

520. Table no. 107 shows the annual operating cost for both public and private development. Note that this cost is 6.3 percent of the capital cost for public development, and 8.5 per cent of the capital cost for private development. Plate no. 42<sup>2</sup> 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 mill for public development, 1.4 mills for private development for an annual operating cost of 8.50 percent of the capital cost, as derived from table no. 107, and 2 mills for private development for an annual operating cost of 12.5 percent of the capital cost, as frequently used by the public utility companies.

TABLE NO. 107.—*Estimate of annual cost of power production at Kettle Falls with an installed capacity of 447,700 kilowatts*

	Public development	Private development
<b>1. Investment cost:</b>		
Lands and water rights.....	\$10,605,359	\$10,998,151
Dam and substructures.....	5,955,665	6,176,246
Subtotal "A".....	16,561,024	17,174,397
Power plant machinery and superstructure.....	13,514,124	14,014,647
Total development capital cost.....	30,075,148	31,189,044
<b>2. Basis of annual cost:</b>		
(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) Lands and water rights in percent of capital cost.....	0	0
(2) Dam and substructures, 100-year sinking fund basis, in percent of capital cost.....	0.08	0.018
(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
<b>3. Total annual cost:</b>		
Items included in subtotal "A":		
Interest or return.....	662,441	1,030,464
Amortization.....	173,891	
Depreciation.....	4,764	1,111
Taxes.....		257,616
Subtotal.....	841,096	1,289,191
Power plant:		
Interest or return.....	540,565	840,879
Amortization.....	141,898	
Depreciation.....	240,551	176,584
Taxes.....		210,219
Maintenance and operation.....	148,616	148,616
Subtotal.....	1,071,630	1,376,298
Total project:		
Interest or return.....	1,203,006	1,871,343
Amortization.....	315,789	
Depreciation.....	245,315	177,695
Taxes.....		467,835
Maintenance and operation.....	148,616	148,616
Total annual cost.....	1,912,726	2,665,489
Annual operating cost in percent of capital cost.....	6.3	8.5

## 2. EARLIER PLANS OF DEVELOPMENT

521. The Washington Water Power Co. made application to the Federal Power Commission on April 4, 1925, for a license to develop the site in pursuance of a preliminary permit issued July 26, 1922. Their plans called for a normal forebay elevation of 1,245 feet, which would back water up to the Little Dalles site and create a maximum head of 80 feet at minimum flow.

<sup>2</sup> Not printed.

522. *a. Principal works proposed.*—As planned, in the application for license, a dam would be constructed in the main channel above the upper falls, about midway of Hayes Island, thence an abutment section would extend downstream to the dam crossing minor channel at the south end of the island. Thence, another abutment section would cross the peninsula to connect with the power house. The major dam was designed with seventeen gate openings, each 50 feet wide, fourteen, 45 feet high, and three, 22.5 feet high. The minor dam provided for 6 gate openings, 40 feet wide, and one 20 feet wide, all of which would be 20 feet high. The total spillway capacity would be approximately 825,000 second-feet.

523. *b. Power.*—The licensee proposed to develop 150,000 continuous and 80,000 secondary horsepower, by stages. A total of 8 units was proposed, the first 4 to be propeller-type turbines; the other 4 might be either propeller or Francis-type turbines. The generators were to be rated at 27,000 kilovolt-amperes, 90 percent power factor, 11,000 volts, 3-phase, 60-cycle, and 128.6 revolutions per minute. The voltage was to be stepped up to 154,000 volts by a bank of 24 transformers, each of 9,000 kilovolt-amperes capacity.

524. *c. Estimated cost.*—The estimated cost of the complete development, to be made in 10 stages is approximately \$110 per kilowatt.

## (B) GRAND COULEE

### 1. DETAILED DESCRIPTION

525. This site is located on the Columbia River at the head of the Grand Coulee, in section 1, township 28 north, range 30 east, Willamette meridian. It is 75 miles westward of the city of Spokane, and is 75 miles northeast of the city of Wenatchee. The site is 151 miles, by river, from the international boundary, 109 miles below the Kettle Falls site, 53 miles above the Foster Creek site, and 274 miles above the mouth of the Snake River. The stream at this location flows due north through a canyon approximately 1,000 feet deep, 2,000 feet wide at the bottom, and a mile wide at the top.

526. The country rock is a light-gray, medium-grained granite, except along the upper rim of the left bank, where basalt is found. Both slopes show many outcrops of granite, with the intervening overburden on the slopes generally of shallow depth. Test holes indicate that this formation extends across the bottom of the canyon at an elevation of about 870 feet, for a width of 2,500 feet and then rises with a slope of about one vertical on two horizontal on either side. See plate no. 43 for topography and for records of core drilling. Information of subsurface conditions, as obtained from 16 drill holes, indicates in general a dense rock, interspersed by a few open seams. Practically all of the drill water returned to the surface. With adequate grouting, the formation appears capable of sustaining a dam of any reasonable height. The overburden varies in depth from 40 feet at midstream to 200 feet at the toes of the surface slopes. It consists of sand, gravel, and boulders in the upper portions, and principally a heavy blue clay for a thickness of about 40 feet directly over bedrock. Of the 16 drill holes just mentioned, 14 were put down by the State of Washington in 1921, and 2 were put down by this department in 1930.

527. The elevation of natural low water is 933 feet, and for maximum month of record (436,000 second-feet) was 980 feet. The estimated flood level for a discharge of 910,000 second-feet is at elevation 1,022 feet. The head of the Grand Coulee is situated on the left bank directly above the dam site. The elevation of the Coulee floor is, roughly, 1,500 feet.

528. Monthly stream-flow records have been prepared by the United States Geological Survey for this site for the 18-year period from April 1913 to March 1931 inclusive. The mean monthly discharges for natural and regulated flow are shown in tables nos. 23 and 47. It will be observed that low water obtains from October to April each year, after which the discharge rapidly increases to a maximum about the middle of June and then decreases to low water again in October.

529. Studies of this site have been made for two distinct forebay levels, as follows:

a. Low Dam (normal forebay elevation 1,157.6 feet), which would back water to Kettle Falls and drown out the Narrows site on Spokane River.

b. High Dam (normal forebay elevation 1,287.6 feet), which would back water to the international boundary and drown out Kettle Falls on the main stream, and the Narrows and Fish Hawk sites on Spokane River.

530. These studies will be described separately hereafter.

531. a. *Low dam.*—The set-up, involving the low dam at the Grand Coulee, has been considered in conjunction with both the gravity and pumping plans of irrigation of the Columbia Basin irrigation project. In the gravity plan it would be purely a commercial generating plant, the only effect of this irrigation being the diversion of water upstream at Albany Falls on Clark Fork, while in the pumping plan a large block of power, principally secondary power, would be used directly at the site to pump water into the Grand Coulee for irrigation of the Columbia Basin irrigation project. These plans will be referred to hereafter as the gravity and pumping plans.

a'. *Résumé*—

Drainage area.....	square miles.....	74, 100
Length of pool.....	.....miles.....	109
Length of dam.....	.....feet.....	3, 720
Height of dam (maximum section, foundation to walkway).....	.....do.....	360
Drawdown (elevation 1,157.6 to 1,127.6 feet).....	.....do.....	30
Useful storage.....	.....acre-feet.....	776, 000
Natural low-water elevation.....	.....feet.....	933
Maximum known discharge (June 1894).....	.....second-foot.....	725, 000
Spillway capacity.....	.....do.....	910, 000
Natural river flow (April 1913 to March 1931, inclusive):		
Maximum discharge (24 hours).....	.....do.....	492, 000
Average discharge.....	.....do.....	109, 000
Minimum, average for 12 days, discharge.....	.....do.....	17, 000
Average static head.....	.....feet.....	210. 4
Power capacity (Federal Power Commission definition		
(horsepower).....		478, 000
Proposed hydraulic capacity:		
Gravity plan.....	.....second-foot.....	73, 600
Pumping plan.....	.....do.....	85, 000
Proposed installed capacity:		
Gravity plan.....	.....kilowatts.....	1, 066, 000
Pumping plan.....	.....do.....	1, 230, 000

532. The average static head for the 17-year period ended March 31, 1930, would be 210.4 feet, based on natural flow and a constant

forebay level of 1,157.6 feet. The head varies from a maximum of 224.6 feet, for a discharge of 18,800 second-feet (minimum monthly flow), to 177.6 feet for a discharge of 436,000 second-feet (maximum monthly flow). As previously stated, the elevation of the tail-water, with the assumed maximum discharge, is estimated to be 1,022 feet, which would still leave a head of 138 feet on the turbines under the extreme estimated flood conditions; hence the plant could operate at any stage of the river. The power capacity for natural flow as defined by the Federal Power Commission is 478,000 horsepower.

533. *b'. Power possibilities.*—Investigation of backwater effects has been made to determine the relation of range of forebay at the Grand Coulee site to the tailrace at the Kettle Falls site, with tentative results as shown in table no. 108.

TABLE No. 108.—*Backwater conditions at Kettle Falls*

Discharge at Kettle Falls	Forebay elevation at Grand Coulee	Tailrace elevation at Kettle Falls		Backwater effect
		Natural	With Grand Coulee dam constructed	
<i>Second-feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Feet</i>
22,220	1,157.6	1,165.0	† 1,165.0	0
22,220	1,159.6	1,165.0	1,165.0	0
156,400	1,157.6	1,180.9	† 1,180.9	0
468,000	1,157.6	1,197.4	1,198.2	.8
735,000	1,157.6	1,208.7	1,209.4	.7

† Backwater effect runs out at Grand Rapids.

534. With the forebay maintained at elevation 1,157.6 feet, these data show that the backwater effect at Kettle Falls would be very small for high flows and nil for the lower discharges. The spillway of the dam was designed to maintain the forebay at elevation 1,157.6 feet for ordinary discharges, but, to pass the maximum estimated flood of 910,000 second-feet, the forebay would rise to elevation 1,159.6 feet.

535. Plate no. 44<sup>2</sup> 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 hydraulic capacities and for three conditions of flow. The latter consists of natural flow (case 1 of table no. 109), regulated flow with gravity plan (case 2 of table no. 109), and regulated flow with pumping plan (case 6 of table no. 109). Note especially that graphs 10 to 27, inclusive, take into account the effect of regulation of upstream storage, but no regulation of storage at the site. The three flows considered on plate no. 44<sup>2</sup> are those obtaining under natural conditions, 35, 50, and 90 percent of the time. 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 the résumé and hereafter in this report. The three plant capacities expressed in kilowatts are those capacities which correspond to the above-selected flows, and to the heads obtaining at those flows at 80 percent efficiency. The tables below the graphs show the utilization and plant capacity factors for 100 percent operation. The resulting plant capacity and utilization factors are shown graphically on plate no. 45<sup>2</sup> for natural flow and for regulated flow for both the pumping and gravity plans. By comparison of graphs 2, 11, and 20 of plate no. 44,<sup>2</sup> it is noted that regulation increases

<sup>2</sup> Not printed.

the annual utilization factor from 58 percent to 71 and 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 equalled or exceeded 50 percent of the time. (See case 1 of table no. 109). Likewise, the total energy available for the low year with the above plant capacity is respectively 637,000, 721,000, and 686,000 kilowatt-years for natural flow and for regulated flow for pumping and gravity.

536. Table no. 109 shows the flow and 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:	Approximate capacity in 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.....	<sup>36</sup> 430, 000
Grand Coulee (low dam).....	776, 000
Total.....	6, 740, 000

537. With the exception of case 1, the flow as shown in table no. 109 does not include water as demanded for irrigation in any of the various pumping or gravity plans. In cases 2 and 3 the Columbia Basin irrigation project would be irrigated by gravity with water from Clark Fork and Spokane River. In case 5 it would be irrigated by gravity with water from Clark Fork, Spokane, and Wenatchee Rivers. In cases 6, 7, 9, and 10, all the irrigation water would be pumped from the Columbia River at the Grand Coulee site.

TABLE NO. 109.—Principal data, Grand Coulee Low Dam, for the 17-year period ended Mar. 31, 1930. For power-duration curves, see plates nos. 47<sup>a</sup> and 48<sup>a</sup>

Plan	Regulation	Case no.	Time	Flow	Static head <sup>b</sup>	Potential power at 80 percent efficiency		Potential energy available annually	
						Total	Commercial <sup>a</sup>	Total	Commercial <sup>c</sup>
			Per cent	1,000 sec.-ft.	Feet	1,000 kw.	1,000 kw.	1,000 kw.-yrs.	1,000 kw.-yrs.
Natural...	No regulation.....	1	35	109.0	208.6	1,546	1,546	1,030	1,030
			50	65.7	215.2	961	961	788	788
			65	47.8	218.4	710	710	644	644
			80	38.2	220.3	572	572	544	544
			90	28.4	222.4	430	430	425	425
			100	18.8	224.6	287	287	287	287
Gravity...	Upstream regulation without Columbia River storage—Plan no. 2-A.	2	35	101.0	209.7	1,435	1,435	1,025	1,025
			50	68.0	214.8	993	993	844	844
			65	52.8	217.5	781	781	722	722
			80	42.6	219.4	635	635	617	617
			90	36.7	220.6	551	551	546	546
			100	27.3	222.6	413	413	413	413
Gravity...	Upstream regulation including Columbia River storage—Plan no. 2-A.	3	35	101.0	-----	1,417	1,417	1,006	1,006
			50	67.7	-----	968	968	826	826
			65	53.7	-----	783	783	723	723
			80	43.3	-----	625	625	609	609
			90	39.6	-----	557	557	553	553
			100	32.8	-----	446	446	445	446

<sup>a</sup> Not printed.

<sup>b</sup> For normal forebay elevation of 1,157.6 feet, with a maximum draw-down of 30 feet, as regulated in cases 3, 5, 7, and 9. The head for these cases varies from year to year depending on operation.

<sup>c</sup> Total less pumping.

<sup>36</sup> Includes 155,000 acre-feet now used by the Washington Water Power Co.

TABLE No. 109.—Principal data, Grand Coulee Low Dam, for the 17-year period ended Mar. 31, 1930. For power-duration curves, see plates nos. 47 and 48—Continued

Plan	Regulation	Case no.	Time	Flow	Static head	Potential power at 80 percent efficiency		Potential energy available annually	
						Total	Commercial	Total	Commercial
			Per cent	1,000 sec.-ft.	Feet	1,000 kw.	1,000 kw.	1,000 kw.-yrs.	1,000 kw.-yrs.
Gravity	Upstream regulation including Columbia River storage. Quincy Flats irrigated from Wenatchee Lake—Plan no. 6-A.	5	35	101.0	-----	1,440	1,440	1,015	1,015
			50	68.2	-----	991	991	836	836
			65	55.5	-----	778	778	719	719
			80	44.9	-----	628	628	611	611
			90	39.7	-----	547	547	543	543
Pumping	Upstream regulation without Columbia River storage—Plan no. 4.	6	100	33.9	-----	456	456	456	456
			35	96.3	210.4	1,377	974	1,017	775
			50	68.1	214.8	994	792	861	701
			65	55.9	216.9	825	666	766	630
			80	45.8	218.8	681	568	664	559
Pumping	Upstream regulation including Columbia River storage—Plan no. 4.	7	90	39.9	219.9	597	522	594	520
			100	32.9	221.4	495	495	495	495
			35	96.3	-----	1,372	971	997	768
			50	68.0	-----	964	757	838	672
			65	56.0	-----	785	643	738	608
Pumping	Upstream regulation including Columbia River storage. Partial pumping power furnished by downstream plants, no. 4.	9	80	48.2	-----	665	564	652	551
			90	42.7	-----	602	526	599	518
			100	37.4	-----	520	520	520	520
			35	96.3	-----	1,372	976	997	787
			50	68.0	-----	964	792	838	716
Pumping	No regulation. Same as case 1, excepting that the flow has been reduced by irrigation demand.	10	65	56.0	-----	785	681	738	652
			80	48.2	-----	665	608	652	600
			90	42.7	-----	602	575	599	572
			100	37.4	-----	520	500	520	500
			35	102.0	209.6	1,450	1,040	972	727
			50	61.8	215.9	907	690	749	585
			65	46.4	218.7	690	553	625	507
			80	36.6	220.6	549	429	528	417
			90	27.3	222.6	414	355	410	354
			100	18.8	224.6	287	287	287	287

538. The commercial power, as shown for cases 6, 7, 9, and 10, is the power available after deducting that necessary for pumping. In case 9, a part of the power necessary for pumping would be furnished by Columbia River sites above the Snake River other than the Grand Coulee, in order to effect a higher utilization of the river as a whole. Case 10 covers the condition of irrigation by pumping with power generated at Grand Coulee without regulation at the Grand Coulee or at any upstream reservoirs. The last two columns show the annual energy available in kilowatt-years for certain percentages of time for each case. Note that the available power and energy as shown in table no. 109 are not limited by a plant capacity which is in marked contrast to the data presented on plates nos. 44 and 46, both of which are limited by plant capacities.

539. As stated in the introduction to this section of the report, the columns showing durations of flow, power, and energy each refer to the percent of time and have no direct relation to each other. For instance, in case 7, 100 percent of the time, the total power is given as 520,000 kilowatts, and the commercial as 320,000 kilowatts. It does not follow that the pumping power was 200,000 kilowatts for the month of minimum total power. As a matter of fact, the minimum total power, amounting to 520,000 kilowatts, occurred in March 1930, while the minimum commercial power, amounting to 320,000 kilowatts, occurred in May 1929 when the required pumping power was 716,000 kilowatts or a total of 1,036,000 kilowatts. The

exceptionally large requirement for pumping power in this month was caused by the replenishment of storage of irrigation water in the Grand Coulee Reservoir, as indicated on plate no. 46<sup>2</sup> hereafter explained.

540. The total potential power at the site in cases 1, 3, and 7 is shown graphically on plate no. 47<sup>2</sup> by duration curves prepared for the 17-year period ended March 31, 1930. Note that the total available power 90 percent of the time for natural flow (case 1), is 430,000 kilowatts; for full regulation, gravity plan (case 3), is 557,000 kilowatts and for full regulation, pumping plan (case 7), is 602,000 kilowatts as shown in table no. 109. Hence, the pumping plan exceeds the gravity plan in power available 90 percent of the time by 45,000 kilowatts, or 8 percent.

541. The commercial power available after deducting the power required for pumping in cases 7, 9, and 10, is shown graphically on plate no. 48<sup>2</sup> as duration curves prepared for the 17-year period ended March 31, 1930. Note that about 350,000 kilowatts are available 99 percent of the time with no regulation (case 10). Note also that the commercial power available 90 percent of the time is 526,000 kilowatts for case 7, and 575,000 kilowatts for case 9.

542. The distribution of power for the 17-year period that ended March 31, 1930, is shown for case 7 on plate no. 46.<sup>2</sup> The upper limit of the graphs indicates the total available power for a hydraulic capacity of 85,000 second-feet at 80 percent efficiency, and the shaded area shows the power required to pump irrigation water for the Columbia Basin irrigation project at 70 percent efficiency. The irrigation requirements are fully discussed elsewhere in this report. As shown therein, the maximum demand for each month, including an allowance of 1,000 second-feet for possible leakage from the Grand Coulee Reservoir, is as follows:

Month:	Maximum demand (second feet)
April.....	7, 440
May.....	11, 650
June.....	11, 340
July.....	12, 160
August.....	11, 670
September.....	8, 240
October.....	4, 030
All winter months.....	1, 000

543. The static pumping head as used in the preparation of the graphs, amounts to 415 feet plus the drawdown in the Columbia River forebay due to regulation. This head is shown graphically by the stepped line in the upper chart which refers to the scale at the right. The upper chart also shows the amount of storage in the Grand Coulee Reservoir that would be required to supply the above irrigation demands 100 percent of the time. A drawdown to elevation 1,560 feet (214,000 acre-feet) would be allowable in July, but in April the reservoir could be drawn down to elevation 1,553 (365,000 acre-feet and still supply the irrigation demands. The lowest drawdown occurred in the month of April in the years 1920, 1924, and 1929. Concerning the unusual climatological conditions for these periods, official reports of the United States Weather Bureau for the Washington section are quoted as follows:

April 1920 was the coldest April since climatological record of the State began in 1890. The precipitation was decidedly more than normal and rainy days

<sup>2</sup> Not printed.

were so frequent and the soil so cold and wet that preparing the ground, seeding, and planting were greatly delayed.

April 1924: A marked deficiency in precipitation, and unseasonably low night temperatures in the eastern division from the 15th to 26th were the outstanding features of the weather of the month.

April 1929: This was the coldest April of record and frosts were frequent and the season was from one to three weeks late.

544. These data indicate that the seasons during the years in question were unusually cold and backward, and that there probably would not have been the usual demand for irrigation water. Any actual deficiency could be met by supplying additional pumping power from an outside source.

545. The portions of the shaded area below the heavy line on plate no. 46<sup>2</sup> represent the secondary power that would be supplied by other Columbia River plants as set up in case 9 of table no. 109, in order to effect a more economical utilization of the stream as a whole. This heavy line represents the commercial power available, month by month, at Grand Coulee as derived from the water-supply studies, on the assumption that Columbia River Reservoir would be regulated to secure uniform power output in all the plants in that section of the river between Grand Coulee and Priest Rapids, inclusive. This plan penalizes power output at Grand Coulee to produce the greatest system output. In general, plate no. 46<sup>2</sup> shows that 500,000 kilowatts of prime power are available 100 percent of the time for commercial use with an installed hydraulic capacity of 85,000 second-feet.

546. The energy required for pumping an acre-foot of water averaged 585 kilowatt-hours for the 17-year period, as set up in case 7. The maximum requirement for pumping power was 722,000 kilowatts occurring in May 1920, the average was 301,100 kilowatts, and the minimum was 22,600 kilowatts to provide for leakage in the Grand Coulee Reservoir, except that in January 1930 no pumping was done, the leakage being supplied wholly from storage.

547. *c'. Proposed development.*—The pumping plan of development involves the construction of a straight gravity dam at right angles to the stream, a power house parallel and adjacent to the downstream face of the dam near the left bank, and a pumping plant paralleling the left bank and located upstream from the dam. See plate no. 49.<sup>2</sup> The development for the gravity plan, that is for a purely commercial power plant, would be practically the same, excepting that the pumping plant would be omitted. Locks for navigation if required, would be located along the right bank.

548. In either plan the spillway would occupy the central portion and right end of the dam. (See pl. no. 50<sup>2</sup> for sections of dam.) Radial gates, 48 in number, each 35 feet wide by 25 feet high, and 12 radial gates, each 35 feet wide by 18 feet high, would provide spillway capacity of 910,000 second-feet with forebay at elevation 1,159.6 feet, which is 2 feet above normal. The total length of the spillway would be 2,460 feet. A 30-foot draw-down would give a useful storage of 776,000 acre-feet.

549. Methods of dissipating the kinetic energy that would be generated at the toe of the spillway section have been carefully investigated. Table no. 110 shows the general characteristics of the higher dams in the United States that are subject to deep overflow. Aside from the proposed Grand Coulee Dams, there are only two that show

<sup>2</sup> Not printed.

a kinetic energy over 10,000 horsepower per lineal foot of crest, neither of which had been operated at the date of the report. Note that the kinetic energy is computed on the net crest length, and not on the total length of the spillway section, and on the basis of the total difference in head between the forebay and the top of the bucket, making no allowance for depth of tail water, as this is variable, and, further, because the operation of the gates can be, and oftentimes is, independent from the tail-water elevation.

TABLE NO. 110.—*Characteristics of certain dams*

Name and location	Maximum flow and discharge per foot of clear crest	Depth of flow over crest and maximum fall to apron	Kinetic energy for maximum fall per foot of clear crest	Depth of water cushions for maximum flow
	<i>Sec.-ft.</i>	<i>Feet</i>	<i>Horsepower</i>	<i>Feet</i>
Ariel Dam, Lewis River at Ariel, Wash.....	130,000 565			
Bagnell Dam, Osage River, Mo.....	162,000 396	22 127	5,720	69
Baker River Dam, Baker River, Concrete, Wash.....	27,400 125	12 245	3,500	
Bull Run Dam, Portland, Oreg.....	21,000 175	14 175	3,500	8
Calderwood Dam, Little Tennessee River.....	200,000 333	20 200	7,670	65
Cheat Haven Dam, Cheat River, W. Va.....	150,000 281	17 96	3,060	34
Chute-A-Caron Dam, Saguenay River, Quebec.....	600,000 975	40 182	20,200	
Conowingo Dam, Susquehanna River, Md.....	880,000 430	22.5 93.5	4,570	25
Grand Coulee Low Dam, Columbia River.....	910,000 481	24 272	14,850	132
Grand Coulee High Dam, Columbia River.....	910,000 481	24 402	22,000	132
Holter Dam, Missouri River, Mont.....	215 15	100 15	2,450	62
Keokuk Dam, Mississippi River.....	142 30	11 30	629	
Long Lake Dam, Spokane River, Wash.....	65,000 434	19 190	9,380	
Martin Dam, Tallapoosa River, Ala.....	243 317	16 70	4,100	
Mitchell Dam, Coosa River, Ala.....	300,000 491	19 90	2,850	
Morony Dam, Missouri River, Mont.....	120,000 250,000	26 180	5,020	
Narrows Dam, Yadkin River, N.C.....	257 170,000	11 20	5,250	
Ohl Dam, Kiso River in Japan.....	323 209,000	161 25	5,900	56
Oxford Dam, Catawba River, N.C.....	464 70,000	90 18	4,740	
Pit River No. 3, Pit River, Calif.....	290 180,000	120 24	3,980	
Ruskin Dam, Stave River, British Columbia.....	562 30,060	175 19.6	11,200	
Spillway No. 4, Isle Malgine, Saguenay River, Quebec.....	563 334	27.5 111	7,510	
Stoney Gorge Dam, Stoney Creek, Calif.....	32,000 154	12 12	4,240	
Watanga River Dam, Horseshoe, Vt.....	311 685,000	18 92.5	3,270	
Wilson Dam, Tennessee River, Muscle Shoals.....				

550. For the low and high Grand Coulee Dams, the energy at the toe would be 14,850 and 22,000 horsepower per lineal foot, for the maximum fall to the spillway apron, or 7,650 and 14,900 horsepower, respectively, for a fall to the tail-water surface at elevation 1,022 feet

for capacity flows. The depth-of-water cushion for maximum discharge would be 132 feet. Extensive tests with large-scale models will be necessary to prove beyond question the feasibility of the spillway sections, as outlined above and shown on plates nos. 49 and 50.<sup>2</sup> However, the experience of the Aluminum Co. of America with their spillways, as reported in the March and May 1931 numbers of Civil Engineering, would tend to show that the kinetic energy can be safely dissipated in the deep-water cushion existing at the higher flows. Stringent rules for regulation of the crest gates would have to be made and enforced.

551. The power house would be of sufficient size to accommodate 15 main units in the pumping plan, as shown on plate no. 49, or 13 main units in the gravity plan, omitting the 2 units shown in the pumping plan at right angles to the dam. Each unit would consist of a vertical Francis turbine of 5,670 second-feet capacity, direct-connected to a generator of 82,000-kilowatt capacity. Hence, the total installed capacity for the pumping plan would be 1,230,000 kilowatts, and for the gravity plan, 1,066,000 kilowatts. In the pumping plan 12 units would be connected to 6 outgoing power lines through oil circuit-breakers and transformers. The voltage would be stepped up to 220,000 volts. See wiring diagram on plate no 59.<sup>2</sup> Seven of these units and the three remaining units would be connected direct to the motors in the pumping plant. In the gravity plan, 12 units would serve the 6 outgoing lines, with 1 unit in reserve. Two house units of 500 kilowatts each would also be provided.

552. The pumping plant would consist of 10 units. Each unit would be composed of two separate 55,000-horsepower motors direct-connected to their respective pumps. The two pumps in each unit would be connected in series hydraulically, and would have a capacity of 1,600 second-feet. Ten steel penstocks, 11 feet 6 inches in diameter, would connect the units with the canal at the head of the Grand Coulee.

553. For construction purposes it is planned to extend a branch line of the Great Northern Railway from Mansfield to the site, a distance of 34 miles, or extend a branch line of the Northern Pacific from Coulee City.

554. The reservoir is located in a sparsely populated district. Little tillable land would be affected. The State highway bridge at Kettle Falls, the only bridge crossing the Columbia within the reservoir area, will not be affected. It would be necessary to reconstruct a few small bridges crossing tributaries.

555. The natural low water at the Narrows power site on the Spokane River near its mouth has an elevation of about 1,080 feet, and hence would be flooded out. As shown in table no. 165 of this report, the power available at this site 90 percent of the time, for plan no. 2-A, is 17,900 kilowatts and for plan no. 4 is 20,700 kilowatts.

556. *d'. Economic features.*—The principal items of construction and the estimated cost of the power plant for the pumping plan are shown in table no. 111. The estimated cost of the pumping plant is shown and discussed in the irrigation section of this report. The cost of locks and other navigation features in connection with the power

<sup>2</sup> Not printed.

project are not shown herein, but will be given in the section under Combined Uses. Note that the total cost per kilowatt of installed capacity for public development is \$87.50, and for private development is \$92.75.

TABLE NO. 111.—*Estimated capital cost of development at Grand Coulee (low dam) for installed capacity of 1,230,000 kilowatts*

Preliminary expense.....	\$1, 567, 500
Construction roads.....	1, 231, 250
Reservoir rights and clearing.....	2, 000, 000
River diversion.....	6, 068, 204
Dam and intake.....	42, 261, 074
Power-house substructure.....	2, 961, 540
Power-house superstructure.....	1, 406, 880
Hydraulic equipment.....	9, 075, 000
Electrical equipment.....	8, 610, 000
Miscellaneous equipment.....	225, 000
Tailrace improvement.....	150, 000
Permanent quarters and shops.....	75, 000
Contingencies, 10 percent.....	7, 563, 144
<b>Total field cost.....</b>	<b>83, 194, 592</b>
Overhead, 12½ percent.....	10, 399, 324
<b>Total construction cost.....</b>	<b>93, 593, 916</b>
<b>For public development:</b>	
Total construction cost.....	93, 593, 916
Interest charged during construction, 15 percent.....	14, 039, 087
<b>Total capital cost.....</b>	<b>107, 633, 003</b>
<b>Capital cost per kilowatt.....</b>	<b>87. 50</b>
<b>For private development:</b>	
Total construction cost.....	93, 593, 916
Interest charged during construction, 22 percent.....	20, 590, 659
<b>Total capital cost.....</b>	<b>114, 184, 575</b>
<b>Capital cost per kilowatt.....</b>	<b>92. 75</b>

557. Table no. 112 shows the annual operating cost of the completed power plant for the pumping plan 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 cost of operation is 5.76 percent of the capital cost for public development with 4 percent money, and that the cost of operation is 8.02 percent of the capital cost for private development with 6 percent money.

TABLE NO. 112.—*Estimate of annual cost of power production at Grand Coulee Low Dam, pumping plan, with an installed capacity of 1,230,000 kilowatts*

	Public development	Private development
<b>1. Investment cost:</b>		
Lands and water rights and nondepreciated items.....	\$18,958,161	\$20,112,136
Dam and substructures.....	66,491,350	59,929,953
Subtotal "A".....	75,449,511	80,042,089
Power plant, machinery, and superstructure.....	32,183,492	34,142,487
Total development, capital cost.....	107,633,003	114,184,576
<b>2. Basis of annual cost:</b>		
(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, etc., 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.....	\$151,758	\$151,758
<b>3. Total annual cost:</b>		
Items included in subtotal "A":		
Interest or return.....	3,017,980	4,802,525
Amortization.....	792,219	
Depreciation.....	45,193	10,787
Taxes.....		1,200,631
Maintenance and operation (included under power plant).....		
Subtotal.....	3,855,392	6,013,943
<b>Power plant:</b>		
Interest or return.....	1,287,340	2,048,549
Amortization.....	337,927	
Depreciation.....	572,866	430,195
Taxes.....		512,137
Maintenance and operation.....	151,758	151,758
Subtotal.....	2,349,891	3,142,639
<b>Total project:</b>		
Interest or return.....	4,305,320	6,851,074
Amortization.....	1,130,146	
Depreciation.....	618,059	440,982
Taxes.....		1,712,768
Maintenance and operation.....	151,758	151,758
Total annual cost.....	6,205,283	9,156,582
Total annual cost in percent of capital cost.....	5.76	8.02

558. Plate no. 51<sup>2</sup> shows graphically the cost of power for plant capacity factors varying from 10 to 100 percent. The lower curve shows the cost per kilowatt-hour for an annual operating cost of \$6,205,283, or 5.76 percent of the capital cost, as shown in table no. 112 for public development. Likewise, the second curve shows the cost of power for an annual operating cost of \$9,156,582, or 8.02 percent of the capital cost, as shown for private development in the same table. The third curve shows the cost of power for an assumed operating cost of 12.5 percent of the capital cost for private development, which is the percentage often used by public utility companies. This would give an annual operating cost of \$14,273,072. Note that the cost per kilowatt-hour for a 50 percent plant capacity factor is

<sup>2</sup> Not printed.

1.1 mills, 1.7 mills, and 2.6 mills, respectively, for public development at 5.76 percent, for private development at 8.02 percent, and for private development at 12.5 percent of the capital cost. The upper curve shows the cost of power generated by a steam plant using fuel oil at \$1 per barrel. To make a direct comparison with the steam plant the cost of transmission should be added to the cost as shown by the curves for the hydro plants.

559. A step development of the Grand Coulee site and schedule of installation of equipment, as shown in table no. 113, is assumed to be in accordance with the demand for power after 1940, and a program of development of the Columbia Basin irrigation project based on placing 50,000 acres under irrigation each year. The demand for power (column 4 of the table) has been taken as one half the estimated increase for Washington and Oregon. The installation of generating equipment has been scheduled so that there will be sufficient generating capacity in addition to that required for pumping to deliver the commercial power having peaks twice the average commercial load until 15 units have been installed. Table no. 113 also shows plant capacity factors for the month of July resulting from the above schedule of development.

TABLE No. 113.—Schedule of installation for Grand Coulee low dam

Year (1)	Number of units (2)	Capacity 82,000 × (2) (3)	Annual output commercial power (4)	Pump demand (5)	Total demand (4) + (5) (6)	Peak demand July (2 × (4)) + (5) (7)	Plant capacity factor, July (8)
		<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Percent</i>
1941	3	246,000	53,675	73,631	127,306	180,981	52
1942	4	328,000	111,340	97,002	208,342	319,682	63
1943	6	492,000	173,116	120,373	293,489	466,605	60
1944	8	656,000	239,095	143,744	382,839	621,934	58
1945	10	820,000	309,343	167,115	476,458	785,801	58
1946	11	902,000	350,000	190,485	540,485	890,485	60
1947	12	984,000	350,000	213,856	563,856	913,856	57
1948	12	984,000	350,000	237,227	587,227	937,227	60
1949	12	984,000	350,000	260,598	610,598	960,598	62
1950	13	1,066,000	350,000	283,969	633,969	983,969	59
1951	13	1,066,000	400,000	307,340	707,340	1,107,340	66
1952	13	1,066,000	400,000	330,711	730,711	1,130,711	69
1953	14	1,148,000	400,000	354,082	784,082	1,154,082	66
1954	14	1,148,000	400,000	377,453	777,453	1,177,453	68
1955	14	1,148,000	400,000	400,824	800,824	1,200,824	70
1956	15	1,230,000	450,000	424,194	874,194	1,230,000	71
1957	15	1,230,000	450,000	447,565	897,565	1,230,000	73
1958	15	1,230,000	450,000	470,936	920,936	1,230,000	75
1959	15	1,230,000	450,000	494,307	944,307	1,230,000	77
1960	15	1,230,000	450,000	517,678	967,678	1,230,000	79
1961	15	1,230,000	500,000	541,049	1,041,049	1,230,000	85
1962	15	1,230,000	500,000	564,420	1,064,420	1,230,000	87
1963	15	1,230,000	500,000	587,791	1,087,791	1,230,000	88
1964	15	1,230,000	500,000	611,162	1,111,162	1,230,000	90
1965	15	1,230,000	500,000	611,162	1,111,162	1,230,000	90
1966	15	1,230,000	500,000	611,162	1,111,162	1,230,000	90
1967	15	1,230,000	500,000	611,162	1,111,162	1,230,000	90

<sup>1</sup> Peak limited by plant capacity.

560. Table no. 114 shows plant capacity factors for each month, and an annual factor for the storage year 1929-30.

TABLE No. 114.—*Monthly plant capacity factor for Grand Coulee low dam for period April 1929 to March 1930*

Month (1)	Pump demand for year 1929-30 (2)	Pumping power furnished by Grand Coulee (3)	Pumping power plus 500,000 kilowatts, commercial (4)	Plant-capacity factor (5)
	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Percent</i>
April.....	126,100	36,000	538,000	44
May.....	715,850	490,000	990,000	80
June.....	629,000	629,000	1,129,000	92
July.....	611,000	611,000	1,111,000	90
August.....	692,000	692,000	1,192,000	97
September.....	414,000	414,000	914,000	74
October.....	181,000	56,000	556,000	45
November.....	72,400	22,000	522,000	42
December.....	31,900	10,000	510,000	41
January.....			500,000	41
February.....	22,600	7,000	507,000	41
March.....	53,500	15,000	515,000	42
Mean.....				60.8

561. Inspection of table no. 114 shows maximum factors of 92 percent for June and 97 percent for August. These are the result of pumping more than the irrigation requirements for those months, the surplus being used to fill the Grand Coulee Reservoir. Sufficient pumping units would be provided so that some pumping could be done during off-peak hours in the period of maximum irrigation demand. Although maximum monthly factors of 92 and 97 percent occur, the minimum monthly factor is 41 percent and annual factor 60.8 percent. It must be recognized that the above conditions will not exist until the entire irrigation development has been completed, including all the areas to be supplied by supplemental pumping. Since the maximum pumping load occurs when the Columbia River is at high stage, it is only necessary to install additional generating equipment to reduce the plant capacity factors to a smaller value. If additional units are installed and the power house extended toward the center of the stream, the spillway section would be decreased and depth of water over crest increased during maximum floods.

562. The cost for initial development would not be materially changed and the cost for additional units would be about \$1,750,000 each, or a cost of \$21.40 per kilowatt for the extension and additional equipment. The installation of three additional units would reduce the monthly plant capacity factor for the month of July from 90 to 75 percent, and the annual plant capacity factor from 64 to 54.7 percent.

563. Table no. 115 is a financial set-up for a step development of the power plant for the pumping plan beginning with the year 1941, and paying out in 40 years. The rate of development is the same as that used in table no. 113. The rates of depreciation and amortization are the same as those used in table no. 112. However, these items have been deferred for 10 years. Note that the income shown in column

(15) is computed on the commercial power output only (see column 4 of table no. 113), no income being considered from the power used for pumping. The rate of 2.5 mills per kilowatt-hour at the low-tension bus bars was used in the set-up. When the plant is fully developed in the year 1961, it shows an annual surplus of \$3,435,894 or 0.78 mill per kilowatt-hour on an output of 500,000 kilowatt-years of commercial power.

TABLE No. 115.—Financial set-up for step development of pour plant for Grand Coulee low dam

Year	Year after completion of initial installation	Installation of beginning of year		Cost, including interest during construction beginning of year	Investment, unpaid balances including interest during construction at beginning of year	Interest on investment at end of year	Depreciation		Amortization of funded structures at 4 per cent, R=0.0105	Operation and maintenance supplies and labor	Annual expense		Commercial power		Surplus (minus sign denotes deficit)
		Num-ber of units	Capacity in kilowatts				Dam and substructures, 100-year life fund, R=0.0008	Machinery and super-structures at 30-year life fund, R=0.0178			(7)	(8)	(9)	(10)	
1941	1	3	246,000	84,927,453	84,927,453	3,397,098	45,193	415,450	1,072,521	76,758	3,473,856	1,088,735	53,875	1,175,483	2,998,373
1942	2	4	328,000	86,524,886	88,528,259	3,557,130	45,193	415,450	1,072,521	76,758	3,633,888	2,361,588	111,810	2,438,346	-1,435,542
1943	3	6	492,000	90,634,752	93,528,667	3,741,147	45,193	445,139	1,040,734	151,758	3,842,906	3,689,482	173,116	2,791,240	-51,065
1944	4	8	656,000	93,946,969	97,049,649	3,881,982	45,193	445,139	1,040,734	151,758	4,067,411	5,194,423	238,093	3,251,181	1,996,666
1945	5	10	820,000	96,973,185	99,266,325	3,970,653	(1)	(1)	(1)	126,758	4,097,411	5,251,188	309,343	3,714,612	2,194,055
1946	6	11	902,000	98,675,617	99,068,222	3,987,529	(1)	(1)	(1)	126,758	4,114,287	5,343,289	350,000	4,065,000	2,194,000
1947	7	12	984,000	100,410,226	100,057,071	4,002,683	(1)	(1)	(1)	126,758	4,124,441	5,433,642	350,000	4,365,000	2,194,000
1948	8	12	984,000	100,410,226	97,147,914	3,946,444	(1)	(1)	(1)	126,758	4,072,202	5,453,642	350,000	4,665,000	1,974,802
1949	9	12	984,000	102,144,835	97,334,797	3,893,392	(1)	(1)	(1)	151,758	4,043,159	5,508,350	350,000	4,965,000	1,636,778
1950	10	13	1,066,000	102,144,835	95,689,859	3,827,963	45,193	415,450	1,072,521	151,758	5,512,513	5,588,350	400,000	5,260,000	1,536,728
1951	11	13	1,066,000	102,144,835	93,879,082	3,759,163	45,193	445,139	1,040,734	151,758	5,444,085	5,588,350	400,000	5,560,000	1,301,166
1952	12	13	1,066,000	102,144,835	93,879,082	3,757,380	45,193	445,139	1,040,734	151,758	5,490,204	5,636,070	400,000	5,860,000	1,091,106
1953	13	14	1,148,000	103,879,444	92,055,814	3,682,182	45,193	445,139	1,040,734	151,758	5,418,016	5,636,070	400,000	6,160,000	1,301,106
1954	14	14	1,148,000	103,879,444	90,101,896	3,604,077	45,193	472,106	1,07,342	151,758	5,386,901	5,737,707	450,000	6,460,000	2,340,894
1955	15	15	1,203,000	105,461,166	89,651,865	3,586,067	45,193	472,106	1,07,342	151,758	5,362,466	5,737,707	450,000	6,760,000	2,340,894
1956	16	15	1,203,000	105,461,166	87,500,025	3,500,001	45,193	472,106	1,07,342	151,758	5,276,400	5,737,707	450,000	7,060,000	2,340,894
1957	17	15	1,203,000	105,461,166	85,262,319	3,410,493	45,193	472,106	1,07,342	151,758	5,186,822	5,737,707	450,000	7,360,000	2,340,894
1958	18	15	1,203,000	105,461,166	82,935,105	3,317,494	45,193	472,106	1,07,342	151,758	5,093,860	5,737,707	450,000	7,660,000	2,340,894
1959	19	15	1,203,000	105,461,166	80,514,802	3,220,992	45,193	472,106	1,07,342	151,758	4,996,961	5,737,707	450,000	7,960,000	2,340,894
1960	20	15	1,203,000	105,461,166	77,997,687	3,119,907	45,193	472,106	1,07,342	151,758	4,896,309	5,737,707	450,000	8,260,000	2,340,894
1961	21	15	1,203,000	105,461,166	75,379,887	3,016,195	45,193	472,106	1,07,342	151,758	4,791,584	5,737,707	450,000	8,560,000	2,340,894
1962	22	15	1,203,000	105,461,166	72,657,375	2,906,265	45,193	472,106	1,07,342	151,758	4,682,584	5,737,707	450,000	8,860,000	2,340,894
1963	23	15	1,203,000	105,461,166	69,825,963	2,795,262	45,193	472,106	1,07,342	151,758	4,569,437	5,737,707	450,000	9,160,000	2,340,894
1964	24	15	1,203,000	105,461,166	66,881,294	2,678,262	45,193	472,106	1,07,342	151,758	4,451,651	5,737,707	450,000	9,460,000	2,340,894
1965	25	15	1,203,000	105,461,166	63,818,839	2,552,754	45,193	472,106	1,07,342	151,758	4,329,153	5,737,707	450,000	9,760,000	2,340,894
1966	26	15	1,203,000	105,461,166	60,633,886	2,426,355	45,193	472,106	1,07,342	151,758	4,201,754	5,737,707	450,000	10,060,000	2,340,894
1967	27	15	1,203,000	105,461,166	57,321,534	2,292,861	45,193	472,106	1,07,342	151,758	4,069,260	5,737,707	450,000	10,360,000	2,340,894
1968	28	15	1,203,000	105,461,166	53,876,688	2,155,068	45,193	472,106	1,07,342	151,758	3,931,467	5,737,707	450,000	10,660,000	2,340,894
1969	29	15	1,203,000	105,461,166	50,294,049	2,011,762	45,193	472,106	1,07,342	151,758	3,793,399	5,737,707	450,000	10,960,000	2,340,894
1970	30	15	1,203,000	105,461,166	46,568,104	1,862,725	45,193	472,106	1,07,342	151,758	3,659,121	5,737,707	450,000	11,260,000	2,340,894
1971	31	15	1,203,000	105,461,166	42,762,725	1,715,725	45,193	472,106	1,07,342	151,758	3,524,399	5,737,707	450,000	11,560,000	2,340,894

1972	32	15	1,230,000	42,693,122	1,707,725	45,193	472,106	1,107,342	151,758	1,776,399	3,484,124	5,737,707	500,000	10,950,000	3,435,894
1973	33	15	1,230,000	38,683,140	1,546,526	45,193	472,106	1,107,342	151,758	1,776,399	3,292,925	5,737,707	500,000	10,950,000	3,435,894
1974	34	15	1,230,000	34,471,950	1,378,878	45,193	472,106	1,107,342	151,758	1,776,399	3,155,271	5,737,707	500,000	10,950,000	3,435,894
1975	35	15	1,230,000	30,113,130	1,204,525	45,193	472,106	1,107,342	151,758	1,776,399	2,980,924	5,737,707	500,000	10,950,000	3,435,894
1976	36	15	1,230,000	25,579,948	1,023,198	45,193	472,106	1,107,342	151,758	1,776,399	2,793,597	5,737,707	500,000	10,950,000	3,435,894
1977	37	15	1,230,000	20,865,439	834,618	45,193	472,106	1,107,342	151,758	1,776,399	2,511,017	5,737,707	500,000	10,950,000	3,435,894
1978	38	15	1,230,000	15,962,350	638,494	45,193	472,106	1,107,342	151,758	1,776,399	2,210,893	5,737,707	500,000	10,950,000	3,435,894
1979	39	15	1,230,000	10,863,137	434,525	45,193	472,106	1,107,342	151,758	1,776,399	1,998,792	5,737,707	500,000	10,950,000	3,435,894
1980	40	15	1,230,000	5,569,955	222,398	45,193	472,106	1,107,342	151,758	1,776,399	1,804,293	5,737,707	500,000	10,950,000	3,435,894
1981	41	15	1,230,000			45,193		1,107,342	151,758	1,776,399	1,604,293		500,000	10,950,000	3,435,894

<sup>1</sup> Depreciation and amortization charges deferred 10 years.

564. *b. High dam.*—The set-up, involving the high dam at Grand Coulee, has been considered in conjunction with both the gravity and pumping plans of irrigation of the Columbia Basin irrigation project. In the gravity plan it would be purely a commercial generating plant, the only effect of this irrigation being the diversion of water upstream at Albany Falls on Clark Fork, while in the pumping plan a large block of power, principally the secondary power, would be used directly at the site to pump water into the Grand Coulee for irrigation of the Columbia Basin irrigation project. These plans will be referred to hereafter as the gravity and pumping plans.

*a. Résumé.*—

Drainage area.....	square miles..	74, 100
Length of pool.....	miles.....	151
Length of dam.....	feet.....	4, 290
Height of dam (maximum section foundation to walkway).....	do.....	490
Draw-down (elevation 1,287.6 to 1,207.6 feet).....	do.....	80
Useful storage.....	acre-feet.....	5, 028, 000
Natural low-water elevation.....	feet.....	933
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
Average discharge.....	do.....	109, 000
Minimum discharge, average for 12 days.....	do.....	17, 000
Average static head.....	feet.....	340. 4
Power capacity (Federal Power Commission definition)		
horsepower.....		773, 400
Proposed hydraulic capacity, gravity or pumping plan.....	second-feet..	65, 000
Proposed installed capacity, gravity or pumping plan.....	kilowatts..	1, 575, 000

565. *b'. Power possibilities.*—The spillway of the dam was designed to maintain the forebay at elevation 1,287.6 feet for ordinary discharges, but, to pass the maximum estimated flood of 910,000 second-feet, the forebay would rise to elevation 1,289.6 feet. The mean static head for the 17-year period that ended March 1930 is 340.4 feet, based on natural flow and a constant forebay level of 1,287.6 feet. The head varies from a maximum of 354.6 feet for a discharge of 18,800 second-feet, minimum monthly flow, to 307.5 feet for a discharge of 436,000 second-feet, maximum monthly flow, for the 18-year period. As previously stated, the elevation of the tail water with assumed maximum discharge is estimated to be 1,022 feet at the site, which would still leave a head of 267.6 feet on the turbines under extreme estimated flood conditions; hence, the plant could operate effectively at any stage of the river. The power capacity for natural flow as defined by the Federal Power Commission is 773,400 horsepower.

566. Plate no. 52<sup>2</sup> 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 3 hydraulic capacities and for 3 conditions of flow. The latter consist of natural flow, case 1 of table no. 116, regulated flow with gravity plan, case 2 of table no. 116, and regulated flow with pumping plan, case 6 of table no. 116. Note especially that graphs 10 to 27, inclusive, take into account the effect of regulation of upstream storage, but with no regulation of storage at the site.

<sup>2</sup> Not printed.

TABLE NO. 116.—Principal data, Grand Coulee High Dam, for the 17-year period ended Mar. 31, 1930. For power-duration curves, see plates nos. 55<sup>2</sup> and 56<sup>2</sup>

Plan	Regulation	Case no.	Time	Flow	Static head <sup>1</sup>	Potential power at 80 percent efficiency		Potential energy available annually		
						Total	Commercial <sup>2</sup>	Total	Commercial <sup>2</sup>	
			Per-cent	1,000 sec.-ft.	Feet	1,000 kw.	1,000 kw.	1,000 kw.-yrs.	1,000 kw.-yrs.	
Natural...	No regulation.....	1	35	109.0	338.6	2,510	2,510	1,662	1,662	
			50	65.7	345.2	1,542	1,542	1,261	1,261	
			65	47.8	348.4	1,133	1,133	1,026	1,026	
			80	38.2	350.3	910	910	865	865	
			90	28.4	352.4	681	681	673	673	
			100	18.8	354.6	453	453	453	453	
Gravity...	Upstream regulation without Columbia River storage, plan no. 2-A.	2	35	101.0	339.7	2,325	2,325	1,651	1,651	
			50	68.0	344.8	1,594	1,594	1,352	1,352	
			65	52.8	347.5	1,247	1,247	1,153	1,153	
			80	42.6	349.4	1,012	1,012	982	982	
			90	36.7	350.6	875	875	868	868	
				100	27.3	352.6	655	655	655	655
	Upstream regulation including Columbia River storage, plan no. 2-A.	4	35	100.0	-----	2,108	2,108	1,635	1,635	
			50	73.9	-----	1,576	1,576	1,414	1,414	
			65	64.0	-----	1,365	1,365	1,294	1,294	
			80	56.0	-----	1,184	1,184	1,162	1,162	
90			50.4	-----	1,082	1,082	1,076	1,076		
			100	45.5	-----	938	938	938		
Pumping..	Upstream regulation without Columbia River storage, plan no. 4.	6	35	96.3	340.4	2,228	1,943	1,635	1,471	
			50	68.1	344.8	1,596	1,457	1,378	1,275	
			65	55.9	346.9	1,319	1,210	1,224	1,134	
			80	45.3	348.9	1,075	1,002	1,060	983	
			90	39.9	349.9	953	912	947	907	
				100	32.9	351.4	785	785	785	785
	Upstream regulation including Columbia River storage, plan no. 4.	8	35	88.1	-----	1,926	1,667	1,572	1,393	
			50	72.3	-----	1,550	1,434	1,421	1,300	
			65	65.8	-----	1,383	1,252	1,324	1,196	
			80	57.1	-----	1,242	1,138	1,224	1,112	
			90	53.5	-----	1,157	1,063	1,152	1,048	
				100	49.4	-----	1,024	615	1,024	615
	Upstream regulation including Columbia River storage. Partial pumping power deducted, plan no. 4.	11	35	88.1	-----	1,926	1,681	1,572	1,433	
			50	72.3	-----	1,550	1,455	1,421	1,342	
			65	65.8	-----	1,383	1,306	1,324	1,256	
80			57.1	-----	1,242	1,189	1,224	1,172		
90			53.5	-----	1,157	1,115	1,152	1,110		
			100	49.4	-----	1,024	976	1,024	976	
No regulation. Same as case 1, excepting that flow has been reduced by irrigation demand.	12	35	102.0	339.6	2,366	2,049	1,576	1,396		
		50	61.9	345.8	1,455	1,348	1,200	1,112		
		65	46.4	348.7	1,101	1,036	995	936		
		80	36.6	350.6	872	802	831	768		
		90	27.5	352.6	659	621	651	615		
			100	18.8	354.6	453	453	453		

<sup>1</sup> For normal forebay elevation of 1,287.6 feet, with a maximum draw-down of 80 feet, as regulated in cases 4, 8, and 11. The head for these cases varies from year to year, depending on operation.

<sup>2</sup> Total less pumping.

567. The three flows considered on plate no. 52<sup>2</sup> are those obtaining under natural conditions, 35, 50, and 90 percent of the time. 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 the résumé and hereafter in this report.

568. The three plant capacities expressed in kilowatts are those capacities which correspond to the above-selected flows, and to the

<sup>3</sup> Not printed.

heads obtaining at these flows at 80 percent efficiency. The tables beneath the graphs also show the utilization and plant-capacity factors for 100 percent operation.

569. The resulting plant capacity and utilization factors are shown graphically on plate no. 53,<sup>2</sup> for natural flow and for regulated flow for both the pumping and gravity plans. By comparison of graphs 2, 11, and 20 of plate no. 52,<sup>2</sup> it is noted that regulation increases the annual utilization factor from 58 to 70 and 67 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. See case 1 of table no. 116. Likewise, the total power available for the low year with the above plant capacity is, respectively, 1,030,000, 1,160,000, and 1,104,000 kilowatt-years for natural flow and for regulated flow for pumping and gravity.

570. Table no. 116 shows the flow and power duration for 35, 50, 65, 80, 90, and 100 percent of the time, for the 17-year period ended March 1930, for the natural flow and for six assumed conditions of regulation and irrigation. Regulation would be effected by control of the following reservoirs, 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
Kootenai Lake.....	715, 000
Coeur d'Alene Lake.....	<sup>37</sup> 430, 000
Grand Coulee, high dam.....	5, 028, 000
Total.....	10, 992, 000

571. With the exception of case 1, the flow as shown in table no. 116 does not include water as demanded for irrigation in any of the various pumping or gravity plans. In cases 2 and 4 the Columbia Basin irrigation project would be irrigated by gravity with water from Clark Fork and Spokane River. In cases 6, 8, 11, and 12, all the irrigation water would be pumped from the Columbia River at the Grand Coulee site. The commercial power, as shown for cases 6, 8, 11, and 12, is the power available after deducting that necessary for pumping. In case 11, a part of the power necessary for pumping would be furnished by Columbia River sites above the Snake River other than the Grand Coulee, in order to effect a higher utilization of the river as a whole. Case 12 covers the plan for irrigation by pumping with power generated at the Grand Coulee without regulation at the Grand Coulee or from any upstream reservoirs.

572. The last two columns of table no. 116 show the annual energy available in kilowatt-years for certain percentages of time for each case. Note that the available power and energy are not limited by a plant capacity which is in marked contrast to the data presented on plate nos. 52<sup>2</sup> and 54<sup>2</sup>, both of which are limited by plant capacities. The columns in table no. 116 showing duration of flow, power, and energy each refer to the column showing the percent of time and bear no direct relation to each other.

573. Note that the flow 100 percent of the time with upstream regulation, case 6, table no. 116, is 32,900 second-feet, or an increase

<sup>1</sup> Not printed.

<sup>2</sup> Includes 155,000 acre-feet now used by The Washington Water Power Co.

of 75 percent over the natural flow, case 1. Also note that the combined storage capacity of the upstream reservoirs is 5,960,000 acre-feet, which is slightly greater than the useful capacity of the Columbia River Reservoir at Grand Coulee. A study was made to show the effect of regulation of the Columbia River Reservoir without the benefit of upstream regulation, that is, with natural inflow. This study shows that the flow 100 percent of the time for the 18-year period ended March 31, 1931, would be 41,400 second-feet. To make this comparable to the flow as shown for case 6 above, 1,000 second-feet should be deducted as the irrigation diversion during the months of low flow, leaving 40,400 second-feet. This is an increase over natural flow of 114.8 percent. The average head for this low flow would be approximately 330 feet, and the available power at 80 percent efficiency would amount to 906,500 kilowatts 100 percent of the time. Hence, the regulation of Columbia River storage is more effective than regulation of a like or even greater amount of upstream storage. However, to be conservative, the estimates have been limited to the conditions of case 6.

574. The potential power at the site in cases 1, 4, 6, and 8 is shown graphically on plate no. 55<sup>2</sup> by duration curves for the 17-year period ended March 31, 1930. Note that the total available power 90 percent of the time for natural flow, case 1, is 681,000 kilowatts; for full regulation, gravity plan, case 4, is 1,082,000 kilowatts; and for full regulation, pumping plan, case 8, is 1,157,000 kilowatts. Hence, the pumping plan exceeds the gravity plan in power by 75,000 kilowatts, or 7 percent.

575. The commercial power available after deducting the power required for pumping in cases 8, 11, and 12, is shown graphically on plate no. 56,<sup>2</sup> as duration curves for the 17-year period ended March 31, 1930. Note that about 500,000 kilowatts are available 98.5 percent of the time with no regulation, case 12. Note also that the commercial power available 90 percent of the time is 1,063,000 kilowatts for case 8 and 1,115,000 kilowatts for case 11.

576. The distribution of power for the 17-year period ended March 31, 1930, is shown for case 8 on plate no. 54.<sup>2</sup> The upper limit of the graphs indicates the total available power for a hydraulic capacity of 65,000 second-feet at 80 percent efficiency, and the shaded area shows the power required to pump irrigation water for the Columbia Basin irrigation project at 70 percent efficiency. The irrigation requirements are discussed elsewhere in this report. As shown therein, the maximum demand each month, including an allowance of 1,000 second-feet for possible leakage from the Grand Coulee Reservoir, is as stated in the following table:

Month:	<i>Maximum demand, second-feet</i>
April.....	7, 440
May.....	11, 650
June.....	11, 340
July.....	12, 160
August.....	11, 670
September.....	8, 240
October.....	4, 030
All winter months.....	1, 000

577. The static pumping head, as used in the preparation of the graphs, amounts to 285 feet, plus the drawdown in the Columbia

<sup>2</sup> Not printed.

River forebay due to regulation. This head is shown graphically by the stepped line in the upper chart which refers to the scale on the right. The upper chart also shows the amount of storage in the Grand Coulee Reservoir that would be required to supply the above irrigation demands 100 percent of the time. A draw-down to elevation 1,560 feet (214,000 acre-feet) would be allowable in July, but in April the reservoir could be drawn down to elevation 1,553 (365,000 acre-feet) and still supply the irrigation demands. The lowest draw-down occurred in the month of April in the years of 1920, 1924, and 1929.

578. As shown in the discussion of the power graph for the low Grand Coulee project, these particular seasons were unusually cold and backward and probably would not have demanded the amount of irrigation water as set up in the study. It is apparent, that the shortage in April 1920 could have been averted without using prime power at Grand Coulee by keeping the Grand Coulee Reservoir full until March 1. Of course this would reduce the flow and the available power at all downstream sites during the 3 preceding months.

579. The portions of the shaded area below the heavy line on plate no. 54<sup>2</sup> represent the power that would be supplied by other Columbia River plants as set up in case 11 of table no. 116, in order to effect a more economical utilization of the stream as a whole. This heavy line represents the commercial power available, month by month, at Grand Coulee as derived from the water-supply studies, on the assumption that Columbia River Reservoir would be regulated to secure uniform power output in all the plants in that section of the river between Grand Coulee and Priest Rapids, inclusive. This plan penalizes power output at Grand Coulee to produce the greatest system output. In general, plate no. 54<sup>2</sup> shows that 980,000 kilowatts of prime power are available 98.5 percent of the time for commercial use with an installed hydraulic capacity of 65,000 second-feet.

580. The energy required for pumping an acre-foot of water averaged 420 kilowatt-hours for the 17-year period as set up in case 8. The maximum power required for pumping was 707,540 kilowatts for the month of May 1920. The average for the period was 216,245 kilowatts; no pumping was done in January and February in the years 1920 and 1930.

581. *c'. Proposed development.*—The pumping plan of development involves the construction of a straight gravity dam at right angles to the stream, a power house parallel and adjacent to the downstream face of the dam near the left bank, and a pumping plant paralleling the left bank and located upstream from the dam. See plate no. 57. The development for the gravity plan, that is, for a purely commercial power plant, would practically be the same excepting that the pumping plant would be omitted.

582. In either plan the spillway would occupy the central portion and right end of the dam. See plate no. 58 for sections of dam. Radial gates, 48 in number, each 35 feet wide by 24 feet high, and 20 radial gates 35 feet wide by 17 feet high, would provide a spillway capacity of 932,000 second-feet with forebay at elevation 1,289.6 feet, which is 2 feet above normal. The total length of the spillway would be 2,788 feet. The plant provides for a drawdown of 80 feet for regulation with a resulting useful storage of 5,028,000 acre-feet.

<sup>2</sup> Not printed.

583. The methods of dissipating the kinetic energy that would be present at the toe of the spillway section of the dam has been discussed in conjunction with the Grand Coulee low dam in paragraph 549.

584. The power house would be of sufficient size to accommodate 15 main units, for either the gravity or the pumping plan. Each unit would consist of a vertical Francis-type turbine of 4,330 second-foot capacity, direct connected to a 22,000-volt, 105,000-kilowatt generator. Hence, the total installed capacity would be 1,575,000 kilowatts. In either plan each of the units would be connected to an outgoing power line through oil circuit breakers and transformers. The voltage would be stepped up to 220,000. See plate no. 59<sup>2</sup> for wiring diagram. Seven of these units could be connected direct to the motors in the pumping plant without stepping up the voltage. Two house units of 500 kilowatts each would also be provided.

585. The pumping plant would consist of 10 units. Each unit would consist of two separate 50,000-horsepower motors direct connected to their respective pumps. The two pumps in each unit would be connected in series hydraulically and would have a capacity of 1,600 second-feet. Ten steel penstocks, 11 feet 6 inches in diameter, would connect the units with the canal at the head of the Grand Coulee.

586. Three existing bridges cross the Columbia River within the project area. The one farthest upstream is the Great Northern Railway bridge at Northport, 140 miles from the dam site. It has sufficient clearance for ordinary floods, but would apparently have to be raised to clear the assumed maximum flood and to provide for navigation. It has been used as a highway bridge since 1924. The second bridge is located at Marcus, 113 miles upstream from the dam site. It is owned and operated by the Great Northern Railway as a part of the Kettle Falls branch. It has a clearance elevation of 1,252 feet, the total length of the truss spans is 1,360 feet, with 700 feet of pile trestle approach. It would be necessary to increase the clearance about 50 feet. The third bridge is located near Kettle Falls, 109 miles from the dam site, and is owned and operated by the State highway department. The main river span is a deck cantilever 880 feet long, with a roadway elevation of 1,308 feet. Hence, it would be necessary to make extensive revisions.

587. A number of small towns, several miles of highway and railroad, and a considerable area of tillable land would be inundated.

588. The natural-low water elevation of the Spokane River at the Little Falls power station of The Washington Water Power Co. is, roughly, 1,281 feet. The maximum high-water elevation is approximately 1,296 feet. The plant is operated under a maximum head of 72 feet, and has an installed capacity of 32,000 horsepower. During periods of low flow in the Spokane River the head would be reduced 10 or 12 feet by the backwater from the Columbia River Dam. At high stages of the Spokane River the backwater effect would be nominal.

589. The Fish Hawk power site on the Spokane River would be entirely inundated at normal forebay level. As shown later under "Tributary Effects" the potential power available 90 percent of the time is 15,000 kilowatts for plan no. 2-A, or 17,400 kilowatts for

<sup>2</sup> Not printed.

plan no. 4. The narrows power site, still farther down the Spokane River, would also be flooded. Information in the same section shows the power available 90 percent of the time equals 17,900 kilowatts for plan no. 2-A, or 20,700 kilowatts for plan no. 4.

590. *d'. Economic features.*—The principal items of construction and the estimated cost of the power plant for the pumping plan as shown in table no. 117 are for complete development initially. The estimated cost of the pumping plant is shown and discussed in the irrigation section of this report. The cost of locks and other navigation features in connection with the power project are not shown herein, but will be given in the section under "Combined Uses." Note that the total cost per kilowatt of installed capacity for public development is \$108.70, and for private development is \$115.30.

TABLE No. 117.—*Estimate of capital cost of development at Grand Coulee, High Dam, for installed capacity of 1,575,000 kilowatts*

Preliminary expense.....	\$1, 567, 500
Construction roads.....	1, 231, 250
Reservoir rights and clearing.....	6, 661, 200
River diversion.....	7, 117, 190
Dam and intake.....	81, 828, 789
Power house substructure.....	2, 961, 540
Power house superstructure.....	1, 406, 880
Hydraulic equipment.....	8, 040, 000
Electrical equipment.....	9, 000, 000
Miscellaneous equipment.....	225, 000
Tailrace improvement.....	150, 000
Permanent buildings.....	100, 000
Contingencies, 10 percent.....	12, 028, 934
<hr/>	<hr/>
Total field cost.....	132, 318, 283
Overhead, 12½ percent.....	16, 539, 785
<hr/>	<hr/>
Total construction cost.....	148, 858, 068
<hr/>	<hr/>
For public development:	
Total construction cost.....	148, 858, 068
Interest charged during construction, 15 percent.....	22, 328, 709
<hr/>	<hr/>
Total capital cost.....	171, 186, 777
Capital cost per kilowatt.....	108. 70
<hr/>	<hr/>
For private development:	
Total construction cost.....	148, 858, 068
Interest charged during construction, 22 percent.....	32, 748, 774
<hr/>	<hr/>
Total capital cost.....	181, 606, 842
Capital cost per kilowatt.....	115. 30

591. Table no. 118 shows the annual operating cost of the completed power plant for the pumping plan 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 cost of operation is 5.52 percent of the capital cost for public development to yield a return of 4 percent on the investment, and that the cost of operation is 7.83 percent of the capital cost for private development to yield a return of 6 percent.

592. Plate no. 60<sup>2</sup> shows graphically the cost of power for plant-capacity factors varying from 10 to 100 percent. The lower curve shows the cost per kilowatt-hour for an annual operating cost of \$9,461,928, or 5.52 percent of the capital cost as shown in table no. 118 for public development. Likewise the second curve shows the cost of power for an annual operating cost of \$14,226,950, or 7.83 percent of the capital cost as shown for private development in the same table. The third curve shows the cost of power for an assumed operating cost of 12.5 percent of the capital cost for private development, which is the percentage often used by public utility companies. This would give an annual operating cost of \$22,700,855. Note that the cost per kilowatt-hour for a 50 percent plant-capacity factor is 1.3 mills, 2.06 mills and 3.29 mills, respectively, for public development at 5.50 percent, for private development at 7.83 percent, and for private development at 12.5 percent. The upper curve shows the cost of power generated by a steam plant burning fuel oil at \$1 per barrel. To make a direct comparison with the steam plant the cost of transmission should be added to the cost as shown by the curves for the hydro plant.

TABLE NO. 118.—*Estimate of annual cost of power production at Grand Coulee High Dam, gravity or pumping plan, with an installed capacity of 1,575,000 kilowatts*

	Public develop- ment	Private devel- opment
<b>1. Investment cost:</b>		
Lands and water rights and nondepreciated items.....	\$29,213,550	\$30,991,766
Dam and substructures.....	109,522,610	116,189,203
Subtotal A.....	138,736,160	147,180,969
Power plant, machinery, and superstructure.....	32,450,617	34,425,872
Total development, capital cost.....	171,186,777	181,606,841
<b>2. Basis of annual cost:</b>		
(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.....	0.08	0.018
(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.....	\$151,758	\$151,758
<b>3. Total annual cost:</b>		
Items included in subtotal A:		
Interest or return.....	5,549,446	8,830,858
Amortization.....	1,456,729	—
Depreciation.....	87,618	20,914
Taxes.....	—	2,207,714
Subtotal.....	7,093,793	11,059,486
Power plant:		
Interest or return.....	1,298,025	2,065,552
Amortization.....	340,731	—
Depreciation.....	577,621	433,766
Taxes.....	—	516,388
Maintenance and operation.....	151,758	151,758
Subtotal.....	2,368,135	3,167,464
Total project:		
Interest or return.....	6,847,471	10,896,410
Amortization.....	1,797,460	—
Depreciation.....	665,239	454,880
Taxes.....	—	2,724,102
Maintenance and operation.....	151,758	151,758
Total annual cost.....	9,461,928	14,226,950
Total annual cost in percent of capital cost.....	5.52	7.83

<sup>2</sup> Not printed.

593. A step development of the Grand Coulee site and schedule of installation of equipment, as shown in table no. 119, is assumed to be in accordance with the demand for power after 1940, and a program of development of the Columbia Basin irrigation project based on placing 50,000 acres under irrigation each year. The demand for power, column 4 of the table, has been taken as one half the increase in the power market for Washington and Oregon. The installation of generating equipment has been scheduled so that there will be sufficient generating capacity in addition to that required for pumping to deliver the commercial power having peaks twice the average commercial load until 15 units have been installed. Table no. 119 also shows plant-capacity factors and load factors resulting from the above development.

TABLE NO. 119.—*Schedule of installation of power equipment for Grand Coulee High Dam, irrigation developed at rate of 50,000 acres per annum*

Year	Number of units	Plant capacity	Power-market demand	Pump demand <sup>1</sup>	Total demand	Peak demand <sup>2</sup> by (4)+(5)	Plant-capacity factor <sup>1</sup> (6)÷(3)	Load factor <sup>1</sup> (6)÷(7)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
		<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Percent</i>	<i>Percent</i>
1941.....	3	315,000	53,675	50,543	104,218	157,893	33	66
1942.....	3	315,000	111,340	66,585	177,925	289,265	57	62
1943.....	5	525,000	173,116	82,628	255,744	428,860	49	60
1944.....	6	630,000	239,095	98,670	337,765	576,860	54	59
1945.....	7	735,000	309,343	114,713	424,056	733,399	58	58
1946.....	9	945,000	383,890	130,755	514,645	898,535	54	57
1947.....	11	1,155,000	462,733	146,798	609,531	1,072,264	53	57
1948.....	13	1,365,000	545,823	162,840	708,663	1,254,486	52	56
1949.....	14	1,470,000	633,170	178,883	812,053	1,445,223	55	55
1950.....	15	1,575,000	724,448	194,925	919,373	<sup>2</sup> 1,575,000	58	58
1951.....	15	1,575,000	819,563	210,968	1,030,531	1,575,000	65	65
1952.....	15	1,575,000	850,000	227,010	1,077,010	1,575,000	68	68
1953.....	15	1,575,000	850,000	243,053	1,093,053	1,575,000	69	69
1954.....	15	1,575,000	850,000	259,095	1,109,095	1,575,000	70	70
1955.....	15	1,575,000	900,000	275,138	1,175,138	1,575,000	75	75
1956.....	15	1,575,000	900,000	291,180	1,191,180	1,575,000	76	76
1957.....	15	1,575,000	900,000	307,223	1,207,223	1,575,000	77	77
1958.....	15	1,575,000	950,000	323,265	1,273,265	1,575,000	81	81
1959.....	15	1,575,000	950,000	339,308	1,289,308	1,575,000	82	82
1960.....	15	1,575,000	950,000	355,350	1,305,350	1,575,000	83	83
1961.....	15	1,575,000	950,000	371,393	1,321,393	1,575,000	84	84
1962.....	15	1,575,000	950,000	387,435	1,337,435	1,575,000	85	85
1963.....	15	1,575,000	950,000	403,478	1,353,478	1,575,000	86	86
1964.....	15	1,575,000	950,000	419,520	1,369,520	1,575,000	87	87

<sup>1</sup> For month of July during maximum demand for irrigation.

<sup>2</sup> Peak limited by plant capacity.

594. Table no. 120 shows the plant-capacity factor for each month and the mean annual factor for the period April 1929 to March 1930, for delivery of 950,000 kilowatts continuous commercial power in addition to the power required for pumping, for plant capacities of 1,575,000 kilowatts as set up in case 11.

TABLE No. 120.—*Monthly plant-capacity factor for Grand Coulee high dam for period April 1929 to March 1930*

Month (1)	Pump demand for year 1929-30 (2)	Pumping power furnished by Grand Coulee (3)	Pumping power plus 950,000 kilowatts commercial (4)	Plant-capacity factor (5)
	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Kilowatts</i>	<i>Percent</i>
April.....	139,029	51,000	1,001,000	64
May.....	656,608	240,000	1,190,000	75
June.....	428,000	428,000	1,378,000	88
July.....	420,000	420,000	1,370,000	87
August.....	403,000	403,000	1,353,000	86
September.....	284,000	284,000	1,234,000	78
October.....	140,000	58,000	1,008,000	64
November.....	35,620	14,000	964,000	61
December.....	6,406	3,000	953,000	60
January.....			950,000	60
February.....			950,000	60
March.....	37,994	14,000	964,000	61
Mean.....				70.3

595. Column 2 of table no. 120 shows the power demanded for pumping for each month, and column 3 shows the portion of this power supplied by the Grand Coulee project as set up in the water-supply study. These quantities are also shown graphically on the power graph on plate no. 54.<sup>2</sup> The exceptionally large pumping power demanded for May 1929 is caused partially by the refilling of the Grand Coulee Reservoir and partially by the high pumping head caused by a drawdown of over 60 feet in the Columbia River Reservoir at Grand Coulee.

596. Table no. 121 is a financial set-up for a step development of the power plant for the pumping plan beginning with the year 1941, and paying out in 40 years. The rate of development is the same as that used in table no. 119. The rates of depreciation and amortization are the same as those used in table no. 118. However, these items have been deferred for 10 years. Note that the income shown in column 15 is computed on the commercial power output only (see column 4 of table no. 119), no income being considered from the power used for pumping. The rate of 2.5 mills per kilowatt-hour at the low-tension bus bars was used in the set-up. After the year 1957 this shows an annual surplus of \$8,455,449, or 1.02 mills per kilowatt-hour on an output of 950,000 kilowatt-years.

<sup>2</sup> Not printed.

TABLE No. 121.—Financial set-up for step development of power plant for Grand Coulee high dam

Year after completion of initial installation	Year	Installation at beginning of year		Capacity in kilowatts	(3b)	(4)	Investment, unpaid balance including interest during construction at beginning of year	(5)	(6)	Depreciation		(9)	(10)	Annual expense			Commercial power		Surplus (minus sign denotes deficit)
		Num. of units	(3a)							Dam and structures, 100-year life, 4 percent	Machinery and super-structures, 30-year life, 4 percent			Operation and maintenance labor and supplies	Operation and depreciation	Operation and depreciation, and interest	Payment, including interest	Output in kilowatt-years	
1941	1	3	315,000	149,044,785	149,044,785	5,961,791	149,044,785	149,044,785	5,961,791	37,618	504,469	1,775,223	76,758	76,758	6,038,549	1,068,724	53,675	1,175,482	-4,863,067
1942	2	3	315,000	149,044,785	153,907,852	6,156,314	153,907,852	153,907,852	6,156,314	37,618	504,469	1,775,223	76,758	76,758	6,233,072	2,361,588	171,340	2,438,346	-3,794,726
1943	3	3	520,000	152,396,883	161,054,678	6,442,187	161,054,678	161,054,678	6,442,187	37,618	504,469	1,775,223	101,758	101,758	6,543,945	3,689,482	3,791,240	3,791,240	-2,752,705
1944	4	6	620,000	154,056,848	165,467,346	6,818,694	165,467,346	165,467,346	6,818,694	37,618	504,469	1,775,223	101,758	101,758	6,720,452	5,134,422	309,095	5,236,180	-1,484,272
1945	5	7	721,000	155,716,810	168,611,680	7,144,463	168,611,680	168,611,680	7,144,463	37,618	504,469	1,775,223	126,758	126,758	6,871,221	6,647,854	309,343	6,774,612	-96,969
1946	6	9	945,000	159,133,259	172,124,638	7,534,985	172,124,638	172,124,638	7,534,985	37,618	504,469	1,775,223	126,758	126,758	7,011,741	8,280,433	383,890	8,407,191	383,890
1947	7	11	1,155,000	162,485,369	174,081,290	7,963,252	174,081,290	174,081,290	7,963,252	37,618	504,469	1,775,223	151,758	151,758	7,115,010	9,452,614	462,733	10,133,852	462,733
1948	8	13	1,365,000	165,869,633	174,976,202	8,429,048	174,976,202	174,976,202	8,429,048	37,618	504,469	1,775,223	151,758	151,758	7,150,806	9,641,180	545,823	11,953,623	545,823
1949	9	14	1,470,000	167,469,240	173,933,668	8,957,817	173,933,668	173,933,668	8,957,817	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	633,170	13,866,423	633,170
1950	10	15	1,575,000	169,068,847	172,767,730	9,510,709	172,767,730	172,767,730	9,510,709	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	724,448	15,848,429	724,448
1951	11	15	1,575,000	169,847,956	173,679,918	9,762,918	173,679,918	173,679,918	9,762,918	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	819,563	17,948,429	819,563
1952	12	15	1,575,000	169,811,391	173,679,918	9,762,918	169,811,391	169,811,391	9,762,918	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	850,000	18,615,000	850,000
1953	13	15	1,575,000	169,653,364	173,679,918	9,762,918	169,653,364	169,653,364	9,762,918	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	850,000	18,615,000	850,000
1954	14	15	1,575,000	169,369,016	173,679,918	9,762,918	169,369,016	169,369,016	9,762,918	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	850,000	18,615,000	850,000
1955	15	15	1,575,000	168,963,294	173,679,918	9,762,918	168,963,294	168,963,294	9,762,918	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	850,000	18,615,000	850,000
1956	16	15	1,575,000	168,400,943	173,679,918	9,762,918	168,400,943	168,400,943	9,762,918	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	850,000	18,615,000	850,000
1957	17	15	1,575,000	149,706,448	159,858,259	9,985,259	149,706,448	149,706,448	9,985,259	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	900,000	19,710,000	900,000
1958	18	15	1,575,000	149,864,264	159,858,259	9,985,259	149,864,264	149,864,264	9,985,259	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	900,000	19,710,000	900,000
1959	19	15	1,575,000	141,968,352	167,474,734	10,534,571	141,968,352	141,968,352	10,534,571	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	900,000	19,710,000	900,000
1960	20	15	1,575,000	137,712,643	162,508,504	10,808,504	137,712,643	137,712,643	10,808,504	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1961	21	15	1,575,000	133,890,626	158,533,625	11,113,625	133,890,626	133,890,626	11,113,625	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1962	22	15	1,575,000	128,865,766	154,568,831	11,448,831	128,865,766	128,865,766	11,448,831	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1963	23	15	1,575,000	124,221,114	150,593,475	11,774,379	124,221,114	124,221,114	11,774,379	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1964	24	15	1,575,000	119,359,475	146,614,054	12,109,054	119,359,475	119,359,475	12,109,054	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1965	25	15	1,575,000	114,303,371	142,631,891	12,444,891	114,303,371	114,303,371	12,444,891	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1966	26	15	1,575,000	109,045,023	138,648,912	12,779,912	109,045,023	109,045,023	12,779,912	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1967	27	15	1,575,000	103,576,341	134,664,912	13,115,912	103,576,341	103,576,341	13,115,912	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1968	28	15	1,575,000	97,888,912	130,684,912	13,452,912	97,888,912	97,888,912	13,452,912	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1969	29	15	1,575,000	91,973,081	126,700,912	13,790,912	91,973,081	91,973,081	13,790,912	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1970	30	15	1,575,000	85,822,461	122,716,912	14,126,912	85,822,461	85,822,461	14,126,912	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000
1971	31	15	1,575,000	79,424,876	118,733,912	14,463,912	79,424,876	79,424,876	14,463,912	37,618	504,469	1,775,223	151,758	151,758	7,062,467	9,830,483	950,000	20,805,000	950,000

1972	32	1,575,000	72,771,388	2,910,855	87,618	504,469	1,775,223	151,738	2,519,083	5,620,923	9,830,483	950,000	20,805,000	8,455,449
1973	33	1,575,000	65,851,760	2,634,070	87,618	504,469	1,775,223	151,738	2,519,083	5,153,123	9,830,483	950,000	20,805,000	8,455,449
1974	34	1,575,000	58,695,347	2,346,214	87,618	504,469	1,775,223	151,738	2,519,083	4,686,263	9,830,483	950,000	20,805,000	8,455,449
1975	35	1,575,000	51,171,078	2,046,843	87,618	504,469	1,775,223	151,738	2,519,083	4,219,303	9,830,483	950,000	20,805,000	8,455,449
1976	36	1,575,000	43,387,438	1,735,497	87,618	504,469	1,775,223	151,738	2,519,083	3,752,343	9,830,483	950,000	20,805,000	8,455,449
1977	37	1,575,000	35,282,452	1,411,698	87,618	504,469	1,775,223	151,738	2,519,083	3,285,383	9,830,483	950,000	20,805,000	8,455,449
1978	38	1,575,000	26,873,657	1,074,947	87,618	504,469	1,775,223	151,738	2,519,083	2,818,423	9,830,483	950,000	20,805,000	8,455,449
1979	39	1,575,000	18,118,131	734,725	87,618	504,469	1,775,223	151,738	2,519,083	2,351,463	9,830,483	950,000	20,805,000	8,455,449
1980	40	1,575,000	9,012,373	360,495	87,618	504,469	1,775,223	151,738	2,519,083	1,884,503	9,830,483	950,000	20,805,000	8,455,449
1981	41	1,575,000	-----	-----	87,618	504,469	1,775,223	151,738	2,519,083	1,417,543	9,830,483	950,000	20,805,000	8,455,449
1981	41	1,575,000	-----	-----	87,618	504,469	1,775,223	151,738	2,519,083	2,015,594	9,830,483	950,000	20,805,000	18,790,401

1 Depreciation and amortization charges deferred 10 years.

## 2. EARLIER PLANS OF DEVELOPMENT

597. *a. Columbia Basin report.*—The Columbia Basin Survey Commission organized under a special act of the legislature of the State of Washington, issued a report in 1920 that discussed very briefly a dam and pumping plant at the Grand Coulee site. The pumps were to be turbine driven and no commercial power was to be developed. A dam 180 feet in height was considered, but no detailed estimate of cost was made of this feature due to lack of subsurface data.

598. *b. Report of consulting engineers.*—A board of engineers composed of D. C. Henny, James Munn, and C. T. Pease reviewed the State's Columbia Basin report for the United States Bureau of Reclamation in December 1920. No new data were presented on the Grand Coulee site.

599. *c. Batcheller report.*—W. T. Batcheller prepared a voluminous report for the State Columbia Basin Survey Commission in 1922. As irrigation was the primary object, commercial power at the Grand Coulee site was mentioned as a byproduct only. Estimates were made on various plans to develop from 100,000 to 700,000 horsepower, at an additional cost for installation of \$16 to \$23 per horsepower.

600. *d. Gault report.*—In 1924 H. J. Gault, under authority of the United States Bureau of Reclamation, prepared a report on the Columbia Basin Project. This report includes a discussion of a dam, power house, and pumping plant at Grand Coulee.

601. *a'. Principal works proposed.*—The principal project works proposed by Mr. Gault include a gravity dam at the site with a normal forebay elevation of 1,160 feet, State datum, 1,157.6 feet, United States Geological Survey datum, as used in present report. Spillway capacity is provided by an overflow crest along the major portion of the dam. The power plant was to be located in a cavity in the dam itself, and under the spillway crest. The pumping station was placed on the left bank immediately upstream from the dam.

*b'. Power.*

Normal water surface in forebay, elevation.....feet.....	1, 160
Normal water surface in canal, elevation.....do.....	1, 560
Approximate static pumping head.....do.....	400
Continuous power available, from natural flow.....horsepower.....	484, 000
Continuous power available from upstream regulation.....do.....	618, 000
Maximum quantity pumped.....second-feet.....	13, 416
Power required for pumping.....horsepower.....	840, 000
Installed capacity:	
For pumping 15 units, at 60,000 kilowatts.....kilowatts.....	900, 000
Commercial power 15 units, 60,000 kilowatts.....do.....	900, 000
Capacity of pumps 15 units, at 1,000 second-feet.....second-feet.....	15, 000
Capacity of motors 30 at 30,000 horsepower.....horsepower.....	900, 000

602. *c'. Estimated cost.*—As the report was made primarily in the interest of irrigation, the available commercial power was considered as a byproduct, and the cost for this feature was not segregated. The average annual charge to be carried by the power development, made up the three items, operation and maintenance, depreciation and interest, was given as \$5,485,540, or 1.36 mills per kilowatt-hour for the estimated output of 4,039,900,000 kilowatt-hours. The estimated cost of the dam was \$88,063,400 and of the power plant \$41,500,000.

603. *e. Goethals report.*—George W. Goethals & Co., made a report to the Department of Conservation and Development, State of Washington, on March 30, 1922. This report reviewed the Columbia