & Seattle Ry. Co.:			
Main line.....	36.0	1.0	37.0
Branch line.....	1.0	.0	1.0
Columbia River Highway.....	12.0	.0	12.0
Total.....	89.8	4.9	94.7

810. *General data.*—The principal facts relative to development at The Dalles with pool elevation 183, as in series B, follow:

Drainage area.....	square miles	237,000
Area of pool.....	acres	23,000
Length of pool.....	miles	51.0
Natural mean low water elevation.....		45
Length of dam (including power-house section).....	feet	8,600
Height of dam (maximum section, foundation to walkway).....	do	293
Maximum effective head.....	do	128
Minimum effective head (at record flood).....	do	65
Firm power (99.3 percent of time).....	kilowatts	500,000
Power output.....	kilowatt-hours	4,380,000,000
Construction cost, including carrying charges, and based on 50 percent load factor and 4 percent money.....		\$115,880,000

Cost in mills per kilowatt-hour for load factors from 50 to 100 percent for 4 and 6 percent money, and for 50 and 100 percent power market factors are shown graphically on plate 96.²

811. *c'. The Dalles development to elevation 330.*—This development which proposes to raise the water level to elevation 330 has the same

² Not printed.

location as The Dalles project with head water elevation 150, described in paragraph 782. The plan of development is shown on plate 76.

812. The project raising the headwater to elevation 150 connects to the higher ground just north of the present Spokane, Portland & Seattle Railway Co. at Three Mile Rapids. The higher head project, however, requires closing of the low gap at a general elevation of slightly above elevation 200, which extends north of Three Mile Rapids for a distance of about $2\frac{1}{2}$ miles.

813. *Dam.*—The maximum height of the dam would be 440 feet for a distance of less than 100 feet in the deep river channel between Big Eddy Island and the Oregon shore. At the deepest point the base width of the dam would be about 380 feet, the dam being of the straight gravity type. The schedule for diversion and unwatering in this alternate scheme would be the same as described for the dam to elevation 150, paragraph 785, but the temporary arch cofferdams would have to be located farther apart because of greater base width of the main dam. This would mean somewhat longer spans and consequently a greater yardage to be placed by the tremic method for the cofferdams than was estimated for the low-head project.

814. Starting at the 340 contour on the Oregon side, a dam of the nonoverflow, straight gravity type would be constructed across the main river channel, over Big Eddy Island to connect with powerhouse section on Washington shore. The total length of this section would be about 2,700 feet with a maximum height of about 440 feet in the deep channel and less than 300 feet on the shores. The power house, about 2,800 feet in length, would be located parallel to the stream on the Washington shore starting upstream at a point close to Big Eddy Island. The intake to the water wheels would form a part of the dam, which would be designed as a straight gravity structure, averaging 225 feet in height with intake provisions and penstocks incorporated. The power house would be located at the toe of this dam and the substructure built as an integral part of the dam.

815. From the lower end of the power house, a straight gravity dam about 240 feet in height and 2,200 feet in length would be built to the foot of the higher ground north of the present Spokane, Portland & Seattle Railway. At the end of this gravity wall a multiple-arch dam, less than 100 feet in height, would be built for a distance of about 5,200 feet in a westerly direction.

816. At the end of the multiple-arch dam section and the beginning of the spillway section, the axis of the dam would make a nearly 90-degree bend, the axis now pointing almost true north and toward the high hills on the Washington side. The spillway is designed as an overflow gravity dam with spillway crest at elevation 300. This section would be 2,500 feet in length. The regulation of the flow would be effected by 17 roller gates, 130 feet long by 30 feet in vertical height, separated by piers 16 feet thick. A concrete apron would protect the foundation below the spillway from erosion and dissipate the energy of the water going over the dam. It will be noted that 17 roller gates 130 by 30 feet are proposed for this development, whereas in the other proposed developments 15 similar gates are estimated. Fifteen gates would cause a rise in the pool level of about 3 feet for a flow of 1,400,000 second-feet. With 17 gates the pool level would remain at elevation 330 for the same flow. The greater

number of gates is used for the reason that with the long pool in this development backwater might cause some damage in the upper reaches if the pool level at the dam should be allowed to rise.

817. The dam as described would be founded entirely on basaltic rock, which is exposed for the full length of the dam, with a very few and short exceptions.

818. From the end of the spillway, however, and to the connection with the high hills, a distance of about 4,700 feet, there are three stretches of considerable length, which total 2,600 feet, where the rock is not exposed and where considerable overburden overlies the bedrock. One drill hole put down in this overburden struck rock at depth of 109 feet. To found a masonry dam on bedrock at this point would involve a large expenditure. The average level of this stretch of the dam site would be about 50 or 60 feet below the controlled water level of 330. An earth embankment 4,700 feet long, with concrete core wall to bedrock has been designed for this section.

819. The flood water discharged over the spillway would empty into the Columbia at a point downstream from The Dalles. By locating the spillway as proposed, the flood water would pass around the power house and get back to the river below Three Mile Rapids thus avoiding the rise in river levels at flood stage caused by the restriction in the channel at these rapids. A higher head for the water wheels at the plant would thus be realized than if the spillway had been located between Big Eddy and Three Mile Rapids. Plan and details of the dam are shown on plates 76, 77, and 78.

820. *Power house and equipment.*—The power house, located parallel to the river channel on the Washington shore, as shown on plate 76, would be about 2,800 feet long. The firm power based on a discharge of 70,000 second-feet, made possible by utilizing storage, would total 1,450,000 kilowatts. There would be installed 38 units, rated at 100,000 kilowatts at a head of 270 feet. This installation would carry a peak load of 2,900,000 kilowatts at 50-percent load factor. The turbines would be of the vertical reaction type. Steel scroll cases and butterfly valves are included in the cost of the hydraulic equipment for this project. A section of the power house is shown on plate 78.

821. The substation equipment would be located on the roof of the power house.

822. *Navigation locks.*—Navigation in this project would be provided by construction of a flight of six locks from below Three Mile Rapids, connecting with the dam in the multiple-arch section some distance west of present Spokane, Portland & Seattle Railway.

823. *Fishways.*—The ordinary type of fish ladder would not be practicable for this project on account of the high head, 280 feet. Should this project be constructed, some other means of conveying the salmon from lower to upper pool acceptable to United States Bureau of Fisheries must be worked out. A lump sum has been included in the estimate to care for interests to fishing.

824. *General property damage.*—The pool created by The Dalles Dam to elevation 330 would have a length of 147 miles and a surface area of 140,000 acres. The item for general property damage would not greatly exceed that for John Day site to same elevation (par. 754). The item covering railroad and highway revision, however, would be much greater.

825. *Revision of railroads and highways.*—Construction of a dam at The Dalles site with pool level at elevation 330 would necessitate the revision of 323 miles of railroad, assuming that profile grade be maintained at an elevation of 10 feet above water surface in the pool.

826. Revision of the tracks of the Union Pacific Railroad Co. would begin at a point about 9 miles west of the dam site and terminate at a point about 1 mile west of Attalia, Wash., a distance of 133 miles. Two summits in this distance would reduce the main-line track to be revised to a total of 123 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 192 feet. Revisions on branch lines of this company would add 21 miles, bringing the total of Union Pacific line to be revised to approximately 144 miles.

827. On the Great Southern Railroad approximately 9 miles of track immediately east of The Dalles, Oreg., would require revision, while on the Washington, Columbia River, and Pendleton branches of the Northern Pacific Railroad Co. 3.4 miles of track immediately north of Wallula, Wash., would require revision.

828. Revision of the tracks of the Spokane, Portland & Seattle Railway Co. would begin at a point about 25 miles west of the dam site and terminate at a point near Hover, Wash., a distance of 148 miles. The maximum change in elevation of grade would occur at the dam site and would amount to 208 feet. Revisions on branch lines of this company would add 19 miles, bringing the total of Spokane, Portland & Seattle Railway Co.'s line to be revised to approximately 167 miles.

829. Revision of 103 miles of highway would be necessary, assuming that profile grade be maintained at an elevation not less than 10 feet above water surface in the pool. This revision would involve relocation of portions that are below the proposed grade or within the proposed right of way of the Union Pacific tracks. Revision of the Columbia River Highway would begin about 1 mile west of the dam site and terminate about 2 miles east of Umatilla, Oreg., a distance of 100 miles. The Inland Empire Highway would require revision, beginning at Wallula, Wash., and terminating at Attalia, Wash., a distance of 3 miles. There are no modern highways on the north bank of Columbia River that would be affected by construction of a dam at The Dalles site with pool level at elevation 330.

830. The tabulation below shows the mileage of required revision of railroads and highways.

Railroads and highways	Miles		
	Relocate	Raise	Revise
Union Pacific system:			
Main line.....	122.0	1.0	123.0
Branch line.....	11.7	9.3	21.0
Great Southern R.R. Co., main line.....	9.0	0	9.0
Northern Pacific R.R. Co., branch line.....	0	3.4	3.4
Spokane, Portland & Seattle Ry. Co.:			
Main line.....	146.2	1.8	148.0
Branch line.....	19.0	0	19.0
Columbia River Highway.....	100.0	0	100.0
Inland Empire Highway.....	3.1	0	3.1
Total.....	411.0	15.5	426.5

831. *General data.*—The principal facts relative to development at The Dalles with pool elevation 330 follow:

Drainage area.....	Square miles.....	237, 000
Area of pool.....	acres.....	140, 000
Length of pool.....	miles.....	147
Maximum drawdown.....	feet.....	40
Storage available (upper 40 feet of reservoir).....	acre-feet.....	4, 625, 000
Natural mean low-water elevation.....		45
Length of dam.....	feet.....	20, 000
Height of dam (maximum section, foundation to walkway):		
In deepest river channel.....	do.....	440
On shores.....	do.....	260
Average static head.....	do.....	266
Proposed hydraulic capacity.....	second-feet.....	189, 600
Power capacity.....	horsepower.....	1, 504, 500
Plant capacity factor.....	percent.....	69
Firm power (99.3 percent of time).....	kilowatts.....	1, 450, 000
Firm output.....	kilowatt-hours.....	12, 702, 000, 000
Secondary power:		
90 percent of time.....	kilowatts.....	20, 000
80 percent of time.....	do.....	170, 000
70 percent of time.....	do.....	410, 000

Head, tailwater, and power curves, hydrographs, and powergraphs, output in kilowatt-hours for firm, secondary, and potential power are shown graphically on plates² 79, 80, and 81.

Cost in mills per kilowatt-hour for load factors from 50 to 100 percent, for 4 and 6 percent money, and for 50 and 100 percent power-market factors are shown graphically on plate 98.

TABLE 25.—*The Dalles development to elevation 330*

ESTIMATE OF COST		
I. Preliminary expense.....		\$1, 800, 000
II. Railroads, roads, and bridges (for construction purposes only).....		200, 000
III. Reservoir and damages.....		71, 300, 000
IV. Dam and diversion:		
River diversion and pumping.....	\$5, 550, 000	
Dam complete.....	60, 450, 000	
		66, 000, 000
V. Conduits, including forebay.....		
VI. Intake and equipment, including gates, racks, cranes, etc.....		8, 100, 000
VII. Power house substructure.....		6, 700, 000
VIII. Power house superstructure.....		5, 140, 000
IX. Hydraulic equipment, including governors and auxiliary equipment.....		19, 190, 000
X. Electrical equipment, including generators and all electrical equipment between generators and low-tension side of transformers.....		19, 000, 000
XI. Power-house cranes and miscellaneous auxiliary equipment.....		300, 000
XII. Tailrace.....		1, 000, 000
XIII. Fishways.....		500, 000
XIV. Switching station (structural only).....		1, 520, 000
XV. Operators, village and permanent improvements.....		570, 000
XVI. Contingencies, 10 percent.....		20, 132, 000
XVII. Overhead (engineering, supervision, clerical, legal, insurance, etc.).....		27, 678, 000
XVIII. Interest during construction (5 years to build), 4 percent money.....		24, 910, 000
XIX. Carrying charges, 50 percent power-market factor and 4 percent money.....		70, 460, 000
Total estimated cost, chargeable to power.....		344, 500, 000
Cost of navigation locks.....		11, 500, 000

² Not printed.

Annual charges

Item	4 percent money	6 percent money
Interest on investment.....	\$13,780,000	\$23,820,000
Depreciation.....	1,596,000	1,150,000
Taxes.....		5,955,000
Amortization.....	3,618,000	
Operating charges.....	760,000	760,000
Total.....	19,724,000	31,665,000

832. The tabulation below shows the cost in mills per kilowatt-hour, dollars per kilowatt-year for power at site, and at Portland, Oreg., for both public and private development, financed with 4 and 6 percent money, respectively, and based on a load factor of 55 percent. Costs were selected from the graphs shown on plate 98.²

Point	Mills per kilowatt-hour (55 percent load factor)		Dollars per kilowatt-year (55 percent load factor)	
	4 percent money	6 percent money	4 percent money	6 percent money
At site.....	1.51	2.44	\$13.20	\$21.40
At Portland.....	1.88	2.90	16.50	25.40

(D) SECTION 3. THE DALLES TO WARRENDALE

833. The Dalles, 188.5 miles from mouth of the Columbia, and Warrendale, Oreg., at head of tidal reach, 140 miles from the sea, mark the upper and lower limits of The Dalles-Warrendale section of the river.

834. This section may be considered as being divided into two parts, the flat portion, which extends from foot of Three Mile Rapids to head of Cascades Rapids, a distance of 43.0 miles, and the steep portion, extending from head of Cascades Rapids to Warrendale, a distance of 7 miles.

835. The upper 43.0 miles is virtually a pool produced by the obstruction forming a natural dam at Cascades Rapids. At extreme low water the river falls in this stretch from elevation 41.5 to elevation 37.5, or 4.0 feet; at mean low water, 60,000 second-feet, it falls from elevation 45 to elevation 41, or 4 feet; and at record flood, 1,170,000 second-feet, from elevation 106.5 to elevation 92.5, or 14 feet. Consideration has been given to the construction of a dam at some favorable point in this stretch.

836. *a. Wind Mountain development to elevation 330—Geology.*—Wind Mountain rises to elevation 1,910 on the Washington shore, at a point 33.5 miles downstream from The Dalles and 155 miles from the mouth of the Columbia. Shell Rock Mountain rises also from water edge nearly opposite on the Oregon shore to elevation 2,068. These two mountains are composed of rock distinct in character from the lava flows and related volcanics by which they are surrounded. This rock is of light gray color, massive in structure, and designated as granodiorite porphyry. It is believed that the two mountains

² Not printed.

are parts of one intrusive mass, and that with the same foundation rock connecting across between them in the bed of the river, they constitute a location superior to any to be found in the lava formation prevailing at all other dam sites so far discussed. Owing to the virtual continuity of the rock in the vertical, as well as horizontal, direction, with no persistent structure lines or surfaces of separation, the possibility of loss of water by percolation should be much less than for the typical basalt formation made up of many flows with frequently pervious materials along the contact zones. Its strength is abundantly ample, and the site considered in all respects as adequate to support a dam equal to any yet built, contemplated, or in course of construction.

837. *Plan for development.*—The dam proposed for Wind Mountain site would be a concrete, gravity type, overfall structure, subject at low water to a static head of about 290 feet and having a maximum height of about 350 feet, assuming bedrock to be found at or near river bottom. The river at narrowest point between the two mountains has a width of about 1,500 feet. However, to provide space for the overflow section of the dam, it is necessary to have a spillway approximately 3,500 feet in length. This would be obtained by setting it at an approximate angle of 45° with the course of the channel. An extended apron would be required to dissipate the energy of the falling water and to protect the river bottom from destructive erosion. A map of this site is shown on plate 82.²

838. *Damage to property.*—A dam to elevation 330 at Wind Mountain would create a pool having a length of 184 miles and a water surface of 172,000 acres. It would submerge portions of Hood River and The Dalles, Oreg., a portion of White Salmon, Wash., and would entirely submerge Lyle, Wash., and several smaller towns. It would necessitate the revising of 70 miles more of main line railroad, 35 miles on south and 35 miles on north bank, than would be required for construction of a dam to the same height at The Dalles. As the relocated railroads would extend along steep or precipitous mountain sides, requiring much tunneling and many viaducts, the cost of reconstruction would involve a very large sum. The highways would not require complete reconstruction because at points they are now located above elevation 330. However, to rebuild the portions that would be submerged would be expensive.

839. *Power output.*—An approximate 40-foot draw-down of the reservoir would make available 5,000,000 acre-feet storage. This would yield a total firm power output of 1,550,000 kilowatts.

840. The power developed at Wind Mountain site would be but little greater than at The Dalles with a dam to same elevation; the property damage would be many millions of dollars greater. For these reasons detailed studies and estimates of cost for Wind Mountain site have not been made.

841. *b. Cascades Rapids to Warrendale—General.*—At Cascades Rapids, 147 miles from its mouth, the Columbia cuts through the axis of the Cascade Range. From the foot of these rapids for a distance of about 7 miles the river flows through a gorge. Warrendale, Oreg., and Beacon Rock, rising to a height of 800 feet at water's edge on Washington shore, mark the foot of this gorge and also the head of

² Not printed.

tidal influence on the Columbia at time of low water. A map of this section of the river is shown on plate 83.

842. *Natural fall.*—The Columbia drops at Cascades Rapids from elevation 41 to elevation 16, or 25 feet in a short distance at mean low water, 60,000 second-feet. In the next 7 miles through the gorge, from foot of the rapids to the head of tidal reach at Warrendale, there is an additional fall of 12 feet, making a total of 37 feet. The river, as the discharge increases, rises more slowly at the head of the steep rapids than in the contracted gorge immediately below, with the result that the concentrated fall decreases until, for discharge of 800,000 second-feet, it amounts to but 14 feet. Though the river thus rises more slowly at the head of Cascades Rapids than at their foot, it nevertheless, for extreme floods, rises more rapidly at Cascades Rapids than at the lower end of the gorge, 7 miles away. As a consequence the total fall between the head of the rapids and Warrendale increases from about 37 feet at mean low water to a maximum of about 45.5 feet at peak of record flood. The tabulation below gives the concentrated fall in main rapids and total fall through site for various stream flows:

Stream flow in second-feet	Concentrated fall in main rapids in feet	Total fall through rapids and gorge
50,000.....	24.5	37.5
200,000.....	20	38.0
500,000.....	14.5	37.5
800,000.....	14	40.0
1,200,000.....	12	45.5

843. *Natural flow.*—For discharge relations in this section of Columbia River see paragraph 570.

844. *Geologic formation.*—In contrast with conditions at the sites investigated farther upstream, good foundation rock is not in evidence at the Cascades Rapids site. The prevailing country rock in much of eastern Oregon and eastern Washington in the region through which Columbia River flows is a volcanic lava designated as Columbia River basalt. This formation is exposed along the banks and in the bed of the Columbia for much of the distance between the mouth of the Snake and a point a few miles upstream from Cascades Rapids. Here the underlying Eagle Creek formation appears from under the basalts and rises westward beneath the latter into a broad rather flat arch, with summit seen distinctly on the Oregon side, into the center or axis of the Cascade range almost directly opposite Cascades Rapids. From this summit the entire rock structure of the range drops in the downstream direction, so that the base of the Columbia River basalt, hence the top of the underlying Eagle Creek formation, passes below river level again at a point about 4 miles to west of Warrendale, Oreg.

845. The contact of the basalt upon the underlying beds may be observed in stream gulches and at many other points along the abrupt mountain slopes on both Oregon and Washington sides of river. It rises on the Oregon side to about elevation 700 and on the Washington side to 2,400 feet. The difference in elevation of its

position on the two sides indicates that the actual inclination or pitch is crosswise of the channel at this place. The Eagle Creek formation consists of irregularly arranged bouldery agglomerate, cemented gravels, soft sandstones, tuffs, volcanic ash and ashy shales, and some hard lava. It is so named because of the typical exposure of these beds in the canyon of Eagle Creek, which enters the Columbia from the Oregon side 2 miles below Cascades Rapids. The foundation bed-rock at Cascades Rapids site, so far as now known, consists of the fragmental phases of this formation.

846. *The great slide.*—About 2 miles below Stevenson, Wash., the Columbia River makes a sharp bend to the south as it enters the funnel-like contraction of its channel at the head of Cascades Rapids. This abrupt change in course is generally considered to have been caused by a great landslide, or series of slides from the north, which forced the river out of its former bed and caused it to form a new channel down the present slope of Cascades Rapids. There has been some discussion as to whether the obstruction which produces the present rapids is caused by material brought down in the slide or is Eagle Creek formation in place. The test borings put down on the north shore and on the two islands above the brink of the main rapids show overburden to a great depth, though there is not as yet positive evidence that the backbone of the obstruction over which the water tumbles is not some part of the undisturbed Eagle Creek beds.

847. That a great landslide, or series of slides, of sufficient suddenness and volume to interfere with the flow of the river occurred here in a comparatively recent period, geologically speaking, is the opinion of all competent observers. Evidence of such an occurrence is seen in the abrupt slopes of Table Mountain and of Red Bluff which rise to upward of 3,000 feet some 3 miles to the northwest; in the successive waves of disheveled rock materials and the numerous small lakes which occupy the space from these precipitous mountain walls to the river; in the pool which, at low water, extends upstream from head of the rapids almost to The Dalles, a distance of 40 miles; in the stumps of trees along the river at several points above the Cascades Rapids with roots below present water level; and in the sluggish current of Klickitat River which enters the Columbia from the Washington side, some 32 miles upstream. These features indicate a ponding of the waters of the Columbia.

848. *a'. Earlier investigations.*—Much interest has centered about the possibility of developing power in the 7-mile stretch of swift water between the head of Cascades Rapids and Warrendale. The latter is only 30 miles in an air line from both Portland, Oreg., and Vancouver, Wash. Three plans of development have been proposed by earlier investigators. These will be briefly reviewed.

A preliminary investigation looking to the development of power in the Cascades Rapids-Warrendale stretch was made by the State of Oregon and the results set forth in a publication from the office of the State engineer under date of 1916, entitled "Oregon's Opportunity in National Preparedness." The plan proposed a dam in Columbia River below Cascades Rapids with crest at elevation 50 at a point about 2,000 feet upstream from foot of Bradford Island and a canal down the Oregon shore to a power house to be located a short distance below Bonneville station on Union Pacific Railroad. The pool created by the dam would submerge the rapids and the head would vary from approximately 45 feet at mean low water to about 38 feet at time of record flood. No test boring was done and the report was based principally on an office study.

A plan and preliminary estimate of cost of building a dam, power plant, and navigation locks at Warrendale is given in a report by the district engineer, Corps of Engineers, Portland, entitled "Survey of Columbia River, The Dalles to Vancouver, Wash.," dated November 29, 1922 (unpublished). The dam as proposed in that report would have its crest at elevation 50, and give a head of about 46 feet at low water.

An application was filed in 1927 with the Federal Power Commission for a preliminary permit to construct a dam and power plant at Cascades Rapids. It was proposed to construct at head of the rapids a dam with crest at elevation 60 and a short head race, or forebay pond, extending down the Oregon shore to a power house to be located with downstream end at foot of present navigation canal. As no provision was included for investigating the possibility of utilizing the head in the gorge below the rapids, the application was denied.

849. *b'. Present investigation.*—In the course of the present investigation several plans have been considered for developing power at Cascades Rapids-Warrendale site. Four of these will be outlined here. They are:

1. Cascades Rapids plan.
2. North shore plan.
3. Bonneville plan.
4. Warrendale plan.

850. *a''. Cascades Rapids plan—Location.*—This plan proposes the building of a dam at the head of Cascades Rapids and a canal on south bank from the dam to a power house to be located at the foot of the present navigation canal which would be left intact. (See pl. 83.) An alternate to this plan would be that of excavating the canal from north end of the dam down Washington shore to a power house to be located below the present highway bridge known as The Bridge of the Gods. The great depth of material to be removed, together with the possibility of this excavation starting slides of objectionable magnitude, leads to the conclusion that the Oregon side of the river offers the least objectionable location.

851. *Test borings.*—Test borings were put down by the Corps of Engineers on Oregon shore at Cascades Rapids in 1882-83 preparatory to constructing the present navigation canal; by the Portland Electric Power Co., now the Portland General Electric Co., on the Washington shore in 1929; and by the Corps of Engineers as a part of the present investigation on the south shore and on two of the islands at head of rapids in 1930. The nature of the material penetrated in making these borings is shown on plate 84. The information gained by the drillings may be summed up by stating that Eagle Creek formation in the form of ashy shale, sandstone, tuff, or harder material was found at or near ground surface on the Oregon shore, but under an overburden of sand, clay, gravel, boulders, and broken-up material to a depth of 70 to 150 feet or more on the islands and on Washington side. One of the engineers who was on the construction of Cascades Canal states that the material excavated had to be blasted and came out as rock, but that under the action of sun, air, and rain it slacked so that "gardens could be grown on it in a few years." Water pressure tests made in two of the holes put down in 1930 indicate that the Eagle Creek formation encountered is not impervious, but conclusions as to general permeability cannot well be drawn from tests on so small a number of holes.

852. *Factors limiting head.*—The head obtainable would depend on the height to which it may seem feasible or practicable to build the dam. As the natural pool above Cascades Rapids at low water now

extends with very slight slope to the foot of The Dalles-Celilo site, 45 miles upstream, any dam at the rapids will reduce the low-water head at The Dalles site by virtually the amount it increases the natural head at Cascades Rapids; a fact to be taken into account in planning a comprehensive development of both sites. Consideration was given to a dam with crest at elevation 54, 60, and 72 feet. The resulting heads at Cascades Rapids for various river discharges are shown in the tabulation below.

River discharge in second-feet	Head in feet for dam with pool elevation--		
	54	60	72
50,000.....	40.0	46.0	58.0
200,000.....	22.0	28.0	40.0
500,000.....	14.5	14.5	21.0
800,000.....	14.0	14.0	14.0
1,200,000.....	14.0	14.0	14.0

853. At the Cascades Rapids gage a water surface elevation of 54, under present conditions, corresponds to a discharge of 250,000 second-feet; elevation 60 to a discharge of 360,000 second-feet; and elevation 72 to a discharge of 660,000 second-feet. The lowest flood discharge in the 52-year period, 1878 to 1929, is 269,000 second-feet, this being the only flood peak less than 300,000 second-feet in the same period; a flood peak of 660,000 second-feet or more has occurred during 20 of the 52 years of record. Since elevation 72 seems to be the upper limit of allowable interference with The Dalles site above, as well as the upper limit of the lands which, because of frequent natural flooding, may be purchased from owners at reasonable cost, it is taken as the crest elevation of proposed dam at Cascades Rapids.

854. *Dam.*—The dam, as proposed, would extend northerly in a straight line from a point on the Oregon shore near upper end of present navigation canal and, rounding the head of the rapids, resume a straight line to a connection with the Washington shore some 3,000 feet upstream from the highway bridge known as the Bridge of the Gods. Its total length would be about 2,600 feet.

855. At the end adjoining the Oregon shore there would be a gate section somewhat over 1,600 feet long containing 11 roller gates, each 130 feet long in the clear and 28 feet high. The gates would be separated by piers 16 feet thick and of a height sufficient to allow proper clearance in full raised position at elevation 95, and also to support the operating bridge with roadway at elevation 105. The top of the gates, in closed position, would be at elevation 72; the crest of the weir at elevation 44.

856. From the northerly end of the gate section an open high-water spillway 750 feet in length and with crest at elevation 75 would extend to a bulkhead or nonoverflow section making connection with the Washington shore. The gates and spillway together would pass a flood equal in magnitude to the record flood of 1894 without raising the water surface above the elevation attained at that time.

857. The depth and the uncertain character of Eagle Creek formation make it advisable to design a prospective dam for this location as a "floating weir." The principle, as applied to the design of this