

Basin Commission's report of 1920. Subsequent to the 1920 report, 14 test holes were drilled to bedrock at the Grand Coulee site. Based on these data, the Goethals report presented estimated costs of dams of three different heights. The cost of the highest dam, which corresponds to the low dam as proposed elsewhere in this report, was given as \$65,260,305 including contingencies.

604. *f. Board of Engineers Report.*—A board of engineers composed of A. J. Wiley, James Munn, and J. L. Savage under date of April 6, 1924, made a review of the above reports for the United States Reclamation Service. No new data were presented, but the Gault report was endorsed.

605. *g. Columbia Basin Board of Engineers Report.*—A board of engineers, composed of Louis C. Hill, Joseph Jacobs, Charles H. Locher, Richard R. Lyman, Arthur J. Turner, and O. L. Waller made a report to the United States Bureau of Reclamation under date of February 21, 1925. The report alluded to power development at the Grand Coulee site only in general. The estimated cost of the dam as outlined in the Gault report was reduced to \$73,923,000.

(C) FOSTER CREEK

1. DETAILED DESCRIPTION

606. This site is located in sec. 19, T. 29 N., R. 26 E., and sec. 24, T. 29 N., R. 25 E. W.M. It is about 3 miles east of the town of Bridgeport and about 50 miles northeast of the city of Wenatchee. The site is 204 miles by river from the international boundary, 53 miles below the Grand Coulee site, 41 miles above the Chelan site, and 221 miles above the mouth of the Snake River. The proposed location of the dam is 6,000 feet above the mouth of Foster Creek. The general location is shown on plate no. 1, page 565.

a. Résumé.—

Drainage area.....	square miles..	75,000
Length of pool.....	miles.....	51
Length of dam.....	feet.....	2,000
Height of dam (maximum section, foundation to walkway).....	do.....	225
Draw-down (elevation 928.6 to 923.6 feet).....	do.....	5
Useful pondage.....	acre-feet.....	36,000
Natural low-water elevation.....	feet.....	765
Maximum known discharge (June 1894).....	second-feet.....	725,000
Spillway capacity.....	do.....	910,000
Natural river flow (April 1913 to March 1931, inclusive):		
Maximum discharge, 24 hours.....	do.....	492,000
Mean discharge.....	do.....	109,000
Minimum discharge, 24 hours.....	do.....	17,000
Average static head.....	feet.....	154.9
Power capacity (Federal Power Commission definition)		
	horsepower..	352,000
Proposed hydraulic capacity.....	second-feet..	77,000
Proposed installed capacity (case 6).....	kilowatts..	691,200

607. *b. Topography and geology.*—For 8 miles above the dam site the stream flows southwest in a straight narrow channel with a fall of 4 feet per mile. At the site the stream flows west at the southern extremity of a bend which turns to the northwest. The natural low-water elevation at the site of the power house is 765 feet with a width of 500 to 600 feet. See plate no. 61.² The south (left) bank is fairly flat and irregular, and is composed of solid granite bedrock with little overburden. The same formation apparently extends

² Not printed.

across the bed of the stream. The north (right) bank rises about 250 feet above the water on a steep slope to a comparatively level bench. Six drill holes were put down at or near the site to explore subsurface conditions. See plate no. 61² for the location and record of these holes. Henry Landes, dean of the college of science and professor of geology and mineralogy of the University of Washington, describes the north bank as follows:

The overburden above the granite, in holes 1, 6, and 8, as indicated by the drill logs, is composed of a heterogeneous mixture of boulders, gravel, and sand. Mixed with these materials, there is no doubt a considerable percentage of clay, as is clearly shown along the lower face of the terrace. The whole aggregate would be classified as a till or boulder clay, of glacial origin. * * * The glacial material contains a sufficiently large amount of clay to insure the closing of the voids, thereby preventing water percolation.

608. The test holes show that the granite bedrock extends horizontally beneath the bank at an average elevation of 755 feet. It outcrops about three quarters of a mile north of the river at elevation 1,100 feet. This is the southern boundary of the great Colville batholith which is estimated by geologists as covering an area of 1,700 square miles.

609. During the preliminary investigation of the Columbia River, a site known as the "Gaviota Dam site" was investigated. It is located 190 miles by river from the international boundary, 39 miles below the Grand Coulee site, and 14 miles above the Foster Creek site. A topographic survey of the site was made. See plate no. 62.² The natural low-water elevation is 841 feet. No test borings or other subsurface investigations were made. Granite outcrops along the south bank and shows at several points in the stream bed. To the north the granite outcrop is roughly 3,500 feet back from the water's edge at an elevation of 1,300 feet. The intervening overburden is designated as clay and gravel of unknown depth. A plant could be developed at this site with a maximum head of 90 feet, leaving an available head of about 74 feet at the Foster Creek site. However, it was deemed more economical to develop all of this head at the Foster Creek site and accordingly further consideration of the Gaviota site was abandoned.

610. *c. Power possibilities.*—The mean monthly discharge of both the natural and regulated flows for the 18-year period, April 1913 to March 1931, inclusive, are shown in tables nos. 23 and 47. The proposed elevation of the forebay is 928.6 feet, which is 4 feet below the natural low-water elevation at the Grand Coulee site. A 5-foot draw-down with a resulting pondage of 36,000 acre-feet is considered sufficient to provide for daily variation of load. The maximum head at the site would be 164 feet, and the mean static head 154.9 feet. The head available for the maximum flow month of record (436,000 second-feet) would be 132.4 feet, and for a discharge of 910,000 second-feet it would be 115 feet. Hence, the turbines would not be "drowned out" during any floods. In the study of the power possibilities of this site, no allowance was made for loss of head in the power canal.

611. Plate no. 63² contains 27 power graphs showing the available power for the high, mean, and low years of the 17-year period ended March 31, 1930, for the three installed capacities of natural flow, case

² Not printed.

1 of table 122, and of flows regulated by means of upstream storage for cases 2 and 6 of table 122, draw-down was considered in the Foster Creek Reservoir in the preparation of these graphs. The three hydraulic capacities considered on plate no. 63² are equal to the natural flow for 35, 50, and 90 percent of the time, respectively. These three capacities were selected arbitrarily to study the power possibilities of the site and are not to be confused with the plant capacity as set up in the résumé and hereafter in this report. It so happens that the intermediate capacity of 707,000 kilowatts closely approximates the capacity set up in the résumé. The tables directly under the graphs also show the utilization and plant capacity factors for 100 percent operation. Plate no. 64² shows the annual utilization and plant capacity factors graphically.

612. By comparison of graphs 2, 11, and 20 on plate 63² it is noted that regulation increases the annual utilization factor from 58 percent, to 71 percent and to 68 percent, respectively, for the pumping and gravity plans for the low year with a hydraulic capacity of 65,700 second-feet, which discharge is equaled or exceeded 50 percent of the time during that year. See case 1 of table 122. Likewise the total energy available for the low year with the above plant capacity is respectively 469,000, 531,000, and 505,000 kilowatt-years for natural flow and for regulated flows for the pumping and gravity plans.

613. Table no. 122 shows the power duration 35, 50, 65, 80, 90, and 100 percent of the time for the 17-year period ended March 1930, for natural flow and for seven assumed conditions of regulation and irrigation. In obtaining the regulated flows shown in that table, control of the following reservoirs was assumed after allowing for withdrawal of irrigation water as stated in paragraph 178.

Reservoir:	<i>Approximate capacity in acre-feet</i>
Hungry Horse.....	1, 100, 000
Flathead Lake.....	1, 540, 000
Priest Lake.....	569, 000
Pend Oreille Lake.....	1, 610, 000
Kootenay Lake.....	715, 000
Coeur d'Alene Lake.....	38430, 000
Grand Coulee (low dam).....	776, 000
Grand Coulee (high dam).....	5, 028, 000
Total (low dam).....	6, 740, 000
Total (high dam).....	10, 992, 000

614. In cases 2, 3, and 4 the Columbia Basin irrigation project would be irrigated with water from Clark Fork and Spokane River. In case 5, it would be irrigated with water from Clark Fork, Spokane, and Wenatchee Rivers.

² Not printed.

³ Includes 155,000 acre-feet now used by the Washington Water Power Co.

TABLE No. 122.—Principal data, Foster Creek site, for the 17 year period ended Mar. 31, 1930. For power-duration curves, see plate no. 65²

Plan	Regulation	Case no.	Grand Coulee Dam	Time	Flow	State head, forcbuy elevation 930	Potential power, 80 percent efficiency	Potential energy available annually
							1,000 kw.	1,000 kw.-yrs.
Natural	No regulation	1	None					
				Per cent	1,000 sec.-ft.	Feet	1,000 kw.	1,000 kw.-yrs.
				35	109.0	153.0	1,134	757
				50	65.7	158.2	707	580
				65	47.8	161.0	524	475
Gravity	Upstream regulation without Columbia River storage—plan no. 2-A.	2	Low or high	80	38.2	162.8	423	402
				90	28.4	164.0	317	313
				100	18.8	164.0	210	210
				35	101.0	153.8	1,052	753
				50	68.0	157.9	730	621
Do	Upstream regulation including Columbia River storage—plan no. 2-A.	3	Low dam	65	52.8	160.1	575	532
				80	42.6	161.9	469	455
				90	36.7	163.1	407	404
				100	27.3	164.0	304	304
				35	100.6	153.8	1,052	763
Do	do	4	High dam	50	67.7	157.9	727	629
				65	53.7	160.0	584	546
				80	43.3	161.8	476	467
				90	39.6	162.5	438	434
				100	32.8	163.8	365	365
Do	Upstream regulation including Columbia River storage. Quincy Flats irrigated from Wenatchee Lake—plan no. 6-A.	5	Low dam	35	100.0	153.9	1,047	816
				50	73.9	157.1	789	711
				65	64.0	158.4	689	655
				80	56.0	159.6	608	596
				90	50.4	160.5	550	547
Pumping	Upstream regulation without Columbia River storage—plan no. 4.	6	Low or high	100	45.5	161.4	499	499
				35	101.0	153.8	1,058	767
				50	68.2	157.8	732	633
				65	55.5	159.7	603	560
				80	44.9	161.5	493	481
Do	Upstream regulation including Columbia River storage plan no. 4.	7	Low dam	90	39.7	162.5	439	436
				100	33.9	163.6	377	377
				35	96.3	154.3	1,010	747
				50	68.1	157.9	731	633
				65	55.9	159.6	607	564
Do	do	8	High dam	80	45.8	161.3	502	490
				90	39.9	162.4	441	438
				100	32.9	163.8	366	366
				35	96.3	154.3	1,010	752
				50	68.1	157.9	731	639
Do	do			65	56.0	159.6	608	572
				80	48.2	160.9	527	515
				90	42.7	161.9	471	468
				100	37.4	162.9	414	414
				35	98.1	155.3	931	777
				50	72.3	157.3	773	712
				65	65.8	158.2	708	677
				80	57.1	159.5	619	612
				90	53.5	160.0	582	580
				100	49.4	160.7	540	540

615. As a basis of comparison, the potential power available 90 percent of the time is respectively 317,000, 407,000, 438,000, 550,000, 439,000, 441,000, 471,000, and 582,000 kilowatts for cases 1 to 8, inclusive, or considering case 1 as 100 percent, cases 2 to 8 are 128, 138, 173, 138, 139, 148, and 184 percent, respectively. For similar conditions of regulation, the increase in potential power under the pumping plan for 90 and 100 percent of the time over that obtaining under the gravity plan is worthy of note as is also the marked effect of regulation of storage at the high Grand Coulee Dam as compared with the low Grand Coulee Dam.

616. The duration of potential power for cases 1, 6, and 8 is shown graphically on plate no. 65.² The last column of table no. 122 shows the energy available annually for various cases, some of which are indicated on plate no. 65.²

² Not printed.

617. The installed capacity selected for discussion is 691,200 kilowatts which is based on the available potential power in case no. 6 for 90 percent of the time (441,000 kilowatts) with a 64 percent load factor. The power house as shown on plates nos. 66² and 67² and the estimates of cost given hereafter were based on this installed capacity. The utilization and plant capacity factors for an installation of 691,200 kilowatts for the 17-year period are as shown on plate no. 64.²

618. *d. Proposed development.*—The project works, as planned, involve the construction of a concrete spillway dam at right angles to the channel, and a canal and power house on the left bank. See plates nos. 66² and 61.² The dam would consist of a gravity spillway section, 1,390 feet long, containing 28 Stoney gates, each 35 feet high by 40 feet long, with a total capacity of 910,000 second-feet. The crest elevation would be 893.6 feet. Piers 10 feet thick would support the gates and an operating deck, the latter having a top elevation of 943.6 feet. Concrete wing walls at the north end of the spillway would confine the earth and rock-fill section that seals into the glacial till composing the right bank. A concrete core wall supported on bedrock would connect to the spillway section. At the south end of the spillway, the dam would be extended across the end of the power canal with control gates for unwatering the canal.

619. The kinetic energy that could be developed at the toe of the spillway section of the dam would be 17,850 horsepower per foot of net crest length for a maximum fall to the lowest bucket of 193.6 feet. Similarly, the energy developed for a fall of 114.6 feet to the tail-water level during maximum flow would be 10,580 horsepower per foot of net length of crest. If computed on the gross length of the crest, which equals the total length of the bucket, the energies would be reduced to about 80 percent of the amount shown above. This subject is discussed more fully in paragraph 549 and table no. 110. The gates at the left end of the spillway would be opened only during extreme floods, which would happen very infrequently. Some scour might occur here but it probably would not endanger the structure. Otherwise the pool below the dam should be effective in dissipating the energy.

620. The power canal would have a bottom width of 165 feet, with side slopes of one vertical to one horizontal with a rock embankment on the riverside. The normal water depth would be 35 feet, and the length about half a mile, merging into a forebay 1,600 feet long extending across the back of the power house. A wasteway with a free overflow crest at elevation 929.6 feet would be provided at the lower end of the forebay.

621. The power house, as planned, would be located on the left bank parallel to the stream. Sufficient space would be provided for 12 main units and 2 station units. See plate no. 67² for cross section. Each main unit would consist of a vertical Francis turbine with a capacity of 6,420 second-feet at 132.4-foot head, direct connected to a 57,600-kilowatt generator, 13,800 volts, 3-phase, 60-cycles. Transformers in the back portion of the building would step the voltage up to 220 kilovolts for delivery to an outdoor switching station on the roof.

622. It is planned to construct locks if required, below the power house leading into the forebay, as outlined on plate no. 61.² Revision of the intake gates and canal layout would be necessary.

² Not printed.

623. For construction purposes, it is planned to build a railroad to connect with the Great Northern Railway at a point on their present line about $3\frac{1}{2}$ miles east of Brewster. The track would follow the right bank of the Columbia and cross the Okanogan River on a rather high bridge.

624. The reservoir site lies in a region of very sparse population. Practically no tillable land would be flooded at normal forebay level. There are no bridges crossing this portion of the stream and only three inexpensive ferries. Hence, reservoir flowage rights should not be difficult or expensive to acquire.

625. *e. Economic features.*—The principal items of construction and the estimated capital cost of the project are shown in table no. 123. The cost of locks and other navigation features in connection with the power project are not shown herein, but will be given later in chapter II under "Combined uses." Note that the total cost per kilowatt of installed capacity for public development is \$67 and for private development is \$70.

TABLE NO. 123.—*Estimate of capital cost of Foster Creek site. Plant capacity 691,200 kilowatts*

Preliminary expense.....	\$797, 500
Construction railway.....	802, 800
Reservoir.....	50, 000
River diversion.....	1, 000, 000
Dam and headworks.....	10, 220, 150
Power canal and forebay.....	5, 056, 994
Power house substructure.....	2, 809, 828
Power house superstructure.....	2, 649, 150
Hydraulic equipment.....	5, 558, 400
Electrical equipment (691,200 kilowatts).....	4, 691, 040
Cranes and switching station.....	244, 000
Permanent quarters and shops.....	75, 000
Contingencies, 10 percent.....	3, 395, 486
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Total field cost.....	37, 350, 348
Overhead, $12\frac{1}{2}$ percent.....	4, 668, 794
<hr/>	<hr/>
Total construction cost.....	42, 019, 142
<hr/>	<hr/>
For public development:	
Total construction cost.....	42, 019, 142
Interest charged during construction, 10 percent.....	4, 201, 914
<hr/>	<hr/>
Total capital cost.....	46, 221, 056
Capital cost per kilowatt.....	67
<hr/>	<hr/>
For private development:	
Total construction cost.....	42, 019, 142
Interest charged during construction, 15 percent.....	6, 302, 871
<hr/>	<hr/>
Total capital cost.....	48, 322, 013
Capital cost per kilowatt.....	70

626. The financial set-up and annual operating cost for both public and private development is shown in table no. 124. It is based on delivering power to low-tension side of step-up transformers, including high-tension switch structure but omitting step-up transformers, high-tension insulators, switches, arresters, and oil circuit-breakers, which are included in terminal stations for transmission lines.

627. Plate no. 68² shows graphically the cost per kilowatt-hour of energy generated for plant capacity factors varying from 10 percent to 100 percent. Note that the cost per kilowatt-hour for a 50 percent plant capacity factor is 0.9 mill for public development, 1.3 mills for private development for an annual operating cost of 8.42 percent of the capital cost, and 1.94 mills for private development for an annual operating cost of 12.5 percent of the capital cost. There is also graphically shown the cost of energy generated by steam power with fuel oil at \$1 per barrel.

TABLE NO. 124.—*Estimate of annual cost of power production at Foster Creek with an installed capacity of 691,200 kilowatts*

	Public development	Private development
1. Investment cost:		
Lands and water rights and nondepreciated items.....	\$3,607,574	\$3,771,555
Dams and substructures.....	20,916,798	21,867,561
Subtotal A.....	24,524,372	25,639,116
Power plant, machinery, and superstructures.....	21,696,684	22,682,897
Total development, capital cost.....	46,221,056	48,322,013
2. Basis of annual cost:		
(a) Return or interest in percent of capital cost.....	4	6
(b) Amortization of bonds, 40-year sinking-fund basis, in percent of capital cost.....	1.05	6
(c) Depreciation:		
(1) Lands and water rights in percent of capital cost.....	0	0
(2) Dams and substructures, 100-year sinking-fund basis, in percent of capital cost.....	.08	0.018
(3) Power plant, machinery, and superstructures, 30-year sinking-fund basis, in percent of capital cost.....	1.78	1.26
(d) Taxes, in percent of capital cost.....	0	3.5
(e) Maintenance and operation expense, including 10 percent of cost of labor and material for general expense.....	\$148,616	\$148,616
3. Total annual cost:		
Items included in subtotal A:		
Interest or return.....	\$980,974	\$1,538,346
Amortization.....	257,506	
Depreciation.....	16,733	3,936
Taxes.....		384,587
Maintenance and operation (included under "Power plant").....		
Subtotal.....	1,255,213	1,926,869
Power plant:		
Interest or return.....	867,867	1,360,974
Amortization.....	227,815	
Depreciation.....	386,201	285,804
Taxes.....		340,243
Maintenance and operation.....	148,616	148,616
Subtotal.....	1,630,499	2,135,637
Total project:		
Interest or return.....	1,848,841	2,899,320
Amortization.....	485,321	
Depreciation.....	402,934	289,740
Taxes.....		724,830
Maintenance and operation.....	148,616	148,616
Total annual cost.....	2,885,712	4,062,506
Total annual cost in percent of capital cost.....	6.22	8.42

2. EARLIER PLANS OF DEVELOPMENT

628. On February 10, 1922, W. T. Batcheller submitted a report on the Columbia Basin project to the department of conservation and development, State of Washington, in which he presented plans for development of power at the Foster Creek site.

² Not printed.

629. *a. Principal works proposed.*—Ten different plans and estimates were presented for a project with a capacity of approximately 1,750,000 horsepower; the static head varied from 83.5 feet to 190 feet. The project works, as planned by Mr. Batcheller, involved the construction of a concrete spillway section, arched in plan, in the stream with a forebay and power house adjacent to the dam and paralleling the stream on the left bank. The number of units varied from 42 to 30 and the capacity from 41,000 to 60,000 horsepower to keep the total plant capacity constant within practical limits. The lowest estimated total cost was \$52,600,000 for the plants with the 148- and 165-foot heads. The cost of the plant with the 190-foot head was \$55,300,000, and for the plant with the 83.5-foot head was \$63,300,000. This power was to be used for pumping water for irrigation at the Grand Coulee site. Additional units were estimated to cost from \$22 to \$35 per kilowatt of capacity.

(D) CHELAN

1. DETAILED DESCRIPTION

630. This site is located in sections 20 and 29, township 27 north, range 23 east, Willamette meridian, at the Chelan station of the Great Northern Railway and about 35 miles north of the city of Wenatchee. The site is 245 miles by river from the international boundary, 41 miles below the Foster Creek site, 30 miles above the Rocky Reach site, and 180 miles above the mouth of the Snake River. The proposed location of the dam is about a mile above the mouth of the Chelan River. The general location is shown on plate no. 1, page 565.

a. Résumé.—

Drainage area.....	square miles..	85, 500
Length of pool.....	miles.....	42
Length of dam.....	feet.....	3, 000
Height of dam (maximum section, foundation to walkway).....	do.....	150
Drawdown (elevation 762 to 757 feet).....	do.....	5
Useful pondage.....	acre-feet.....	47, 000
Natural low-water elevation.....	feet.....	667
Maximum known discharge (June 1894).....	second-feet.....	735, 000
Spillway capacity.....	do.....	950, 000
Natural river flow (April 1913 to March 1931, inclusive):		
Maximum discharge, 24 hours.....	do.....	500, 000
Mean discharge.....	do.....	114, 000
Minimum discharge, 24 hours.....	do.....	17, 600
Average static head.....	feet.....	82. 2
Power capacity (Federal Power Commission definition)		
	horsepower..	198, 000
Proposed hydraulic capacity.....	second-feet.....	100, 000
Proposed installed capacity (case 6).....	kilowatts.....	450, 000

631. *b. Topography and geology.*—The stream at the dam site flows in a southerly direction between cliffs composed principally of gneiss. The main valley is about 2,200 feet wide at this location. See plate no. 69.² The low-water channel is from 500 to 600 feet wide and lies close to the east (left) bank. The western portion of the valley is high and rather flat and is partially flooded at extremely high stages only. Two thousand feet farther downstream the low-water channel increases in width to about 1,100 feet. The natural low-water elevation is 667 feet. The elevation of water surface at

² Not printed.

the mouth of Chelan River for the 1894 flood is given by the Great Northern Railway Co. as 726 feet.

632. Test borings indicate that the bedrock is probably continuous across the valley at elevations between 500 and 600 feet. It is composed mainly of gneiss, with minor quantities of mica schist and granite. The overburden is principally sand and gravel intermixed with cobblestones and small boulders. See plate no. 69² for log of test holes. Clay was mentioned in a few places on the drill log. The explorations of the dam site indicate that extensive investigations of the foundations would be necessary before the feasibility of a development of the site could be definitely determined. Therefore, the plan submitted in this report has been made only for the purpose of making an approximate estimate of cost.

633. During the preliminary study of the Columbia River, a site known as the Wells Dam site was investigated. It is located 12 miles above the Chelan site, and 233 miles from the international boundary. A topographic survey was made as shown on plate no. 70.² The natural low-water elevation is 700 feet. Surface indications are favorable for a dam, solid granite bluffs outcropping on both banks of the stream. However, two test holes that were drilled to the right of the low-water channel disclosed no bedrock at a depth of 100 feet. See log of holes on plate no. 70.² The site was therefore abandoned in favor of the Chelan site.

634. *c. Power possibilities.*—The natural discharge of the Columbia River at this site for different percentages of time is shown in table no. 125, case 1, together with corresponding head and potential power. The power capacity of the site with natural discharge, computed in accordance with the formula defined by the Federal Power Commission (0.08 Q.H.) is 198,000 horsepower. The proposed elevation of the forebay is 762 feet, which is 3 feet below the natural low-water elevation at the Foster Creek site. The maximum head at the site would be 95 feet and the average static head would be 82.2 feet for natural flow. The head available for the maximum month (455,000 second-feet) would be 52 feet, and for a discharge of 950,000 second-feet it would be 27 feet at normal forebay level. However, it would be feasible to operate with the forebay above normal for high stream stages without appreciable backwater effect at the Foster Creek site. Hence the turbines would not be "drowned out" by any floods. The mean monthly discharges for natural and regulated flows for the 18-year period, April 1913 to March 1931 inclusive, are shown in tables nos. 24 and 48.

635. Plate no. 71² contains 27 power graphs showing the available power for the high, mean, and low years of the 17-year period ended March 31, 1930, for three installed capacities for natural flow (case 1 of table no. 125), and for flows regulated by means of upstream storage for cases 2 and 6 of table no. 125. No drawdown was considered in the Chelan Reservoir in the preparation of these graphs. The three capacities considered on plate no. 71² correspond to the power available from natural flow for 35 percent, 50 percent, and 90 percent of the time, respectively. These three capacities were selected arbitrarily to study the power possibilities of the site and are not to be confused with the plant capacity as set up in the résumé and hereafter in this report. The tables accompanying the graphs also show

¹ Not printed.

the utilization and plant capacity factors for 100 percent operation. By comparison of graphs 2, 11, and 20 on plate no. 71,² it is noted that regulation increases the annual utilization factor from 61 percent to 72 percent and 70 percent, respectively, for the pumping and gravity plans for the low year, with a hydraulic capacity of 68,400 second-feet, which discharge is equaled or exceeded 50 percent of the time during that year, without regulation (see case 1 of table no. 125). Likewise, the total energy available for the low year with the above plant capacity is, respectively, 261,000, 298,000, and 283,000 kilowatt-years for natural flow and for regulated flow for the pumping and gravity plans. Plate no. 72² shows graphically the annual plant capacity and utilization factors for the three plant capacities given on plate no. 71.²

636. Table no. 125 shows the power duration 35, 50, 65, 80, 90, and 100 percent of the time for the 17-year period ended March 31, 1930, for natural flow, and for seven assumed conditions of regulation and irrigation. In obtaining the regulated flows shown in that table, control of the following reservoirs was assumed after allowing for withdrawal of irrigation water as stated in paragraph 178.

Reservoir:	<i>Approximate capacity (acre-feet)</i>
Hungry Horse.....	1, 100, 000
Flathead Lake.....	1, 540, 000
Priest Lake.....	569, 000
Pend Oreille Lake.....	1, 610, 000
Kootenay Lake.....	715, 000
Coeur d'Alene Lake.....	³⁹ 430, 000
Grand Coulee, low dam.....	776, 000
Grand Coulee, high dam.....	5, 028, 000
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Total, low dam.....	6, 740, 000
Total, high dam.....	10, 992, 000

637. In cases 2, 3, and 4, the Columbia Basin irrigation project would be irrigated with water from Clark Fork and Spokane River. In case 5 it would be irrigated with water from Clark Fork, Spokane, and Wenatchee Rivers.

638. The last column of table no. 125 shows the potential energy available annually in thousands of kilowatt-years for certain percentages of time for each case. Note that both the potential power and the annual energy, as shown in the table, were not limited by any plant capacities.

² Not printed.

³⁹ Includes 155,000 acre-feet now used by the Washington Water Power Co.

TABLE No. 125.—Principal data, Chelan site for the 17-year period ended Mar. 31, 1930. For power-duration curves, see plate no. 73²

Plan	Regulation	Case no.	Grand Coulee Dam	Time	Flow	Static head forebay elevation 762	Potential power, 80 per cent efficiency	Potential energy available annually
							1,000 kilowatts	
Natural...	No regulation.....	1....	None.....					
				Per cent	1,000 second-feet	Feet	1,000 kilowatts	1,000 kilowatt-years
				35	113.0	80.4	618	425
Gravity...	Upstream regulation without Columbia River storage—plan no. 2-A.	2....	Low or high	50	68.4	86.7	403	335
				65	50.3	89.5	306	279
				80	39.8	91.2	247	236
				90	30.1	92.8	190	188
				100	20.4	94.0	130	130
				35	106.8	81.2	589	428
		3....	Low dam..	50	72.2	86.2	423	360
				65	55.5	88.7	335	310
				80	44.5	90.5	274	266
				90	38.8	91.4	241	239
				100	28.9	96.0	183	183
				35	106.8	81.2	589	433
	Upstream regulation including Columbia River storage—plan no. 2-A.	4....	High dam..	50	71.6	86.3	420	364
				65	55.9	88.6	337	316
				80	45.3	90.3	278	273
				90	41.7	90.9	258	256
				100	33.9	92.2	213	213
				35	103.0	81.7	572	456
		5....	Low dam..	50	76.1	85.6	443	402
				65	66.4	87.0	393	374
				80	57.6	88.4	346	340
				90	51.9	89.3	315	314
				100	47.5	90.0	291	291
				35	108.0	81.0	595	436
Upstream regulation including Columbia River storage. Quincy Flats irrigated from Wenatchee Lake—plan no. 6-A.	6....	Low or high	50	71.3	86.3	418	364	
			65	57.7	88.4	347	325	
			80	46.9	90.1	287	280	
			90	41.8	90.9	258	256	
			100	35.0	92.0	219	219	
			35	104.0	81.6	578	429	
Pumping.	Upstream regulation without Columbia River storage—plan no. 4.	7....	Low dam..	50	71.5	86.3	420	365
				65	58.1	88.3	349	326
				80	47.7	90.0	291	284
				90	41.8	90.9	259	257
				100	34.5	92.1	216	216
				35	103.6	81.6	575	430
	8....	High dam..	50	89.9	86.5	411	364	
			65	58.3	88.3	350	330	
			80	49.4	89.7	301	295	
			90	44.7	90.4	275	273	
			100	38.7	91.4	241	241	
			35	91.3	83.4	518	438	
Upstream regulation including Columbia River storage—plan no. 4.	8....	High dam..	50	75.2	85.7	438	405	
			65	68.0	86.8	402	385	
			80	59.3	88.1	355	361	
			90	55.4	88.7	334	333	
			100	51.1	89.4	311	311	

639. As a basis of comparison, the potential power available 90 percent of the time is, respectively, 190,000, 241,000, 258,000, 315,000, 258,000, 259,000, 275,000, and 334,000 kilowatts for cases 1 to 8, inclusive; or, considering case 1 as 100 percent, cases 2 to 8 are 127, 136, 166, 136, 136, 145, and 176 percent, respectively. For similar conditions of regulation, the increase in potential power under the pumping plan for 90 and 100 percent of the time over that obtaining under the gravity plan is worthy of note, as is, also, the marked effect of regulation of storage at the high Grand Coulee Dam as compared with the low Grand Coulee Dam. The duration of potential power for cases 1, 6, and 8 is shown graphically on plate no. 73.²

² Not printed.

640. *d. Proposed development.*—The installed capacity selected for discussion is 450,000 kilowatts, which is based first on a consideration of the power available for 90 percent of the time, under plan no. 4, case 6, delivered on a plant capacity factor of 65 percent. This was later altered by determination of capacity required to deliver 216,000 kilowatts, which is the power available continuously under above plan, on a 50 percent load factor. Such a plant would require a hydraulic capacity of 122,000 second-feet to have available a capacity of 432,000 kilowatts during high flow and low head, which is 52.1 feet for maximum mean monthly discharge of 455,000 second-feet. In order to be conservative, the hydraulic capacity was limited to 100,000 second-feet and the generating capacity to 450,000 kilowatts and estimate of cost based on this capacity.

641. The project works, as herein planned, involve the construction of a power house on the east bank on a gneiss outcrop, at an angle of about 45 degrees to the axis of the stream, and a concrete dam extending upstream about 1,000 feet from the power house, and then crossing the main valley to the cliff on the west side. See plate no. 69² for general plan and sections of the dam and power house.

642. The power house and the adjacent portion of the spillway paralleling the stream are founded on solid rock of good quality. It is planned to support the remainder of the dam on the glacial overburden and protect it from erosion by a concrete apron extending downstream, and by a riprap of heavy boulders. A spillway capacity of 950,000 second-feet would be provided at normal forebay level by 59 vertical gates with clear openings 30 feet wide by 28 feet high. A railway spur and a highway would be carried across the stream on the dam.

643. The kinetic energy that could be developed at the toe of the spillway section of the dam would be 7,370 horsepower per foot of net crest length for a maximum fall to the lowest bucket of 122 feet. Similarly, the energy developed for a fall of 27 feet to the tail-water level during maximum flow would be 375 horsepower per foot of net length of crest. If computed on the gross length of the crest, which equals the total length of the bucket, the energies would be reduced to about 81 percent of the amounts shown above. This subject is discussed more fully in paragraph 549 and table no. 110.

644. The power house as planned would accommodate 12 main units and 2 station units. Each main unit would consist of a vertical propeller-type turbine direct connected to a generator of 37,500 kilowatts capacity, 13,800 volts, 3-phase, 60-cycle. The turbine would have a hydraulic capacity of 8,330 second-feet for a head of 52.1 feet. The power capacity for this head is 29,500 kilowatts. A bank of transformers would be placed on the roof of the power house to step the voltage up to 220 kilovolts. A switching station would be located on the left bank opposite the power house. Provision is made for the construction of locks, if and when required, along the left bank. They would enter the forebay at the east end of the power house.

645. The Beebe toll bridge, which crosses the Columbia at the site, would be removed. Traffic would be accommodated by the roadway constructed on the dam and over the power house.

² Not printed.

646. The Brewster branch of the Great Northern Railway passes the site along the right bank of the stream, with a subgrade elevation of 747 feet. About 10 miles of track above the dam site lies below elevation 775 feet. The grade revision would begin at a point 1½ miles below the dam site, if the ruling grade of 0.4 percent is not to be exceeded. It is planned to raise the Chelan River Bridge and drive a tunnel about 1,000 feet in length through the cliff at the dam site. On the reservoir site the track would be relocated with a minimum subgrade elevation of 775 feet. This revision would involve the relocation of a total of 16 miles of track, including sidings. There are eight large warehouses at Chelan station that would be rendered practically useless by removal of the sidings and would probably have to be purchased.

647. The major portion of the reservoir site is composed of stream bed, sand bars, and steep, rocky slopes of little value. However, about 300 acres of valuable bearing orchard within a few miles of the dam site would be inundated.

648. *e. Economic features.*—The principal items of construction and the estimated capital cost of the project are shown in table no. 126. The cost of locks and other navigation features in connection with the power project are not shown herein, but will be given in a later section under "combined uses." Note that the total cost per kilowatt of installed capacity for public development is \$84, and for private development is \$87.

TABLE NO. 126.—*Estimate of capital cost of development at Chelan site for an installed capacity of 450,000 kilowatts*

Preliminary expense.....	\$505,000
Construction roads.....	75,000
Reservoir.....	1,200,000
River diversion.....	1,500,000
Dam.....	10,487,850
Headgates and racks.....	800,000
Power-house substructure.....	4,262,500
Power-house superstructure.....	2,380,000
Hydraulic equipment.....	3,000,000
Electrical equipment.....	3,442,500
Miscellaneous equipment.....	250,000
Tailrace.....	134,250
Switching station.....	80,000
Permanent buildings.....	50,000
Contingencies, 10 percent.....	2,816,710
Total field cost.....	30,983,810
Overhead, 12½ percent.....	3,872,976
Total construction cost.....	34,856,786
For public development:	
Total construction cost.....	34,856,786
Interest charged during construction, 8 percent.....	2,788,543
Total capital cost.....	37,645,329
Capital cost per kilowatt.....	84
For private development:	
Total construction cost.....	34,856,786
Interest charged during construction, 12 percent.....	4,182,814
Total capital cost.....	39,039,600
Capital cost per kilowatt.....	87

649. The annual operating cost of the project is shown on table no. 127. Note that the annual cost for public development computed on a 4 percent basis is \$2,329,459 or 6.19 percent of the capital cost, and for private development on a 6 percent basis, the annual operating cost is \$3,275,281 or 8.39 percent of the capital cost. Plate no. 74² shows graphically the cost per kilowatt-hour of energy generated for plant-capacity factors varying from 10 percent to 100 percent. It will be noted that the cost per kilowatt-hour for a 50 percent plant-capacity factor would be 1.2 mills for public development, 1.7 mills for private development for an annual operating cost of 8.39 percent of the capital cost, and 2.4 mills for private development for annual operating cost of 12.5 percent of the capital cost. The cost of steam-generated power for the same range of plant-capacity factors is also shown, computed for fuel oil at \$1 per barrel.

TABLE NO. 127.—*Estimate of annual cost of power production at Chelan with an installed capacity of 450,000 kilowatts*

	Public development	Private development
1. Investment cost:		
Lands and water rights and nondepreciated items.....	\$6,034,097	\$6,257,582
Dam and substructures.....	16,642,767	17,259,165
Subtotal A.....	22,676,864	23,516,747
Power plant, machinery, and superstructure.....	14,968,465	15,522,853
Total development, capital cost.....	37,645,329	39,039,600
2. Basis of annual cost:		
(a) Return or interest in percent of capital cost.....	4	6
(b) Amortization of bonds, 40-year sinking-fund basis, in percent of capital cost.....	1.05	0
(c) Depreciation:		
(1) Land and water rights, in percent of capital cost.....	0	0
(2) Dam and substructures, 100-year sinking-fund basis, in percent of capital cost.....	.08	.018
(3) Power plant, machinery, and superstructures, 30-year sinking-fund basis, in percent of capital cost.....	1.78	1.26
(d) Taxes, in percent of capital cost.....	0	1.5
(e) Maintenance and operation expense, including 10 percent of cost of labor and material for general expense.....	\$148,616	\$148,616
3. Total annual cost:		
Items included in subtotal A:		
Interest or return.....	907,075	1,411,005
Amortization.....	238,107	
Depreciation.....	13,314	3,107
Taxes.....		362,751
Subtotal.....	1,158,496	1,766,863
Power plant:		
Interest or return.....	598,739	931,371
Amortization.....	157,169	
Depreciation.....	260,439	195,588
Taxes.....		232,843
Maintenance and operation.....	148,616	148,616
Subtotal.....	1,170,963	1,508,418
Total project:		
Interest or return.....	1,505,814	2,342,376
Amortization.....	395,276	
Depreciation.....	279,753	198,695
Taxes.....		585,594
Maintenance and operation.....	148,616	148,616
Total annual cost.....	2,329,459	3,275,281
Total annual cost in percent of capital cost.....	6.19	8.39

2. EARLIER PLANS OF DEVELOPMENT

650. No comprehensive plans of development have previously been made for this site.

² Not printed.

(E) ROCKY REACH

1. DETAILED DESCRIPTION

651. This site is located in sections 25, 35, and 36, township 24 north, range 20 east, Willamette meridian, about 8 miles north of the city of Wenatchee. The site is 274 miles by river from the international boundary, 28 miles below the Chelan site, 23 miles above the Rock Island site, and 152 miles above the mouth of the Snake River. The proposed location of the dam is about $1\frac{3}{4}$ miles above the mouth of Swakane Creek. The general location is shown on plate no. 1, page 565.

a. *Résumé*—

Drainage area.....	square miles..	87, 200
Length of pool.....	miles..	30
Length of dam.....	feet..	2, 500
Height of dam (maximum section, foundation to walkway).....	do..	100
Drawdown (elevation 665 to 660 feet).....	do..	5
Useful pondage.....	acre-feet..	20, 000
Natural low-water elevation.....	feet..	604
Maximum known discharge (June 1894).....	second-feet..	735, 000
Spillway capacity.....	do..	960, 000
Natural river flow (April 1913 to March 1931, inclusive):		
Maximum discharge, 24 hours (approximately).....	do..	510, 000
Mean discharge (approximately).....	do..	117, 000
Minimum discharge, 24 hours (approximately).....	do..	20, 300
Average static head.....	feet..	51. 2
Power capacity (Federal Power Commission definition)	horsepower..	127, 000
Proposed hydraulic capacity.....	second-feet..	100, 000
Proposed installed capacity (case 6).....	kilowatts..	336, 000

652. *b. Topography and geology.*—The stream at this site flows in a southwesterly direction and is about 700 feet wide at low flows. (See pl. no. 75² for topography at the site.) The dam site that was first selected passed through the corner common to sections 25, 26, 35, and 36, township 24 north, range 20 east. At this location granite bedrock outcrops at the water's edge on the right bank and again about 2,000 feet back from the stream on the left bank. Four test holes that were sunk into the terrace on the left bank showed the overburden to be at least 100 feet deep. (See pl. no. 75² for the log of these holes.)

653. On the left (east) bank, about a mile upstream from this location, and isolated butte of gneiss and granite rises to an elevation of about 1,150 feet. Surface conditions indicate that this formation is badly shattered for a considerable depth. Upstream from the butte the natural channel is from 1,200 to 1,500 feet wide, and to the left a dry channel, about 75 feet above the present low-water surface, separates the butte from the bluffs on the left side of the valley. Test hole no. 5 was drilled on the right bank, opposite the upstream end of the butte, and showed the overburden to be 100 feet deep. This location was finally chosen for the dam as set up hereafter in this report. Further investigation of subsurface conditions are necessary to determine beyond question the feasibility of this site.

654. *c. Power possibilities.*—The mean monthly discharge of the natural and regulated flows for the 18-year period, April 1913 to March 1931, inclusive, is shown in tables nos. 25 and 49. The natural low-water elevation is 604 feet at the site of the power house. The proposed elevation of the forebay would be 665 feet, which is

² Not printed.

2 feet below the natural low-water elevation at the Chelan site. The maximum static head at the site would be 61 feet.

655. The power capacity of this site with natural discharge, computed in accordance with the formula defined by the Federal Power Commission, i.e. $(0.08) (Q)(H)$, where Q is the discharge 90 percent of the time and H is the average head; equals $(0.08) (31,000) (51.2)$ or 127,000 horsepower. The maximum monthly discharge for the 17-year period, April 1913 to March 1930, inclusive, was 466,000 second-feet and the corresponding head was 26.2 feet. Higher discharges would probably reduce the head to such an extent that operation of the plant would not be feasible. During flood flows, there is a drop of approximately 10.5 feet in the river between the dam site and the power-house site which are about 1.8 miles apart. Plate no. 77² contains 27 power graphs which compare the power possibilities of three schemes of regulation of discharge for low, mean and high years and with three different hydraulic capacities. Computations are based on controlled forebay of 665 feet. To obtain three points on a curve and compare different schemes of regulation on some basis common to all, the hydraulic capacities were based on natural discharge for 35, 50, and 90 percent of the time. The installed kilowatt capacities are the product of these discharges, the corresponding static heads, and a constant 0.068 based on 80 percent overall efficiency and should not be confused with any proposed installed capacities used elsewhere in this report. Based on 100 percent operation of the plant, each graph shows the installed kilowatt capacity, monthly potential power, monthly available power limited by the particular hydraulic capacity, monthly and annual utilization and plant capacity factors, and maximum output in kilowatt-years. Plate no. 76² contains graphs in which annual utilization and plant capacity factors appearing on plate no. 77² are plotted with their corresponding values of hydraulic capacities showing quite clearly the effect due to change of plant hydraulic capacity. As this capacity is increased, the utilization factor increases and the plant capacity factor, in general, decreases. The greater the hydraulic capacity, the more difficult it becomes to keep it loaded, either due to a shortage of water or a decrease in head.

656. Table no. 128, which is self-explanatory, shows the power duration 35, 50, 65, 80, 90, and 100 percent of the time for the 17-year period ended March 1930, for natural flow and for seven assumed conditions of regulation and irrigation. In obtaining the regulated flows shown in that table, control of the following reservoirs was assumed after allowing for withdrawal of irrigation water, as stated in paragraph 178.

Reservoir:	Approximate capacity (acre-feet)
Hungry Horse.....	1, 100, 000
Flathead Lake.....	1, 540, 000
Priest Lake.....	569, 000
Pend Oreille Lake.....	1, 610, 000
Kootenai Lake.....	715, 000
Coeur d'Alene Lake.....	⁴⁰ 430, 000
Grand Coulee (low dam).....	776, 000
Grand Coulee (high dam).....	5, 028, 000
Chelan.....	665, 000
Total (low dam).....	7, 405, 000
Total (high dam).....	11, 657, 000

² Not printed.

⁴⁰ Includes 155,000 acre-feet now used by The Washington Water Power Co.

657. In cases 2, 3, and 4, the Columbia Basin irrigation project would be irrigated with water from Clark Fork and Spokane River. In case 5, it would be irrigated with water from Clark Fork, Spokane, and Wenatchee Rivers.

658. The power available with natural discharge is shown by power-duration curve, plate no. 78² and table no. 128. Based on monthly values of natural discharge, the power available 100 percent of the time is 92,000 kilowatts and for 90 percent of the time is 125,000 kilowatts. The last column of table no. 128 shows the annual energy available for various percentages of time for each case. Note that the power and energy as shown in this table are not restricted by any proposed plant capacity. Plate no. 78² also shows the power duration for cases 6 and 8.

TABLE No. 128.—Principal data, Rocky Reach site, for the 17-year period ended Mar. 31, 1930. For power duration curves, see plate no. 78²

Plan	Regulation	Case no.	Grand Coulee Dam	Time	Flow	Static head forebay elevation 655	Potential power, 80 percent efficiency	Potential energy available annually	
							1,000 kw.	1,000 kw.-yrs.	
Natural...	No regulation.....	1	None.....	Per cent	1,000 sec.-ft.	Feet	1,000 kw.	1,000 kw.-yrs.	
				35	117.0	49.3	391	272	
				50	70.7	54.0	280	216	
				65	52.4	56.3	201	183	
				80	41.3	57.8	162	155	
				90	31.0	59.3	125	124	
Gravity ..	Upstream regulation without Columbia River storage—plan no. 2-A.	2	Low or high	100	22.4	60.7	92	92	
				35	110.4	49.9	374	275	
				50	75.8	53.5	276	236	
				65	58.1	55.6	220	204	
				80	46.4	57.1	180	176	
				90	41.1	57.9	162	160	
	Upstream regulation including Columbia River storage—plan no. 2-A.	3	Low dam..	100	31.0	59.3	125	125	
				35	110.4	49.9	374	279	
				50	75.8	53.5	276	239	
				65	58.4	55.6	221	208	
				80	47.4	57.0	184	180	
				90	43.2	57.6	169	168	
	Upstream regulation including Columbia River storage; Quincy Flats irrigated from Wenatchee Lake—plan no. 6-A.	5	Low dam..	100	35.9	58.6	143	143	
				35	112.6	49.7	380	282	
				50	73.3	53.7	268	235	
				65	59.8	55.4	225	211	
				80	48.9	56.8	189	185	
				90	43.9	57.5	172	171	
	Pumping..	Upstream regulation without Columbia River storage—plan no. 4.	6	Low or high.	100	37.0	58.4	147	147
					35	109.0	50.0	371	277
					50	74.1	53.7	271	237
					65	60.5	55.3	228	213
					80	49.8	56.7	192	188
					90	43.8	57.5	171	170
Upstream regulation including Columbia River storage—plan no. 4.		7	Low dam..	100	36.6	58.5	146	146	
				35	106.6	50.2	364	276	
				50	72.0	53.9	264	236	
				65	60.6	55.3	228	216	
				80	51.2	56.5	197	193	
				90	47.1	57.1	183	182	
Upstream regulation including Columbia River storage—plan no. 4.		8	High dam..	100	40.7	57.9	160	160	
				35	94.0	51.5	329	281	
				50	77.8	53.2	281	261	
				65	69.9	54.1	257	248	
				80	61.3	55.2	230	227	
				90	57.6	55.7	218	217	
100		53.1	56.3	203	203				

² Not printed.

659. The greatest benefits that could be derived from regulation would occur with plan no. 4, case 8, which includes the Columbia River storage behind the Grand Coulee high dam. The power available under these conditions would be 203,000 kilowatts 100 percent of the time and 218,000 kilowatts for 90 percent of the time; which would be an increase over natural flow of 121 percent for power available 100 percent of time and 74 percent for power available 90 percent of time.

660. The increased energy in kilowatt-years due to different methods of regulation is also shown in table no. 128. The gain in energy under the regulation of case 8 over that of case 1 will be 121 percent, the same as the gain in power, for 100 percent of the time and 75 percent for 90 percent of the time.

661. The installed capacity first selected was 264,000 kilowatts, which was based on 171,000 kilowatts, this being the power available 90 percent of the time for plan no. 4, case 6, table no. 128, and a plant capacity factor of 65 percent. Later consideration was given to a capacity of plant which would deliver the prime power of 146,000 kilowatts for case 6 on a 50 percent load factor, continuously. This would require a plant having a capacity of 292,000 kilowatts with a hydraulic capacity of 164,000 second-feet for the minimum head of 26.2 feet. In order to be conservative, the hydraulic capacity was limited to 100,000 second-feet and the generator capacity to 336,000 kilowatts. The continuous capacity of the plant would be 178,000 kilowatts, which would deliver the prime power on a load factor of 82 percent. The generators could be fully loaded when head reaches 49.5 feet, which would occur when flow is 115,000 second-feet or less, and would occur 67.3 percent of the time during the 17-year period for case 6. The power house as shown on plates nos. 74² and 79,² and estimates of cost, are based on a generator capacity of 336,000 kilowatts.

662. *d. Proposed development.*—The project works, as planned herein, involve the construction of a dam, circular in plan, at the upstream end of the butte, described above; a power canal, about 2 miles long, located in the dry channel on the left of the butte; and a power house at the end of the canal on the left bank. The structures have been designed for a maximum flood discharge of 960,000 second-feet, and the head available with this flow would be about 11 feet; therefore, the turbines would be “drowned out” by unusual floods. The main portion of the dam would consist of a gravity section overflow spillway, with a crest elevation of 639 feet, surmounted by 65 Stoney gates, with openings 30 feet wide by 26 feet high. A 5-foot draw-down, with a resulting pondage of 20,000 acre-feet, can be used to provide for daily variation of load. The crest would be submerged by the tail water for flows over 310,000 second-feet. With a discharge of 960,000 second-feet, the tail-water elevation at the dam would be 680 feet, and the forebay level would rise to elevation 682 feet, which is 17 feet above normal. Similarly, the forebay level at the dam would rise to elevation 668.5 feet when passing 735,000 second-feet, which is the estimated maximum flow for the 1894 flood, and the tail-water for this flow at the dam would be at elevation 665.7 feet.

² Not printed.

663. The kinetic energy that could be developed at the toe of the spillway section of the dam would be 3,920 horsepower per foot of net crest length, for a maximum fall to the apron at elevation 595 feet. Similarly, the energy developed for a fall of 2 feet to the tail-water level during maximum flow would be 112 horsepower per foot of net length of crest. If computed on the gross length of the crest, which equals the total length of the bucket, the energies would be reduced to about 81 percent of the amounts shown above. This subject is discussed more fully in paragraph 549 and table no. 110.

664. The power canal would be 2 miles in length and lined with concrete throughout. Head gates, similar to those on the spillway, would be provided to control the flow during flood periods when the forebay level was above normal. The power house, as planned, would be of sufficient size to accommodate 12 main units and 2 station units. Each main unit would consist of a vertical, propeller-type turbine, with a hydraulic capacity of 8,330 second-feet, at a head of 26.2 feet and a capacity at this head of 14,840 kilowatts. This head would obtain for the month of maximum flow, 466,000 second-feet, for the 17-year period. Each turbine would be direct-connected to a generator of 28,000 kilowatts capacity. The turbine capacity would be equivalent to this generator capacity at a head of 49.5 feet, which would obtain at a stream flow of 115,000 second-feet at normal forebay level. As the effect of the backwater curve would not extend as far upstream for the higher flows, it would be feasible to operate the forebay above the normal elevation during these periods without affecting the tail-water elevation of the Chelan power plant. Hence, the head could be increased for the periods of high flow. No advantage has been taken of this increase in the preparation of data on the power possibilities of the site.

665. A bank of transformers would be placed on the roof of the power house to step the voltage up to 220 kilovolts. A switching station would be located on the left bank opposite the power house. Provision is made for the construction of locks, if and when required, along the left bank. They would enter the forebay at the south end of the power house. Some revision of the canal control gates would be necessary at the time of construction of the locks.

666. A relocation of 5 miles of existing railroad and highway would be necessary. No bridges in the project area would be affected.

667. *e. Economic features.*—The principal items of construction and the estimated capital cost of the project are shown in table no. 129. The cost of locks and other navigation features in connection with the power project are not shown herein, but will be given later in chapter II under "Combined uses". Note that the total cost per kilowatt of installed capacity for public development is \$109, and for private development is \$113.

TABLE No. 129.—*Estimate of capital cost of Rocky Reach site for an installed capacity of 336,000 kilowatts*

Preliminary expense	\$434, 500
Construction roads	51, 000
Reservoir	376, 500
River diversion	1, 500, 000
Dam	7, 368, 080
Canal, headworks and wasteway	4, 587, 060
Power-house substructure	4, 536, 220
Power-house superstructure	2, 500, 000
Hydraulic equipment	2, 910, 000
Electrical equipment	2, 890, 000
Miscellaneous equipment	130, 000
Switching station	72, 000
Permanent buildings	40, 000
Contingencies, 10 percent	2, 739, 536
Total field cost	30, 134, 896
Overhead, 12½ percent	3, 766, 862
Total construction cost	33, 901, 758
For public development:	
Total construction cost	33, 901, 758
Interest charged during construction, 8 percent	2, 712, 141
Total capital cost	36, 613, 899
Capital cost per kilowatt	109
For private development:	
Total construction cost	33, 901, 758
Interest charged during construction, 12 percent	4, 068, 210
Total capital cost	37, 969, 968
Capital cost per kilowatt	113

668. Table no. 130 shows the annual operating cost for both public and private development. It is based on delivering power to the low-tension side of the step-up transformers including high-tension switch structure but omitting step-up transformers, high-tension insulators, switches, arresters, and oil circuit-breakers, which are included in terminal stations for transmission lines. Note that the total annual cost for public development is \$2,244,689 or 6.14 per cent of the capital cost, and for private development is \$3,169,278 or 8.35 per cent of the capital cost. Plate no. 80² shows graphically the cost per kilowatt-hour of energy generated for plant capacity factors varying from 10 to 100 percent. Note that the cost per kilowatt-hour for a 50 percent plant capacity factor is 1.5 mills for public development, 2.1 mills for private development at 8.35 per cent of the capital cost as shown in table no. 130, and 3.3 mills for private development at 12.5 per cent of the capital cost as often used by public utility companies. For purposes of comparison, the cost of steam power is also shown for the same plant capacity factors, with fuel oil at \$1 per barrel.

² Not printed.

TABLE No. 130.—*Estimate of annual cost of power production at Rocky Reach with an installed capacity of 336,000 kilowatts*

	Public development	Private development
1. Investment cost:		
Lands and water rights and nondepreciated items.....	\$2, 576, 103	\$2, 671, 515
Dam and substructures.....	21, 105, 954	21, 887, 656
Subtotal A.....	23, 682, 057	24, 559, 171
Power plant, machinery, and superstructures.....	12, 931, 840	13, 410, 797
Total development, capital cost.....	36, 613, 897	37, 969, 968
2. Basis of annual cost:		
(a) Return or interest, in percent of capital cost.....	4	6
(b) Amortization of bonds, 40-year sinking-fund basis, in percent of capital cost.....	1. 05	0
(c) Depreciation:		
(1) Land and water rights, in percent of capital cost.....	0	0
(2) Dam and substructures, 100-year sinking-fund basis, in percent of capital cost.....	. 08	. 018
(3) Power plant, machinery, and superstructure, 30-year sinking-fund basis, in percent of capital cost.....	1. 78	1. 26
(d) Taxes, in percent of capital cost.....	0	1. 5
(e) Maintenance and operation expense, including 10 percent of cost of labor and material for general expense.....	\$148, 616	\$148, 616
3. Total annual cost:		
Items included in subtotal A:		
Interest or return.....	\$947, 282	\$1, 473, 550
Amortization.....	248, 662	
Depreciation.....	16, 885	3, 939
Taxes.....		368, 388
Maintenance and operation (included under power plant).....		
Subtotal.....	1, 212, 829	1, 845, 877
Power plant:		
Interest or return.....	517, 273	804, 647
Amortization.....	135, 784	
Depreciation.....	230, 187	168, 976
Taxes.....		201, 162
Maintenance and operation.....	148, 616	148, 616
Subtotal.....	1, 031, 860	1, 323, 401
Total project:		
Interest or return.....	1, 464, 555	2, 278, 197
Amortization.....	384, 446	
Depreciation.....	247, 072	172, 915
Taxes.....		569, 550
Maintenance and operation.....	148, 616	148, 616
Total annual cost.....	2, 244, 689	3, 169, 278
Total annual cost in percent of capital cost.....	6. 14	8. 35

2. EARLIER PLANS OF DEVELOPMENT

669. No comprehensive plans of development have previously been made for this site.

(F) ROCK ISLAND

1. DETAILED DESCRIPTION

670. This site is located in section 5, township 21 north, range 22 east, Willamette meridian, at the Rock Island rapids of the Columbia River. It is 12 miles southeast of Wenatchee. The site is 296 miles by river from the international boundary, 23 miles below the Rocky Reach site, 31 miles above the Vantage site, 56 miles above the Priest Rapids site, and 129 miles above the mouth of the Snake River. The general location is shown on plate no. 1, page 565.

(a) *Résumé.*—

Drainage area.....	square miles.....	88, 700
Length of pool.....	miles.....	20
Length of dam (including power house).....	feet.....	3, 200
Height of dam (maximum section, foundation to walkway).....	do.....	140
Draw-down (elevation 599 to 594).....	do.....	5
Useful pondage.....	acre-feet.....	10, 000
Natural low-water elevation.....	feet.....	548
Maximum known discharge (June 1894).....	second-feet.....	740, 000
Spillway capacity.....	do.....	1, 000, 000
Natural river flow (April 1913 to March 1931, inclusive):		
Maximum discharge, 24 hours.....	do.....	528, 000
Mean discharge.....	do.....	121, 000
Minimum discharge.....	do.....	21, 000
Average static head.....	feet.....	42. 1
Power capacity (Federal Power Commission definition)	horsepower.....	108, 400
Proposed hydraulic capacity.....	second-feet.....	85, 200
Proposed installed capacity.....	kilowatts.....	180, 000

671. *b. Topography and geology.*—The Columbia at the site is separated into two channels by a rough mass of basalt known as "Rock Island." (See pl. no. 81² for local topography.) These channels are about the same in size, being approximately 200 feet wide at their narrowest points at low stages of the stream. A number of small islands appear in each channel at low water, most of which are inundated at high stages.

672. The site is now being developed by the Puget Sound Power & Light Co., under Federal Power Commission license, no. 943, issued January 31, 1930. The principal project works are being constructed at the lower end of Rock Island. Henry Landes, dean of the college of science, professor of geology and mineralogy, University of Washington, describes the local formation as a basalt, resulting from lava flows of unusual thickness. He states:

At the cross section chosen as a foundation for the dam and the power house the basalt appears to be all of one flow, and that of unusual thickness. As far as present cores are concerned, they are all from one flow or sheet. All the cores are from rock exceedingly dense and compact and unexcelled anywhere for a foundation. If this condition continues, and each and all the drill holes show that the concrete will rest upon the same continuous thick sheet of basalt, it will make a support for the dam and power house that could not be improved upon. The possible extension of bedrock under the gravel terrace or bench on the south (right) side of the river can only be determined by drilling. The chances are that the rock does continue southward from the river, at the dam site, for probably 300 or 400 feet, but with a declining level.

673. At the lower end of Rock Island the channel is roughly 2,400 feet wide, at high stages, flanked on the left by a bare basaltic cliff 1,000 feet high, and on the right by a bench of glacial origin about 200 feet high.

674. *c. Power possibilities.*—The mean monthly discharges for natural and regulated flows for the 18-year period, April 1913 to March 1931, inclusive, are shown in tables nos. 26 and 50. The proposed elevation of the normal forebay is 599 feet, although the top of the gates is at elevation 600 feet, and the controlled level may occasionally reach that higher elevation. Backwater studies, as made by the licensee, indicate that this forebay level would affect the tail water

² Not printed.

of the proposed plant at Rocky Reach less than a foot for flows under 50,000 second-feet, and proportionately less for higher flows. Taking advantage of this condition, the company contemplates increasing the forebay elevation to a maximum of 608 feet for stream flows over 240,000 second-feet, thus increasing the effective head on the turbines. The tail-water elevation for minimum flow would be approximately 548 feet, but would vary somewhat with the manipulation of the spillway gates. Hence, the maximum head would be 51 feet. The average static head for the 18-year period ended March 31, 1931, would be 42.1 feet for natural flow. For a stream flow of 530,000 second-feet the head would be reduced to 22 feet, with the forebay at elevation 608 feet. For higher stream discharges the turbines would be shut down for lack of head.

675. Plate no. 82² contains 27 power graphs showing the available power for the high, mean, and low years of the 17-year period, ended March 31, 1930, for three installed capacities and for three stream-flow conditions; that is, for natural flow (case 1 of table no. 131), and for flow regulated by means of upstream storage for cases 2 and 6 of table no. 131. These graphs were prepared for a constant forebay level of 599 feet. The three hydraulic capacities considered on plate no. 82 equal the natural flow for 35, 50, and 90 percent of the time, as shown in case 1 of table no. 131. These three flows were arbitrarily selected as a basis for a study of the power possibilities of the site, and are not to be confused with the hydraulic capacity as set up in this report, or as proposed by the licensee. The three plant capacities expressed in kilowatts are those capacities which correspond to the above selected flows and to the heads obtaining at these flows at 80 percent efficiency.

676. The utilization and plant capacity factors for 100 percent operation are shown directly under each graph (plate no. 82).² The annual factors as shown are plotted on plate no. 83. By interpolation of these curves for the regulated pumping plan and a plant capacity of 180,000 kilowatts, as proposed by the licensee, the utilization factor is shown as 67 percent, and the plant capacity factor as 73 percent for the mean year, April 1923 to March, 1924, inclusive. By comparison of graphs 2, 11, and 20, on plate no. 82,² it is noted that regulation increases the annual utilization factor from 65 percent to 75 percent and 73 percent respectively, for the pumping and gravity plans for the low year, with a hydraulic capacity of 73,200 second-feet, which discharge is equaled or exceeded 50 percent of the time during the 17-year period for natural flow. (See case 1 of table no. 131.) Likewise, the total power available for the low year with the above hydraulic capacity is respectively, 144,000 kilowatt-years, 170,000 kilowatt-years, and 162,000 kilowatt-years for natural flow and for regulated flow for pumping and gravity plans.

677. Table no. 131 shows the power duration 35, 50, 65, 80, 90, and 100 percent of the time for the 17-year period ended March 1930, for natural flow and for seven assumed conditions of regulation and irrigation. In obtaining the regulated flows shown in that table

² Not printed.

control of the following reservoirs was assumed, after allowing for withdrawal of irrigation water as stated in paragraph 178.

Reservoir:	Approximate capacity (acre-feet)
Hungry Horse.....	1, 100, 000
Flathead Lake.....	1, 540, 000
Priest Lake.....	569, 000
Pend Oreille Lake.....	1, 610, 000
Kootenai Lake.....	715, 000
Coeur d'Alene Lake.....	41 430, 000
Grand Coulee (low dam).....	776, 000
Grand Coulee (high dam).....	5, 028, 000
Chelan.....	665, 000
Wenatchee Lake.....	1, 000, 000
Chiwawa.....	482, 000
Total (low dam).....	8, 887, 000
Total (high dam).....	13, 139, 000

678. In cases 2, 3, and 4 of table no. 131, the Columbia Basin Irrigation Project would be irrigated with water from Clark Fork and Spokane River. In case 5 it would be irrigated with water from Clark Fork and the Spokane and Wenatchee Rivers.

679. The last column of table no. 131 shows the potential energy available annually in thousands of kilowatt-years for certain percentages of time for each case. Note that both the potential power and the annual energy, as shown in the table, were not limited by plant capacities.

TABLE NO. 131.—Principal data, Rock Island site for the 17-year period ended Mar. 31, 1930. For power-duration curves, see plate no. 84^a

Plan	Regulation	Case no.	Grand Coulee Dam	Time	Flow	Static head, forebay elevation 599	Potential power, 80 per cent efficiency	Potential energy available annually				
Natural...	No regulation.....	1	None.....	Per-	1,000							
				cent	sec.-ft.	Feet	1,000 kw.	1,000 kw.-yrs.				
				35	119.0	40.3	326	233				
				50	73.2	46.5	231	193				
				65	54.1	48.7	179	163				
Gravity...	Upstream regulation without Columbia River storage—plan no. 2-A.	2	Low or high.	80	43.6	49.7	147	140				
				90	32.2	50.2	110	109				
				100	23.3	50.3	80	180				
				35	113.0	41.0	315	240				
				50	79.7	45.7	248	213				
				65	61.0	48.0	199	186				
				80	49.6	49.1	166	161				
				90	43.8	49.7	148	147				
				100	33.8	50.1	115	115				
				Do.....	Upstream regulation including Columbia River storage—plan no. 2-A.	3	Low dam.....	35	113.2	41.0	315	243
50	78.7	45.8	245					214				
65	61.7	47.9	201					189				
80	50.1	49.1	167					164				
90	46.0	49.5	155					154				
Do.....	do.....	4	High dam.....	100	38.3	50.0	130	130				
				35	107.6	41.7	305	254				
				50	82.4	45.3	254	233				
				65	72.2	46.7	229	219				
				80	62.4	47.8	203	200				
				90	57.3	48.4	188	188				
				100	51.0	49.0	170	170				
				Do.....	Upstream regulation including Columbia River storage. Quincy flats irrigated from Wenatchee Lake—plan no. 6-A.	5	Low dam.....	35	114.0	40.9	317	242
								50	75.1	46.3	236	208
								65	61.2	48.0	200	187
80	50.2	49.1	168					164				
90	45.4	49.5	153					152				
100	37.9	50.0	129	129								

^a Not printed.

⁴¹ Includes 155,000 acre-feet now used by the Washington Water Power Co.

TABLE NO. 131.—Principal data, Rock Island site for the 17-year period ended Mar. 31, 1930. For power-duration curves, see plate no. 84—Continued

Plan	Regulation	Case no.	Grand Coulee Dam	Time	Flow	Static head, forebay elevation 599	Potential power, 80 percent efficiency	Potential energy available annually
Pumping	Upstream regulation without Columbia River storage—plan no. 4.	6	Low or high	35	112.0	41.1	313	243
				50	78.4	45.9	245	215
				65	63.4	47.7	208	193
				80	52.9	48.8	175	172
				90	46.8	49.4	157	156
				100	39.4	50.0	134	134
Do.....	Upstream regulation including Columbia River storage—plan no. 4.	7	Low dam...	35	108.2	41.6	305	241
				50	75.6	46.2	238	213
				65	63.4	47.7	206	195
				80	53.3	48.8	177	174
				90	49.9	49.1	167	166
				100	43.1	49.7	146	146
Do	do.....	8	High dam...	35	98.0	42.9	286	248
				50	81.4	45.4	251	234
				65	72.8	46.6	230	222
				80	64.1	47.6	207	205
				90	60.2	48.1	197	196
				100	55.5	48.5	183	183

680. As a basis of comparison, the potential power available 90 percent of the time is respectively, 110,000, 148,000, 155,000, 188,000, 153,000, 157,000, 167,000, and 197,000 kilowatts for cases 1 to 8, inclusive. Considering case 1 as 100 percent, cases 2 to 8 are 134, 141, 171, 139, 143, 152, and 179 percent, respectively. Note the marked effect of regulation of storage at the high Grand Coulee Dam, as compared with the low Grand Coulee Dam. The power duration for cases 1, 6, and 8, is shown graphically on plate no. 84.²

681. *d. Plan of development.*—The Puget Sound Power & Light Co. is now constructing the project works for the initial development. This involves the construction of a power house extending diagonally across the left channel, connecting to the dam, which will extend across the foot of Rock Island and across the right channel. See plate no. 81² for topography, general plan, and principal cross-sections. Initially the power house will provide for 4 main units and 1 station unit. Each main unit will consist of an Allis-Chalmers adjustable blade, propeller-type turbine rated at 21,000 horsepower at 32 feet net head, 100 revolutions per minute, direct-connected to a General Electric Co. alternating-current generator, 15,000 kilowatts, 3-phase, 60-cycles, and 13,800 volts. This unit will be required to operate under a net head varying from 20 to 52 feet. According to data furnished by the licensee, the turbine and generator capacities will be equal at a net head of 34.5 feet, with a turbine capacity of 7,100 second-feet. For higher heads the output is constant, being limited by the generator capacity. For lower heads the output decreases, being limited by the turbine capacity, which reduces to 5,350 second-feet for a 20-foot net head, or 9,720 horsepower at 80 percent efficiency.

682. For the initial development the forebay elevation will be 581.5 feet for the minimum stream flow, and will be allowed to

² Not printed.

gradually increase to 608 feet as the flow increases to 530,000 second-feet, at which stage the net head on the turbines would be approximately 20 feet. It will not be feasible to operate the units for higher stream flows. For the ultimate development, the licensee plans to operate the forebay at a maximum elevation of 600 feet, excepting that this elevation will be allowed to increase to 608 feet for stream discharges between 240,000 and 530,000 second-feet. The licensee expects to put the first and second units into operation on January 1, 1932, and the third and fourth on January 1, 1933. Additional units will be installed and put into operation as the market demands. Provision is being made for 10 units with a possible extension to 12 units if a secondary power market should be developed for the season of high stream flow. The capacity of the future units (nos. 5 to 12, inclusive) has not been definitely established. With the higher heads under ultimate development that will obtain during a major portion of the year, it is feasible and may be desirable to increase the capacity of the generators to at least 20,000 kilowatts. By reference to case 7 of table no. 131, note that 10 units with a hydraulic capacity of 71,000 second-feet could operate on a daily load factor of 70 percent for 90 percent of the time.

683. The station service unit will consist of an Allis-Chalmers turbine of 2,100 horsepower capacity for a 32-foot head, direct-connected to an alternating-current generator of 1,750 kilovolt-amperes, 460 volts, 300 revolutions per minute. Girder cranes of 80-ton capacity will be installed in the generator room to handle the equipment. A gantry crane of the same capacity will be installed to operate the head gates and also the adjacent spillway gates. Another gantry crane of 20-ton capacity will be provided to operate the stop-log gates in the draft tubes. A transfer crane of 75-ton capacity located near the north end of the power house can serve either of the gantry cranes or the railway siding, and can lower equipment to the generator room through a hatch in the roof. Transformers will be placed on the roof of the power house to step the voltage up to 110,000 volts.

684. The top of the parapet wall on the power house, abutment sections and spillway sections, is at elevation 620 feet. The spillway sections of the dam, as planned by the licensee for the ultimate development, will provide for 18 spillway gates, 30 feet wide by 41 feet deep, and 19 gates 30 feet wide by 18.5 feet deep, all to be placed with their tops at elevation 600 feet when in the closed position. Hence, the sills of the smaller gates will be at elevation 581.5 feet. In the open position the bottoms of the gates will be flush with the under side of the deck at elevation 613 feet. The spillway will pass 1,000,000 second-feet without material damage to the principal structures. Each gate, 41 feet in depth, will be made up of two sections, the lower 22.5 feet deep and the upper 18.5 feet deep, both to work in the same gate slot. The smaller of these sections will be used in the 18.5 foot openings. The gate sections, as designed by the licensee, have fixed rollers at each end that bear against vertical rails attached to the gate slots. They will be operated with a gantry crane of 80-ton capacity. Extra slots are provided in front of the regular gate slots to take the gates and thus make the regular slots accessible for repairs.

685. For the initial development, a free spillway crest will be provided at elevation 581.5 feet, by placing the 22.5-foot sections in the deep gate openings.

686. Two fishways are being constructed, one at either bank of the stream. They are 20 feet wide and ascend on a slope of 1 vertical to 10 horizontal. Provision is made for a third fishway located at the lower end of Rock Island, to be constructed if and when the Secretary of Commerce and the proper State authorities consider it necessary. Provision is also made for the construction of locks, if and when required, along the right bank at the end of the dam.

687. *e. Economic features.*—The cost of the complete development of 12 units with a total capacity of 180,000 kilowatts was reported in the Seattle Daily Journal of Commerce of December 4, 1930, as \$28,000,000 or \$155.50 per kilowatt. If the annual operating expense is 12.5 percent of the capital cost, the cost of energy delivered on a 50 percent load factor would be 4.46 mills per kilowatt-hour

2. EARLIER PLANS OF DEVELOPMENT

688. No other comprehensive plans of development have been made for this site.

(G) VANTAGE

1. DETAILED DESCRIPTION

689. This site is located in sections 7 and 8, township 16 north, range 23 east, Willamette Meridian. At this point the Columbia River forms the boundary between Kittitas County and Grant County. The site is about 9 miles north of the town of Beverly, 30 miles east of the city of Ellensburg, 327 miles by river from the international boundary, 31 miles below the Rock Island plant, 26 miles above the Priest Rapids site, and 98 miles above the junction of the Snake River with the Columbia River. The general location is shown on plate no. 1, page 565.

a. Résumé.—

Drainage area.....	square miles.....	89, 700
Length of pool.....	miles.....	30
Length of dam.....	feet.....	3, 560
Height of dam (maximum section, foundation to walkway).....	do.....	128
Normal forebay elevation.....	do.....	540
Drawdown (elevation 540 feet to 535 feet).....	do.....	5
Useful pondage.....	acre-feet.....	27, 500
Natural low-water elevation.....	feet.....	488
Maximum known discharge (June 1894).....	second-feet.....	740, 000
Spillway capacity.....	do.....	1, 000, 000
Natural river flow (May 1913 to May 1931):		
Maximum discharge, 24 hours.....	do.....	528, 000
Mean discharge.....	do.....	121, 000
Minimum discharge, 24 hours.....	do.....	21, 000
Average static head.....	feet.....	43
Power capacity (Federal Power Commission definition)		
horsepower.....		111, 000
Proposed hydraulic capacity.....	second-feet.....	100, 000
Proposed generating capacity.....	kilowatts.....	300, 000

690. *b. Topography and geology.*—For about 17 miles above the Vantage site, the Columbia River flows in a southerly direction and is generally confined in a fairly straight and narrow channel with a fall of about 1.6 feet per mile. The dam site is located about 1

mile below Island Rapids and $1\frac{1}{4}$ miles above the highway bridge at Vantage. At the dam site the natural low-water elevation is 488 feet, the stream is about 800 feet wide at low stages, and flows south along the right bank, at the foot of high basalt cliffs. (See pl. no. 85.²) The major channel is 3,500 feet wide, flanked by steep basalt cliffs on both sides and is practically all inundated at the higher flood stages.

691. At the dam site, the floor of the valley is composed of a thick overburden of sand, gravel, and boulders lying on basalt of more or less fissured character. This overburden has been deposited by stream action, as the point of most southern advance of the glaciers is reported to be a few miles north of this site. No geological report is available for this dam site and the limited subsurface information available has been obtained by means of three drill holes. The location and log of these holes are shown on plate no. 85.² The results of the exploration are probably affected unfavorably on account of the extensive use of explosives during the drilling operations.

692. A site known as Island Rapids, located about 1.5 miles upstream, was also investigated. Topographic surveys were made as plotted on plate no. 86.² After considerable investigation this site was abandoned in favor of the Vantage site.

693. *c. Power possibilities.*—The mean monthly discharges for the natural and regulated flows for the 18-year period, April 1913 to March 1931, inclusive, are shown in tables nos. 26 and 50. The natural low-water elevation is 488 feet at the site. The proposed elevation of the forebay would be 540 feet, which is 8 feet below the natural low-water elevation at the Rock Island project now under construction. The maximum static head at the site would be 52 feet.

694. The power capacity of this site with natural discharge, computed in accordance with the formula defined by the Federal Power Commission, that is, $0.08 QH$, where Q is the discharge 90 percent of the time and H the average head; equals $0.08 \times 32,200 \times 43.0$ or 111,000 horsepower. The maximum monthly discharge for the 17-year period, April 1913 to March 1930, inclusive, was 480,000 second-feet and the corresponding head would be 19.4 feet. Higher discharges would probably reduce the head to such an extent that operation of the plant would not be feasible. Plate no. 87² contains 27 power graphs which compare the power possibilities of three schemes of regulation of discharge for low, mean, and high years and with three different hydraulic capacities. Computations are based on controlled forebay of 665 feet. In order to obtain three points on a curve and compare different schemes of regulation on some basis common to all, the hydraulic capacities were based on natural discharge for 35, 50, and 90 percent of the time. The installed kilowatt capacities are the product of these discharges, the corresponding static heads, and a constant, 0.068, based on 80 percent over-all efficiency, and should not be confused with any proposed installed capacities used elsewhere in this report. Based on 100 percent operation of plant, each graph shows installed kilowatt capacity monthly potential power, monthly available power limited by the particular hydraulic capacity, monthly and annual utilization and plant-capacity factors, and maximum output in kilowatt-years. Plate no. 88² contains graphs in which annual utilization and plant-capacity

² Not printed.

factors appearing on plate no. 87² are plotted with their corresponding values of hydraulic capacity, showing quite clearly the effect due to change of plant hydraulic capacity. As this capacity is increased, the utilization factor increases and plant capacity factor decreases. The greater the hydraulic capacity, the more difficult it becomes to keep it loaded, either due to a shortage of water or a decrease of head.

695. Table no. 132, which is self-explanatory, shows the power duration 35, 50, 65, 80, 90, and 100 percent of the time for the 17-year period ended March 1930 for natural flow and for seven assumed conditions or regulation and irrigation. In obtaining the regulated flows shown in that table, control of the following reservoirs was assumed after allowing for withdrawal of irrigation water, as stated in paragraph 178.

Reservoir:	<i>Approximate capacity (acre-feet)</i>
Hungry Horse-----	1, 100, 000
Flathead Lake-----	1, 540, 000
Priest Lake-----	569, 000
Pend Oreille Lake-----	1, 610, 000
Kootenay Lake-----	715, 000
Coeur d'Alene Lake-----	42 430, 000
Grand Coulee (low dam)-----	776, 000
Grand Coulee (high dam)-----	5, 028, 000
Chelan-----	665, 000
<hr/>	
Total (low dam)-----	7, 405, 000
Total (high dam)-----	11, 657, 000

696. In cases 2, 3, and 4 the Columbia Basin irrigation project would be irrigated with water from Clark Fork and Spokane River. In case 5 it would be irrigated with water from Clark Fork and the Spokane and Wenatchee Rivers.

TABLE NO. 132.—Principal data, Vantage site, for 17-year period ended March 31, 1930. For power-duration curves, see plate no. 89²

Plan	Regulation	Case no.	Grand Coulee Dam	Time	Flow	Static head fore-bay, elevation 540	Potential power, 80 per cent efficiency	Potential energy available annually				
					1,000 second-feet <i>Per cent</i>				<i>Feet</i>	1,000 kilowatts	1,000 kilowatt-years	
Natural...	No regulation-----	1	None-----	35	119.0	42.3	342	239				
				50	73.2	46.2	230	192				
				65	54.1	48.1	177	162				
				80	43.6	49.2	146	139				
				90	32.2	50.7	111	110				
				100	23.3	51.9	82	82				
				Gravity...	Upstream regulation without Columbia River storage—plan no. 2-A.	2	Low or high.	35	113.2	42.7	329	245
								50	79.7	45.6	247	212
								65	61.0	47.4	197	184
								80	49.6	48.5	164	159
90	43.8	49.2	146					145				
100	33.8	50.5	116					116				
	Upstream regulation including Columbia River storage—plan no. 2-A.	3	Low dam..					35	113.2	42.7	329	247
								50	78.7	45.7	245	212
								65	61.7	47.3	190	186
								80	50.1	48.5	165	161
				90	46.0	48.9	153	152				
				100	38.3	49.9	130	130				
						4	High dam..	35	107.6	43.2	316	258
								50	82.4	45.3	254	232
								65	72.2	46.3	227	217
								80	62.4	47.3	201	198
90	57.3	47.8	186					186				
100	51.0	48.4	168					168				

¹ Not printed.

² Includes 155,000 acre-feet now used by the Washington Water Power Co.

TABLE No. 132.—Principal data, Vantage site, for 17-year period ended March 31, 1930. For power-duration curves, see plate no. 89—Continued

Plan	Regulation	Case no.	Grand Coulee Dam	Time	Flow	Static head forebay, elevation 540	Potential power, 80 per cent efficiency	Potential energy available annually
					1,000 second-feet	Feet	1,000 kilowatts	1,000 kilowatt-years
Gravity	Upstream regulation including Columbia River storage, Quincy Flats irrigated from Wenatchee Lake—plan no. 6-A.	5	Low dam	35	114.0	42.7	331	246
				50	75.1	46.0	235	207
				65	61.2	47.4	197	185
				80	50.2	48.5	165	162
				90	45.4	49.0	151	159
Pumping	Upstream regulation without Columbia River storage—plan no. 4.	6	Low or high	100	37.9	49.9	129	129
				35	112.2	42.8	327	247
				50	78.4	45.7	244	213
				65	63.4	47.2	203	191
				80	52.9	48.2	173	169
	Upstream regulation including Columbia River storage—plan no. 4.	7	Low dam	90	46.8	48.8	155	154
				100	39.4	49.7	133	133
				35	108.2	43.1	317	245
				50	75.6	46.0	236	212
				65	63.5	47.2	203	193
	8	High dam	80	53.3	48.2	175	172	
			90	49.0	48.5	165	164	
			100	43.1	49.3	144	144	
			35	98.0	44.0	293	250	
			50	81.4	45.4	251	223	
				65	72.5	46.3	228	230
				80	64.1	47.1	205	203
				90	60.2	47.5	194	194
				100	55.5	47.9	181	181

697. The power available with natural discharge is shown by power duration curve plate no. 89² and table no. 132. Based on monthly values of natural discharge, the power available 100 percent of the time is 82,000 kilowatts; for 90 percent of the time it is 111,000 kilowatts. The last column of table no. 132 shows the annual energy available for various percentages of time for each case. Note that the power and energy as shown in this table, are not restricted by a plant capacity.

698. The greatest benefits that could be derived from any of the schemes of regulation there shown would occur with plan no. 4, case 8, which includes use of the Columbia River storage behind the Grand Coulee high dam. The power available under these conditions would be 181,000 kilowatts for 100 percent of the time, and 194,000 kilowatts for 90 percent of the time; which would be an increase over natural of 121 percent for power available 100 percent of the time and 75 percent for power available 90 percent of the time. The power duration is shown graphically on plate 89 for cases 6 and 8.

699. The increased energy in kilowatt-years due to different methods of regulation of case 8 over that of case 1 will be 121 percent (the same as the gain in power) for 100 percent of the time and a gain of 76 percent for 90 percent of the time.

700. Consideration was given to a capacity of plant which would deliver the prime power for plan no. 4, case 6, of 133,000 kilowatts on a 50 percent load factor, continuously. This would require a plant having a capacity of 266,000 kilowatts with a hydraulic capacity of 202,000 second-feet for the minimum head of 19.4 feet, at normal

² Not printed.

forebay level. In order to be conservative the hydraulic capacity was limited to 100,000 second-feet and generator capacity to 300,000 kilowatts. The continuous capacity of the plant would be 132,000 kilowatts, which would deliver the prime power on a load factor of 100 percent. The generators could be fully loaded when the head reaches 44 feet, which would occur when the flow is 97,900 second-feet or less, and would occur 62.3 percent of the time during the 17-year period for case 6. The power house as shown on plate no. 85² and estimates of cost, are based on a generator capacity of 300,000 kilowatts.

701. *d. Proposed development.*—The project works, as shown on plate no. 85,² involves the construction of a power house and a concrete spillway dam, both to be located on the same center line at right angles to the stream.

702. The power house will be of sufficient size to accommodate 12 units, each unit to consist of a propeller-type turbine with a hydraulic capacity of 8,330 second-feet for a minimum head of 19.4 feet. It will be direct-connected to a generator of 25,000 kilowatts capacity. The power house will extend across the low-water channel and for some distance upon the bank to the left. Test hole no. 3 shows broken basalt at elevation approximately 450 feet and extending to a depth of about 100 feet. The power house could be supported on this broken basalt which could be made impervious by asphalt grouting. Extensive subsurface investigations are necessary to establish without question the feasibility of the site. A 5-foot drawdown with a resulting pondage of 27,500 acre-feet would be sufficient for daily regulation. It is planned to use head increasers on the turbines to offset to some degree the tendency to drown them out at high river stages.

703. The spillway section would extend across the high-water channel on the left to the outcropping basalt cliffs. It would provide for 52 Stoney gates, each 25 feet high by 40 feet wide. The crest elevation would be 516.5 feet. A discharge capacity of 1,000,000 second-feet would be provided for, but the forebay elevation would necessarily rise to 542.5 feet, due to the excessive height of the tail water at this flow. Piers would support the gates and operating deck, the latter having a top elevation of 550 feet. There would be a short overflow section at the extreme left end anchoring into the cliff. The eastern half of this spillway section as shown by section A-A on plate no. 85 would be founded on solid basalt at elevation approximately 425 feet. This section would be used for ordinary discharges. The other half of the spillway section would be founded on the broken basalt as shown in section B-B of plate no. 85,² and would be protected downstream by an apron composed of articulated slab. This portion of the spillway would be used only during extreme floods when the tail-water level is high. The kinetic energy at the toe of the spillway would be 5,920 horsepower per lineal foot of clear crest assuming a fall to the apron at the toe of section A-A. Even at low tail water the depth over this apron would be approximately 60 feet. Therefore, it is considered that the kinetic energy could be safely dissipated.

704. Considerable forebay excavation in sand, gravel, and boulders would be required in order to secure a proper approach for the floods from Island Rapids to the proposed spillway dam. On the downstream side of the spillway it would also be necessary to carry out an extensive excavation, although its amount could be reduced consider-

² Not printed.

ably by excavating two pilot channels as shown on plate no. 85,² and letting the future floods widen and deepen them.

705. It is planned to construct locks on the right bank, if required, their location being as shown on plate no. 85.²

706. For construction purposes, the new highway now under construction on the floor of the valley would be utilized and would be supplemented by the construction of a new road on the right bank of the river which would later be operated as a permanent approach to the power house.

707. The proposed reservoir site lies in a region of very sparse population. Practically no tillable land would be flooded out at the proposed forebay level. There are no bridges crossing this portion of the stream and only three hand-operated ferries. Therefore, the reservoir flood rights should not be difficult or expensive to acquire. At the present time a new State highway is being built directly in the main channel and would have to be condemned.

708. *e. Economic features.*—The principal items of construction and the estimated capital cost of the project are shown in table no. 133. The cost of locks and other navigation features in connection with the power project is not shown herein, but will be given in a later section under "Combined uses." It will be noted that the total capital cost per kilowatt of installed capacity would be \$123 for public development, and \$125 for private development.

TABLE No. 133.—*Estimate of capital cost of development at vantage site for an installed capacity of 300,000 kilowatts*

Preliminary expense	\$891,000
Channel improvements for backwater reduction	350,000
Forebay excavation	655,000
Reservoir	450,000
River diversion	1,400,000
Spillway dam	9,830,050
Intake and power-house substructure	5,421,000
Power-house superstructure	1,400,000
Hydraulic equipment	3,175,200
Electrical equipment	2,880,000
Cranes and miscellaneous equipment	160,000
Tailrace excavation	500,000
Contingencies, 10 percent	2,711,225
Total field cost	29,823,475
Overhead, 12½ percent	3,727,934
Total construction cost	33,551,409
For public development:	
Total construction cost	33,551,409
Interest charged during construction, 8 percent	2,684,112
Total capital cost	36,235,521
Capital cost per kilowatt	123
For private development:	
Total construction cost	33,551,409
Interest charged during construction, 12 percent	4,026,169
Total capital cost	37,577,578
Capital cost per kilowatt	125

² Not printed.

709. Plate no. 90² shows graphically the cost per kilowatt-hour of energy generated for plant capacity factors varying from 10 to 100 percent. It will be noted that the cost per kilowatt-hour for a 50 percent plant capacity factor is 1.75 mills for public development, 2.45 mills for private development for an annual operating cost of 8.57 percent of the capital cost, and 3.55 mills for private development for an annual operating cost of 12½ percent of the capital cost. The upper curve shows the cost of energy generated by steam power burning fuel oil worth \$1 per barrel. The cost of transmission should be added to the hydrogenerated energy to make it comparable with the cost of that generated by steam.

710. The financial set-up and annual operating cost for both public and private development are shown in table 134. They are based on delivering power to the low-tension side of step-up transformers, including high-tension insulators, switches, arresters, and oil circuit-breakers, which are included in the terminal stations for transmission lines.

TABLE NO. 134.—*Estimate of annual cost of power production at Vantage, with an installed capacity of 300,000 kilowatts*

	Public development	Private development
1. Investment cost:		
Lands and water rights and nondepreciated items.....	\$601,490	\$623,768
Dams and substructures.....	16,667,492	17,284,807
Subtotal "A".....	17,268,982	17,908,575
Power plant, machinery and superstructures.....	18,966,539	19,669,003
Total development, capital cost.....	36,235,521	37,577,578
2. Basis of annual cost:		
(a) Return or interest in percent of capital cost.....	4	6
(b) Amortization of bonds, 40-year sinking-fund basis, in percent of capital cost.....	1.05	0
(c) Depreciation:		
(1) Land and water rights, in percent of capital cost.....	0	0
(2) Dams and substructures, 100-year sinking-fund basis, in percent of capital cost.....	.08	.018
(3) Power plant, machinery and superstructures, 30-year sinking-fund basis, in percent of capital cost.....	1.78	1.26
(d) Taxes, in percent of capital cost.....	0	1.5
(e) Maintenance and operation, expense, including 10 percent of cost of labor and material for general expense.....	148,616	148,616
3. Total annual cost:		
Items included in subtotal "A":		
Interest or return.....	690,759	1,074,515
Amortization.....	181,324	.....
Depreciation.....	13,333	3,111
Taxes.....	.....	268,628
Maintenance and operation (included under power plant).....	.....	.....
Subtotal.....	885,416	1,346,254
Power plant:		
Interest or return.....	758,661	1,180,140
Amortization.....	199,149	.....
Depreciation.....	337,604	247,829
Taxes.....	.....	295,035
Maintenance and operation.....	148,616	148,616
Subtotal.....	1,444,030	1,871,620
Total project:		
Interest or return.....	1,449,420	2,254,655
Amortization.....	380,473	.....
Depreciation.....	350,937	250,940
Taxes.....	.....	563,663
Maintenance and operation.....	148,616	148,616
Total annual cost.....	2,329,447	3,217,874
Total annual cost in percent of capital cost.....	6.42	8.57

² Not printed.

2. EARLIER PLANS OF DEVELOPMENT

711. No comprehensive plans of development have previously been made for this site.

(H) PRIEST RAPIDS

1. DETAILED DESCRIPTION

712. This site is located at the foot of Priest Rapids, in sections 2 and 3, township 13 north, range 23 east, Willamette meridian, about 28 miles east of the city of Yakima, and about 13 miles south of the town of Beverly. The site is 352 miles by river from the international boundary, 56 miles below the Rock Island plant, 26 miles below the Vantage site, and 73 miles upstream from the junction of Snake River with Columbia River. The Priest Rapids site is the farthest downstream site on the upper Columbia River which was investigated in this office. The general location of the site is shown on plate no. 1, page 565.

713. Two plans of development for this site have been prepared by this office, which will be differentiated hereafter in the discussion as the "low dam" and the "high dam." The low dam would use all the available head up to the Vantage site, while the high dam would flood out the Vantage site and utilize all the head up to the Rock Island plant now under construction.

714. *a. Low dam.*—This plan of development would involve the construction of a dam to a height which would back the water to the Vantage site.

a'. Résumé.—

Drainage area.....	square miles	95, 400
Length of pool.....	miles	26
Length of dam, including earth embankments.....	feet	10, 500
Height of dam (maximum section, foundation to walkway, excluding cut-off).....	feet	153
Normal forebay elevation.....	do	488
Drawdown.....	do	5
Useful pondage.....	acre-feet	38, 000
Natural low-water elevation.....	feet	406
Maximum known discharge (June 1894).....	second-feet	740, 000
Spillway capacity.....	do	1, 000, 000
Natural river flow (April 1913 to March 1931 inclusive):		
Maximum discharge, 24 hours.....	do	528, 000
Mean discharge.....	do	121, 000
Minimum discharge, 24 hours.....	do	21, 000
Average static head.....	feet	75. 3
Power capacity (Federal Power Commission definition)	horsepower	194, 000
Proposed hydraulic capacity.....	second-feet	93, 000
Proposed installed capacity.....	kilowatts	390, 000

715. *b'. Topography and geology.*—The dam site selected by this office is located near the foot of the rapids, at the end of Panhandle Island. See plate no. 91² for topography. The stream has two channels at this point at all but the highest stages. In addition, there is a small natural channel on the right bank which has been utilized by the Hanford Irrigation & Power Co. as a forebay channel leading to their existing power plant located about a quarter of a mile below the selected dam site. Downstream from Panhandle Island the river flows in a single channel at all stages. This channel is shallow and has a width at ordinary stages of approximately 2,000 feet. The natural low-water elevation, a few hundred feet below the dam site, is 406

²Not printed.