Synchronous condensers:	
10,000 kilovolt-amperes	35, 000. 00
20,000 kilovolt-amperes	58, 000. 00
30,000 kilovolt-amperes	78, 400. 00
40,000 kilovolt-amperes	96, 750. 00

To these costs must be added about 5 percent for freight and from $2,000 to $5,000 per unit for starting equipment.

REPORT BY THE BUREAU OF RECLAMATION, DEPARTMENT OF THE INTERIOR

CONTENTS

	Page
Acknowledgments	481
Summary	481
Conclusions	483
Description of project	485
Previous investigations	485
Irrigable areas	489
Water supply	490
Stream flow	490
Irrigation requirements	492
Grand Coulee Reservoir	493
Columbia River Reservoir	496
Power output	496
Columbia River Dam	497
Scope of investigations	497
Highways	498
Construction railroad	498
Transportation of concrete aggregates	498
Construction power	498
Concrete materials	498
Deposits at dam site	498
Mansfield pit	499
Adrian pit	499
Hartline pit	499
Results of tests on aggregates	500
Foundation conditions	500
Diversion of river during construction	501
Description of dam and appurtenances	502
Power plant	503
Buildings and structures	503
Hydraulic and electrical machinery	503
Annual costs	503
Ultimate irrigation development	504
Columbia River pumping plant	504
Repumping	505
Grand Coulee Reservoir	506
North Grand Coulee Dam	506
South Grand Coulee Dam	506
Canals	507
Tunnels	507
Siphons and penstocks	507
Lateral system	508
Drainage	508
Wasteways	508
Buildings	508
Telephone system	508
Wells	508
Operation and maintenance during construction	509
Summary of estimate of cost of Columbia Basin project for ultimate development	509

CONTENTS—Continued

Page
First unit irrigation development 509
Feature no. 1 509
Feature no. 2 510
Feature no. 3 510
Feature no. 4 510
Feature no. 5-A 510
Feature no. 6-B 510
Feature no. 6-A 510
Feature no. 7 511
Feature no. 8 511
Feature no. 9 511
Feature no. 10 511
Feature no. 11 511
Main West Canal 511
General items 511
Summary of estimate of cost of first unit of Columbia Basin project 511
Estimates showing comparison of costs of different plans of Grand Coulee Reservoir together with the costs of changes in canals and headgates required for the various plans 512
Annual costs 513
Operation and maintenance cost 513
Annual construction repayments 513
Total annual cost of irrigation 517
Ability of land to pay for irrigation benefits 517
Payments by other benefited interests 517
Power market 517
Market area 517
Municipalities 518
Utility companies 518
Manufacturing companies 518
Future increase in power usage 520
Absorption of Columbia River power 521
Competitive power 522
Value of power as determined by the cost of steam-electric power 523
Transmission of Columbia River power 527
Cost of transmission facilities 527
Cost of transmitting energy 528
Value of energy at power plant 534
Financial results 535

LIST OF TABLES

Table no. Title
1. Run-off of Columbia River at Grand Coulee 491
2. Net diversion requirements from Grand Coulee Reservoir for fully-developed Columbia Basin project 493
3. Net irrigation demands on Columbia River for fully-developed Columbia Basin project 495
4. Various kinds of power available each year 497
5. Analysis of concrete aggregates 500
6. Financial operation of irrigation development 514
7. Power market 520
8. Estimated cost of steam-generated energy, public development 525
9. Estimated cost of steam-generated energy, private development 526
10. Estimated yearly cost of steam stand-by, public and private developments 529
11. Cost of transmitting energy to load center, public and private developments without steam stand-by 529
12. Cost of transmitting energy to load center, public development with steam stand-by 530
13. Cost of transmitting energy to load center, private development with steam stand-by 530
14. Estimated annual value of energy at the Columbia River power plant with and without steam stand-by 531
15. Financial operation of power development 536

UNITED STATES DEPARTMENT OF THE INTERIOR,
BUREAU OF RECLAMATION,
Denver, Colo., January 7, 1932.

From: Chief engineer.
To: Commissioner, Washington, D.C.
Subject: Report on proposed Columbia Basin project—Washington.

1. Transmitted herewith is a report prepared in the Denver office on the proposed Columbia Basin project.

2. The report shows that the investment in the dam and power plant will be repaid under the conditions assumed in 50 years, with interest at 4 percent, and leave a substantial surplus for repaying about one half of the investment without interest ultimately required in the entire irrigation development. With this surplus power revenue available for liquidating a portion of the investment in the irrigation development, and on the basis of the estimates and conclusions reached in the report, I believe the Columbia Basin project is physically and financially feasible. With the completion of the power development, the irrigation development may proceed at such time and in units of such size as economic conditions may justify.

3. The postponement of the irrigation development will increase rather than detract from the economic feasibility of the power development, except as such irrigation development affects the power market.

A. F. WALTER.

ACKNOWLEDGMENT

Prior to the preparation of the following report there was made available to the United States Bureau of Reclamation a very comprehensive report and a large amount of supporting data prepared under the immediate direction of Maj. John S. Butler, Corps of Engineers of the United States Army. The investigations by the Corps of Engineers was authorized by the Congress of the United States under section 1 of the Rivers and Harbors Act of January 21, 1927, and in accordance with House Document No. 308, Sixty-ninth Congress, first session.

Full use has been made of the reliable and up-to-date information contained in Major Butler's report. The maps, plans, and calculations contained therein have been of much value, and their availability has saved the expense of surveys and studies which otherwise would have been necessary for the preparation of this report.

Among the other available reports utilized in the preparation of this report, special mention should be made of the comprehensive investigations conducted by the State of Washington and the earlier studies of the Bureau of Reclamation.

SUMMARY

The Columbia Basin project as considered in this report involves the construction of the following principal features.

(*a*) The Columbia River dam, about 450 feet in height above the foundation, which, with appurtenant structures, will contain about 11,266,000 cubic yards of concrete and create a reservoir about 150 miles long, extending to the international boundary, the water surface of which will be about 355 feet above the low-water surface of the Columbia River.

(*b*) The Columbia River power plant containing an installation of turbines and generators of 2,100,000 horsepower capacity.

(*c*) The Columbia River pumping plant, containing an installation of motor-driven pumps of 16,000 c.f.s. total capacity.

(*d*) A dam at each end of the Grand Coulee to form the Grand Coulee Reservoir, about 23 miles long.

(*e*) Pipe lines leading from the Columbia River pumping plant to a supply canal 1.7 miles long which, in turn, leads to the north end of the proposed Grand Coulee Reservoir.

(*f*) An irrigation distribution system consisting of canals, tunnels, siphons, wasteways, bridges, headgates, etc., distributed over the main canal extending from the south end of the proposed Grand Coulee Reservoir, a distance of about 11 miles, from which point it branches into the main west canal and the main east canal. Each of these branch canals supply smaller canals equipped with suitable structures, the final reduction being to the size necessary to supply each 160-acre farm.

(*g*) Power plants and transmission lines at suitable places along the canals of the distribution system for the generation and distribution of about 26,000 kilowatts of seasonal power.

(*h*) Motor-driven pumping plants at suitable places along the canals to repump water a maximum of 100 feet to the various areas adjacent thereto.

(*i*) A drainage system to carry off seepage waters developed with the irrigation of land.

(*j*) Telephones and buildings necessary for the operation of the project and wells for water supply during the construction period.

As a result of the construction of the foregoing items the following uses of power and water are proposed:

(*a*) The production at the power plant at the Columbia River power dam of 800,000 kilowatts of firm continuous power which will be available for commercial sale.

(*b*) The use of the secondary power generated at the Columbia River dam to pump water from the Columbia River Reservoir to the Grand Coulee Reservoir, the maximum difference of elevation between the surfaces of the two reservoirs being about 365 feet.

(*c*) The use of the water pumped into the Grand Coulee Reservoir to furnish an irrigation supply to 1,200,000 acres of land.

(*d*) The seasonal power generated at power plants at various drops on the project canals to be transmitted to pumping plants along the canals to lift water a maximum of 100 feet for irrigating 219,000 acres of the above-mentioned 1,200,000 acres.

The territory considered as the market area for the Columbia River power includes the area within a radius of 300 miles of the dam site embracing all of the State of Washington, the northern part of Oregon, the northern part of Idaho, and the western part of Montana. The present installed capacity of municipal and utility plants within this territory totals about 1,000,000 kilowatts, of which about 28 percent is steam-electric power.

During 1920 to 1930 power requirements in this territory increased at an average rate of 9.5 percent per year, compounded annually. For this report, a gradually decreasing rate of increase has been assumed beginning with 8 percent in 1930 and decreasing to 4 percent in 1960. Practically all of the power of the major hydroelectric developments on which construction has been started by the various power companies and municipalities will have been absorbed by 1940, which is the earliest date that power from the Columbia River development could be made available. The additional generating capacity required during the 15-year period 1940 to 1955 would amount to about 3,000,000 kilowatts, whereas the proposed installation at the Columbia River Dam is 1,500,000 kilowatts or only one half of the expected increase. With proper cooperation on the part of the various power companies and municipalities the proposed Columbia River development should be absorbed in this 15-year period.

Comparative estimates indicate that a price of 2.25 mills per kilowatt-hour should be sufficiently attractive to induce the power companies and municipalities to purchase energy in lieu of constructing additional power plants and to insure that the Columbia River power will be absorbed as rapidly as the growth of load will permit. Based on the absorption of 800,000 kilowatts of continuous power in 15 years, a price of 2.25 mills per kilowatt-hour for firm power, a price of $1 per acre per year for secondary power used for irrigation pumping, which is equivalent to approximately 0.50 mill per kilowatt-hour and land settlement at the rate of 20,000 acres per year, the revenue from power would be sufficient to repay the cost of the Columbia River Dam and power plant with interest at 4 percent per annum in 50 years, in addition to providing for the operation, maintenance, and depreciation of the dam and power plant, and also provide a surplus of approximately $144,000,000 which would be available for repayment of the cost of the irrigation development and other purposes.

With the estimated surplus power earnings available for liquidating a portion of the irrigation investment, the annual construction charges to be paid by the land beginning 4 years after settlement and continuing for 4 years at a rate of $2 per acre and thereafter at $2.50 per acre for 32 years, will repay half of the cost of the investment in the irrigation project within 40 years from the time that water is available for each unit or division.

Investment in project

Columbia River Dam	$125, 750, 000
Columbia River power plant	42, 616, 000
Subtotal	168, 366, 000
Interest during construction on above	17, 524, 000
Subtotal	185, 890, 000
Irrigation development without interest (1,200,000 acres)	208, 265, 000
Total investment	394, 155, 000

The maximum estimated investment in the combined power and irrigation project up to the time when power revenue are sufficient to reduce the investment is $260,000,000.

CONCLUSIONS

1. The market for power in the territory tributary to the proposed Columbia River Dam is sufficient to absorb the total firm power output to be generated at the Columbia River Dam within 15 years after the dam is completed.

2. The time required to absorb the power output is a very important factor in the financial success of the proposed development. The power companies and municipalities operating power systems in the territory will have to cooperate to the fullest extent in the utilization of Columbia River power in order that it may be absorbed as rapidly as possible.

3. The revenue which will be derived from the sale of commercial power at 2.25 mills per kilowatt-hour, combined with the revenue from the sale of power for irrigation pumping at $1 per acre per annum, will be sufficient to return within a period of 50 years the investment in the dam and power plant with interest at 4 percent to pay the cost of operation and maintenance of the dam and power plant and leave a substantial surplus for repayment of a portion of the investment in the irrigation development.

4. The surplus from power revenues is estimated to be sufficient to repay within 40 years about 50 percent of the cost of the irrigation development for the entire acreage of 1,200,000 acres proposed for for the project, or an average of over $85 per acre. The balance of the irrigation investment must be repaid by the lands or from other sources.

5. Assuming the above surplus power revenues to be available, the total annual charge accruing against the land, beginning 4 years after settlement, would have to be $4.59 per acre, of which $2 per acre will be available for repayment of the investment in irrigation works. Beginning with the eighth year after settlement to the end of the fortieth year, the annual charge must be increased to $5.09 per acre, of which $2.59 per acre will be available for repayment of the irrigation investment, without interest.

6. In order to reduce the annual charges for the irrigation benefits accruing against the land, it will be necessary that the State of Washington, municipalities, and all interests benefited within the irrigation district contribute toward the cost in proportion to such benefits.

7. Ultimate irrigation development is proposed for 1,200,000 acres. The slower the irrigation development proceeds the smaller the amount of additional funds that will have to be advanced from the Treasury of the United States.

8. In order to perfect final construction plans, it will be necessary that further information be secured by diamond drilling of the foundation of the Columbia River Dam; that additional field exploration and laboratory tests be made to determine the amount and source of supply of the concrete aggregates for the Columbia River Dam; that a topographic survey and land classification be made of the irrigable area of the project; that test pits and borings be made to determine the classification of material to be excavated in the main canals of the project distribution system for use in final designs and estimates; and that a survey be made to determine the cost of irrigating land by pumping water from the Spokane River and using Columbia River Dam power.

9. No construction on the Columbia River Dam and power plant should be undertaken until contracts are executed for the sale of power which will insure sufficient revenue for annual expenses and the repayment of the investment in the dam and power plant with interest at 4 percent within 50 years.

10. No construction on the irrigation development should be undertaken until the power revenues are assured and a suitable contract for repayment of the investment in irrigation works within 40 years has been executed by the district.

DESCRIPTION OF PROJECT

As considered in this report the proposed Columbia Basin project, located adjacent to and east of the Columbia River in eastern Washington, is a combination of power and irrigation development. The fundamental requisite for either power or irrigation is the construction of a dam in the Columbia River at the so-called Grand Coulee site shown on drawing no. 222-D-14.[31] The Columbia River Dam is to be 4,100 feet long and will raise the water about 355 feet above the low-water surface of the river. It will create an artificial lake 150 miles long extending to the Canadian boundary line. The total height of the dam above the general elevation of the foundation will be about 450 feet.

Hydraulic and electrical machinery is to be installed progressively at the dam for the generation of power. It is contemplated that the firm power will be sold at the dam to responsible agencies engaged in the distribution of electrical energy. Pumping machinery for irrigation requirements is to be installed progressively at the dam and this machinery will utilize the seasonal power available during the high-water season of the Columbia River.

Water for the irrigation project is to be pumped from the Columbia River Reservoir through large discharge pipes to the Grand Coulee Canal, extending a distance of 1.7 miles to Grand Coulee Lake. This lake will be created by the construction of two dams, one at the north end of the Grand Coulee near the Columbia River, and the other near the south end of the Grand Coulee about 4½ miles north of Coulee City. This lake will be about 23 miles long and the difference between the high-water surface in the Grand Coulee Lake and the low-water surface of the Columbia River Reservoir will be about 362 feet.

From the south end of the Grand Coulee Lake, water is conducted through concrete-lined canals, concrete-lined tunnels, steel-pipe siphons, and reinforced concrete pipe siphons to the lateral distribution system which finally delivers water to 981,000 acres of land, including that part of the area considered suitable for irrigation and cultivation. There are a number of places where the larger canals are dropped to lower elevations and the energy of the falling water at such places is to be utilized for repumping to areas lying at a maximum elevation of 100 feet above the canals. This repumping will add an additional irrigable area to the project of 219,000 acres, making the total irrigable area of the project 1,200,000 acres.

PREVIOUS INVESTIGATIONS

The possibilities of irrigating the area along the Columbia River in Grant, Adams, and Franklin Counties in eastern Washington received consideration and investigation by the United States Reclamation Service as early as 1904. Surveys were made for canals using the Columbia, Spokane, and Palouse Rivers as sources of water

[31] Not printed.

supply. A total of $76,400 was spent on these early investigations. The Priest Rapids area was investigated in 1905 at a cost of $6,200.

Again in 1914 and 1915, under a cooperative agreement between the State of Washington and the United States Reclamation Service, an investigation and report was made on a proposed project north and east of Pasco, Wash., using the Palouse River as a source of water supply. This work was in charge of Engineer McCulloch and involved an expenditure by the United States Reclamation Service of $10,200.

Studies by the United States Reclamation Service on the possibilities of power development on the Columbia River at various times prior to 1923 involved an expenditure of $4,000.

The Columbia Basin Commission of the State of Washington of which Marvin Chase, State hydraulic engineer, was chairman, and A. J. Turner, of Spokane, was chief engineer, published a report in 1920 as a result of its surveys and investigations in that year and in 1919. The Commission investigated a number of plans for the project water supply, including several alternatives of a gravity supply diverting from Clark Fork at Albany Falls, a partial water supply from the Wenatchee River and a plan for pumping water from the Columbia River at the Grand Coulee site with a dam in the Columbia River 180 feet in height above low water.

A board of engineers of the United States Reclamation Service, consisting of D. C. Henny, James Munn, and C. T. Pease, reviewed the report of the Columbia Basin Commission of the State of Washington in December 1920. The report of this board suggested a number of changes in unit prices and recommended further investigations.

The State of Washington in 1921 made further investigations at the Columbia River dams site and explored the foundation by diamond drilling. Estimates were made of the costs of developing power, pumping water for irrigation and building transmission lines at the Foster Creek site and also at the Grand Coulee site. The estimates and report of this work were prepared by Willis T. Batchellor, electrical engineer. In the latter part of 1921 the State of Washington employed Gen. George W. Goethals to review existing reports and to make a further report upon the feasibility of the various construction problems of the project. His report dated March 30, 1922, showed considerably lower unit costs than had been used by the Columbia Basin Commission. The cost of work done by the State on completion of this report amounted in round numbers to $150,000.

A board of engineers consisting of J. S. Cavanaugh, colonel, Corps of Engineers, United States Army, D. C. Henny, consulting engineer, United States Reclamation Service; F. F. Henshaw, district engineer, United States Geological Survey; C. S. Heidel, State engineer of Montana; W. G. Swendsen, commissioner, department of reclamation, Idaho; and Marvin Chase, supervisor of hydraulics, State of Washington, made a report to the Federal Power Commission in February 1923. The principal conclusions of this board of engineers as given in the published report were that the Columbia Basin project was the most important single item to be considered in the uses to be made of the Columbia River water above the mouth of the Snake River, that the project could be supplied with water by either a gravity supply diverted from the Clark Fork at Albany Falls or by pumping from the Columbia River at the Grand Coulee dam site, but that information upon which to base a final decision between a gravity and a pumped supply for the Columbia Basin irrigation project was not complete and should be completed.

The United States Bureau of Reclamation made further investigations of the Columbia Basin project in 1923 and 1924, and the report thereon by Engineer H. J. Gault was published by the Senate of the Sixty-ninth Congress, second session, for the use of the Committee on Irrigation and Reclamation. This report considered four alternatives in each of the two general plans for irrigating the Columbia Basin project. The gravity plan was investigated with high and low lines, each with and without repumping. The pumping plan proposing a dam in the Columbia River at the Grand Coulee site, 280 feet in height above low water, was investigated with and without storage, and with and without repumping. Soils, geology, and water were considered in their relation to the project.

A board of engineers consisting of A. J. Wiley, James Munn, and J. L. Savage, of the United States Bureau of Reclamation, reviewed the above-mentioned Gault report, and on April 6, 1924, submitted a report which was published with the Gault report. The board found that the construction cost of irrigation under the pumping plan of lowest cost would be $246.58 per acre, as against $231.40 per acre under the gravity plan of lowest cost. The board in arriving at the cost of $246.58 per acre for the pumping project considered that the power market in the territory was so fully covered by private and municipal developments that no net income could be relied upon from the sale of power to offset the greater cost of both construction and operation of the pumping over the gravity plan. It was judged that the entire cost of the dam in the Columbia River, that part of the power plant required for irrigation pumping, the pumping plants and transmission lines necessary for repumping on the project, amounting to 47.7 percent of the total cost, would have to be borne by the irrigation project in addition to the construction items for the distribution of water and drainage of the lands.

In 1924 a board of engineers and economists was appointed by the Columbia Basin Commission of the United States Department of the Interior to make a further study of the Gault report and an independent investigation of the project including settlement and farm development problems as well as engineering. The Columbia Basin Commission was appointed by the Secretary of the Interior and its membership consisted of Elwood Mead, Commissioner of the Bureau of Reclamation, and John H. Edwards, Solicitor of the Department of the Interior.

The membership of the board of engineers appointed by the Columbia Basin Commission consisted of Louis C. Hill of California, Charles H. Locher of Maryland, Richard R. Lyman of Utah, Arthur J. Turner, O. L. Waller and Joseph Jacobs of Washington. The report of this board dated February 1925 was published with the Gault report. This board found that economic conditions seemed so definitely to favor the gravity projects that it did not deem it necessary to make an elaborate analysis of the entire Columbia River power problem and consequently limited its examination and report to the analyses and estimates of the various plans of supplying water to the Columbia Basin project by diverting water from the Clark Fork at Albany Falls. The board gave consideration to the carrying capacity of the canals and in addition to providing for concrete lining in all canals down to 100-c.f.s. capacity, proposed to line with concrete all laterals below 100-c.f.s. capacity and by such construction estimated that the diversion duty would be increased from 80 acres to the second-foot as used in the Gault report to from 112 to 119 acres to the second-foot for the maximum and minimum project respectively. With the above as a basis, the board found the minimum gravity project of 1,224,000 acres could be constructed at a cost of $158 per acre. It concluded that with the construction of the project the State should assume its proper share of the responsibility for collecting payments from the settlers and should also bear its proper share of the losses, if any, incidental to the development of the project.

The Columbia Basin Commission transmitted the above-mentioned report of the board of engineers and economists to the Secretary by letter of August 25, 1925, and this letter was published with the reports above mentioned. The commission concluded that the time had not arrived when local and national interests justified the construction of the project or that the Bureau of Reclamation was possessed of either the information or the experience to formulate a development program as costly and complex as the one outlined and advocated in the report. The cost of all investigations of the Columbia Basin project made by the United States Bureau of Reclamation up to this time, exclusive of those for which the costs have heretofore been mentioned, amounted in round numbers to $97,000.

From 1926 to the early part of 1930, studies of various water-supply and power-development problems relating to the Columbia Basin project were made by the United States Geological Survey at the request of and collaborating with the State of Washington. The principal reports submitted are as follows:

(1) Power Possibilities of Priest River, Idaho, 1926 by G. L. Parker, district engineer, United States Geological Survey, and Eugene Logan, consulting engineer, for the State of Washington.

(2) Preliminary Report Columbia Basin Project, Water Power Analysis 1926, by G. L. Parker, district engineer, United States Geological Survey, and Eugene Logan, consulting engineer for the State department of conservation and development.

(3) Storage Regulation in Flathead Basin for Power and its Effect on the Columbia Basin Project, 1926, by G. L. Parker, district engineer, United States Geological Survey.

(4) Albany Falls Power Project in Connection with Columbia Basin Irrigation Project, 1930, by Eugene Logan, consulting engineer for the State department of conservation and development, Washington.

A very comprehensive investigation of the Columbia River and its tributaries above the mouth of the Snake River was made during 1928, 1929, 1930, and 1931, by the Corps of Engineers of the War Department. The results of this investigation were submitted in 1931 in a report by Maj. John S. Butler, district engineer in charge of the work. This report consists of 2 volumes and 5 appendices. It considers navigation, flood control, irrigation, and power development. In addition to a number of able officers and civilian employees of the War Department, skilled specialists were employed for the study of the problems in economics, geology, dam design, power and irrigation development. A large amount of data were assembled on climate, vital statistics, population trends, markets, lumbering, mineral resources, irrigation economics, and power installations, and a study of this information was made to determine the probable success of the irrigation project and the future requirement for electrical energy, including that required for the development of the irrigation project.

With particular reference to the irrigation project under the pumping plan, a study and estimate was made of dams of various heights at the Grand Coulee site in the Columbia River. Estimates were made of seven different plans for irrigating the entire project and of two plans for irrigating a part of the project. The following table gives the essential features of the various plans:

Source of water supply, river	Name of area to be irrigated	Acres supplied by gravity only	Acres supplied by pumping 362 feet at Grand Coulee	Acres supplied by repumping 100 feet	Acres supplied by pumping 255 feet	Acres supplied by pumping 635 feet	Acres, total
Wenatchee	Quincy	320, 310	0	0	0	0	320, 310
Columbia River 10 miles above Priest Rapids.	South of Saddle Mountain.	0	0	0	74, 100	66, 420	140, 520
Clark Fork and Spokane	Maximum project	1, 256, 940	0	262, 950	0	0	1, 519, 890
Clark Fork	do	1, 256, 940	0	262, 950	0	0	1, 519, 890
Clark Fork and Wenatchee.	Gravity project only	1, 256, 940	0	0	0	0	1, 256, 940
Clark Fork, Spokane, Wenatchee.	Reduced gravity project	1, 129, 380	0	320, 310	0	0	1, 449, 690
Columbia River at Grand Coulee Dam.	Maximum pumping project.	0	980, 340	219, 090	0	0	1, 199, 430
Columbia River at Grand Coulee and at 10 miles above bend.	South of Saddle Mountain and part of pumping project and repumping.	0	834, 860	199, 250	74, 100	66, 420	1, 174, 630
Columbia River at Grand Coulee.	South of Saddle Mountain and part of pumping project.	0	834, 860	0	74, 100	66, 420	975, 160

IRRIGABLE AREAS

Irrigable areas as referred to in this report are those lands which are expected to produce good crops when cultivated and irrigated. The irrigation of these areas will require lifting the water from the Columbia River Reservoir to the Grand Coulee Lake through a maximum height or primary lift of 362 feet for 981,000 acres and relifting the pumped water an additional height of 100 feet for 219,000 acres.

All irrigable lands of the project will be served by the main canal which extends southward from the Grand Coulee Lake about 11.7 miles to a point where it branches into two canals, the main west and the main east.

The main west canal extends in a westerly and southerly direction beyond Ephrata and Quincy and with its lateral distributaries supplies water to 371,000 acres, all of which are under the primary lift and no areas along the west main canal are to be irrigated by repumping.

The main east canal extends in a southeasterly direction beyond Hatton and Connell and with its lateral distributaries supplies water to a total of 829,000 acres. Of this area 219,000 acres are to be supplied by repumping and while some high areas lying between the boundaries defined by the main canal lines will be supplied by repumping the greater portion of the area lies adjacent to the east of the east main canals.

Extensive areas within the project boundaries have been eliminated from the irrigable areas for various reasons, such as elevation, probable water-logging, rocks, gravel, etc. These determinations have been made by field inspections using as a guide United States Geological Survey maps on scales of one half and 1 inch to 1 mile where they had been made. In order to make a more dependable determination of the irrigable areas, topographic maps should be made on a scale of 400 feet or 1,000 feet to 1 inch and test pits and borings should be made to determine the character and thickness of the soils and subsoil conditions, particularly as the latter may relate to future waterlogging of the soil.

WATER SUPPLY

Stream flow.—The Columbia River above the proposed Columbia River Dam drains a roughly triangular-shaped area of 74,000 square miles located in parts of British Columbia, Idaho, Montana, and Washington. The main source of water supply for the river is from the melting of the abundant snows accumulated at the higher altitudes on the western slope of the Rocky Mountains and on the Selkirk and Bitterroot Mountains. A number of large lakes located near the headwaters, of which the principal ones are Kootenay Lake in British Columbia, Flathead Lake in Montana, and Pend O'reille, Priest, and Coeur d' Alene Lakes in Idaho, tend to regulate the flow of the river naturally by retarding the flood peaks and storing large volumes of water for release when the river and lake stages recede following the flood run-off. It is possible that at some future date the outflow from these lakes may be controlled artificially for power purposes thus creating a greater regulatory effect than now exists. When and if such regulation should be accomplished the winter flow of the Columbia River and hence the firm power possibilities at the Columbia River Reservoir site would be increased somewhat over that shown herein. Plans for the development of the Columbia Basin project make no allowance for such artificial control of these upstream reservoirs hence for the purposes of this report no allowance is made for such additional regulation.

Discharge records, from which estimates of the flow at Grand Coulee are based are available as follows:

At Trail, British Columbia, May 1913 to March 1931.
At Kettle Falls (or Marcus) Wash., April 1916 to March 1931.
At Grand Coulee, Wash., July to December 1923 and June 1928 to March 1931.
At Vernita (or Wenatchee), Wash., May 1913 to March 1931.

In addition, records are available for the principal tributaries, which enter the main stream in this section. Using these records reliable estimates of flow at Grand Coulee were prepared for the period April 1913 to March 1931. (See table no. 1.)

DEPARTMENT OF THE INTERIOR, BUREAU OF RECLAMATION

TABLE NO. 1.—*Run-off of Columbia River at Grand Coulee*

[Unit 1,000 A.F. Drainage area, 74,100 square miles]

Year	October	November	December	January	February	March	April	May	June	July	August	September	Total
1913							4, 030	11, 700	25, 900	17, 200	9, 590	5, 950	74, 370
1913–14	3, 800	3, 080	2, 370	2, 230	1, 930	2, 970	5, 930	13, 500	17, 400	15, 500	8, 120	4, 580	81, 410
1914–15	3, 840	3, 910	2, 970	2, 010	1, 600	2, 260	5, 150	10, 800	11, 200	11, 300	9, 590	5, 430	70, 060
1915–16	3, 120	2, 920	2, 430	1, 750	1, 820	3, 860	6, 720	12, 400	19, 000	25, 800	11, 600	6, 550	97, 970
1916–17	3, 730	2, 750	1, 990	1, 610	1, 440	1, 560	3, 330	11, 300	21, 900	19, 200	9, 160	4, 810	82, 780
1917–18	3, 750	2, 400	2, 570	5, 150	2, 890	2, 800	5, 510	12, 900	18, 300	15, 700	8, 360	5, 380	85, 710
1918–19	3, 980	2, 830	2, 320	2, 180	2, 410	2, 620	5, 250	12, 500	17, 500	13, 900	8, 480	4, 800	78, 770
1919–20	2, 850	1, 800	1, 430	1, 440	1, 460	1, 800	2, 610	8, 610	14, 100	19, 400	10, 900	5, 400	71, 800
1920–21	5, 340	3, 830	2, 830	2, 910	2, 580	3, 830	5, 510	13, 600	23, 200	15, 400	8, 480	4, 170	91, 680
1921–22	3, 150	3, 180	2, 880	2, 100	1, 520	1, 670	3, 190	9, 650	21, 100	13, 400	7, 810	5, 270	74, 920
1922–23	3, 360	2, 330	1, 620	2, 360	1, 460	1, 740	4, 420	11, 600	20, 400	15, 800	8, 360	5, 500	78, 950
1923–24	2, 960	1, 950	1, 740	1, 430	2, 290	2, 350	2, 460	11, 200	13, 500	10, 300	7, 060	4, 920	62, 160
1924–25	2, 900	2, 750	2, 460	2, 540	3, 490	3, 360	8, 200	17, 000	19, 700	15, 300	8, 520	4, 550	90, 770
1925–26	2, 880	1, 930	1, 770	1, 590	1, 680	2, 050	3, 870	10, 300	8, 260	8, 710	5, 550	4, 240	52, 830
1926–27	3, 650	3, 690	3, 680	2, 520	2, 170	2, 600	3, 610	11, 400	21, 800	18, 500	9, 950	7, 400	90, 970
1927–28	6, 520	6, 400	5, 630	3, 690	2, 940	3, 550	5, 500	16, 800	21, 100	16, 000	8, 850	4, 680	101, 660
1928–29	3, 200	2, 460	1, 970	1, 550	1, 180	1, 570	2, 310	7, 130	16, 100	10, 300	6, 820	4, 140	58, 730
1929–30	2, 530	1, 740	1, 460	1, 160	1, 280	1, 750	4, 220	9, 840	13, 200	12, 000	7, 620	4, 580	61, 380
1930–31	2, 770	1, 940	1, 650	1, 390	1, 350	1, 970							11, 070

NOTE.—Actual records available at station during periods July to December 1923, and July 1928 to March 1931; balance of time discharges estimated from other records available at Trail, British Columbia, Kettle Falls and Vernita, Wash. Estimated flows for period, April 1913 to January 1924, published in U.S.G.S.W.S. Paper No. 572. Estimated flows for period, February 1924 to June 1928 based on discharges of Columbia River at Kettle Falls and intervening tributaries between Kettle Falls and Grand Coulee.

During this period the flow at Grand Coulee has varied from 17,000 second-feet to 492,000 second-feet, with an average of 109,000 second-feet, corresponding to an average annual run-off of 79,000,000 acre-feet.

There has been very little additional irrigation development on the upper tributaries of the Columbia River during the past 18 years, so that the flow as recorded in table no. 1 represents the flow under present conditions. However, by the time the Columbia Basin project has been fully developed, additional irrigation development may deplete the present flow of the stream by about 1,000,000 acre-feet annually.

In the Gault report of 1924, the amount of such depletion due to future irrigation development above the dam-site was estimated as about 900,000 acre-feet annually.

The irrigable areas and amount of depletion have been estimated by the Army engineers as follows (pt. 2, appendix 2):

Location of irrigable lands	Area in acres	Estimated annual depletion
		Acre-feet
Above Flathead Lake	125, 000	160, 000
From Priest Lake	20, 000	25, 000
Between Flathead Lake and Lake Pend O'Reille	290, 000	492, 000
Between Lake Pend O'Reille and Grand Coulee, exclusive of Spokane River	170, 000	272, 000
From Spokane River	20, 000	28, 000
Total	625, 000	977, 000

In addition to the above lands there is an irrigable area of about 66,000 acres on the Rathdrum Prairie in Idaho which would receive a water supply from either Priest Lake or Lake Pend O'Reille. Making due allowances for this area and also for the areas now under irrigation in the Columbia River watershed, the estimated depletion for additional irrigation and incidental storage development have been taken as 1,000,000 acre-feet annually, as follows (units acre-feet):

January	0	August	160, 000
February	10, 000	September	70, 000
March	20, 000	October	10, 000
April	90, 000	November	−20, 000
May	150, 000	December	0
June	260, 000		
July	250, 000	Total	1, 000, 000

Irrigation requirements.—On account of the variety of soil and climatic conditions on the Columbia Basin project, the crops grown and the water requirements will vary markedly on the different localities. On the whole, however, it is believed that crops and water requirements will be similar to those on the Sunnyside division of the Yakima project.

The physical features of the two projects compare as follows:

Feature	Sunnyside division, Yakima project	Columbia Basin project
Mean annual temperature	51.2° [1]	50.4°.[2]
Mean temperature April to October.	61.6° [1]	62.2°.[2]
Annual precipitation	0.55 foot [1]	0.68 foot.[2]
Precipitation period April to October.	0.24 foot [1]	0.30 foot.[2]
Average frost-free period	157 days [1]	159 days.[2]
Elevation irrigated area	800 feet	500 to 1,400 feet.
Soil type	Largely deep sandy loam and light volcanic ash. Small areas of decomposed basalt underlain by gravel.	Largely deep soil, varying in texture from fine silty loam to sandy loam. Small areas of shallow sandy soil underlain by gravel.
Annual irrigation requirements delivered to farm.	3.44 acre-feet per acre [3]	Estimated 3.25 acre-feet per acre.

[1] Climatological record at Sunnyside.
[2] Mean of climatological records at Lind, Hatton, Wheeler, Ephrata, and Quincy.
[3] Mean for period 1919 to 1930, inclusive.

From the above tabulation it is noted that while the Columbia Basin project area has slightly higher temperatures in the growing season and a little longer frost-free period than the Sunnyside division, it also receives more precipitation and the soils as a whole are more retentive of moisture than those on the Sunnyside division. In view of these facts the average irrigation requirements on the Columbia Basin project have been estimated at 3.25 acre-feet per acre annually.

Plans for the irrigation of the proposed project contemplate that all main canals and laterals having in excess of 100 second-feet capacity will be lined and also lining laterals below 100 second-feet capacity when indications point to excessive losses, thereby materially saving water that would otherwise be lost by seepage. Some water will still be lost, however, on account of regulatory waste, evaporation loss in the main canals and laterals and seepage losses from the smaller laterals. The total amount of such losses in the distribution system has been estimated at 25 percent of the water diverted into the main canals.

Opportunities for the reuse of return flow are not so good on this project as would be expected on an area of this size, due to the fact that the coulees which form the natural drainage channels of the project are deep and to recover such return flow would require additional pumping. The Gault report of 1924, estimates that a maximum of 512 second-feet could be reused out of Lind Coulee with the pumping plan fully developed with repumping lifts. For this report it is estimated that an average of 500 second-feet of return flow could be used with the fully developed project.

Based on the foregoing discussion the net diversion requirements from the Grand Coulee Reservoir, for irrigation water for the fully developed area, would be as follows:

TABLE NO. 2.—*Net diversion requirements from Grand Coulee Reservoir for fully developed Columbia Basin project*

Month	Rate of delivery acre-feet per acre	Rate of diversion acre-feet per acre	Total diversions for fully developed area, units 1,000 acre-feet [1]	Less usable return-flow, units 1,000 acre-feet [2]	Net irrigation demand on Grand Coulee Reservoir, units 1,000 acre-feet
April	0.39	0.55	660	27	633
May	.51	.67	805	33	772
June	.58	.74	888	36	852
July	.60	.76	912	37	875
August	.55	.71	852	35	817
September	.39	.55	660	27	633
October	.23	.35	420	17	403
Total	3.25	4.33	5,197	212	4,985

[1] Total irrigable area, 1,199,430.
[2] Average of 500 second-feet, April to October, inclusive, distributed throughout year in same proportions as total diversions.

Grand Coulee Reservoir.—The irrigation plan provides for a reservoir to be created in Grand Coulee by the construction of two dams, which will serve as part of the main conduit and eliminate a very expensive portion of the main canal which would otherwise be necessary to convey the water past that vicinity, and will also provide regulatory storage as hereinafter explained.

At various times during the past 11 years geological examinations have been made to determine the suitability of the Grand Coulee Reservoir site and the probable extent of leakage therefrom. Unpublished geological reports of this site are available as follows:

July 1921 by O. P. Jenkins and H. H. Cooper.
March 1924 by Kirk Bryan.
October 1930 by Henry Landes.
November 1930 by Ira A. Williams.
December 1930 by F. L. Ransome.

That portion of the Grand Coulee proposed to be used as a reservoir site has walls composed largely of basalt. Within the flow line of the proposed reservoir, except for the extreme ends of the coulee and at a few places along the side walls, the basalt is covered by unconsolidated talus slopes, sands, gravels, and silt terraces. The floor of the coulee, except for the southern end where basalt is exposed and near the northern end where some granite is exposed, is covered by silts which are underlain by sand and gravel.

All of the geologists who reported on this reservoir agree that the most likely place for serious leakage to occur is at the southern end of the reservoir site, where a steep monoclinal fold occurs in the basalt. The inclined flows and the more permeable contacts between the successive flows along which water could percolate are exposed in the sides and bottom of the coulee. There is some disagreement as to the extent of such leakage; Cooper and Jenkins believe that the sharp folding of the basalt was accompanied by faulting along which water could readily escape; Williams believes that, while no general faulting occurred, the folding caused some fractures in the adjacent basalt; Bryan, Landes and Ransome recognize the possibility of leakage along the inclined contacts between the flows and apparently believe that such fractures as may be accompanied by the folding are superficial or will be sealed by the silt which covers the bed of the reservoir.

Ransome and Bryan believe that an underground hydraulic gradient exists from the plateaus toward the reservoir basin so that the pressure thus created would prevent the movement of water from the reservoir toward the sides. Mr. Williams, on the other hand, believes that a general hydraulic gradient exists from the east to west, so that while the raising of the water level would not be sufficient to reverse the gradient to the east, it would cause a steeper gradient to the west. He states that seepage along the west side of the reservoir would be limited by the permeability of the wall; in this connection he points out the possibility of fractures existing, especially at the southern end near the monoclinal fold.

All of the geologists contemplated a maximum flow line elevation of 1,552.5 feet in the reservoir, while present plans contemplate a maximum flow line elevation of 1,570 feet.

In view of the impossibility of determining in advance the extent of the reservoir leakage, such leakage has been very conservatively estimated as 1,000 second-feet (corresponding to about 1-inch loss per day) for the purposes of this report.

With the project fully developed, the water-surface elevation in the Grand Coulee Reservoir will fluctuate between 1,570 and 1,554.8 feet, thereby creating a storage capacity of 329,000 acre-feet which could be utilized to carry the irrigation requirements for short intervals in case it should become necessary to interrupt the pumps during the irrigation season. This storage would be useful in carrying a large part of the irrigation demand during April of each year at a time when the proposed Columbia River Reservoir would be drawn to low levels, during periods of subnormal run-off. The pumping draft and power required for pumping would be reduced as a result of this usable storage in Grand Coulee Reservoir.

A preliminary study of the joint operations of the Columbia River and Grand Coulee Reservoirs during critical periods of low run-off such as occurred during the winters of 1919–20 and 1929–30 shows that a minimum reduction in firm power output at the Columbia River Reservoir would occur if the Grand Coulee Reservoir were maintained at elevation 1,570 throughout the winter until the end of March and then allowed to drop to elevation 1,554.8 during April.

In May and the succeeding months there is always a surplus of water available at the Columbia River Reservoir, so that pumping plants could be run continuously at full capacity and the storage in Grand Coulee Reservoir replenished as rapidly as possible.

While the operation of this reservoir could be varied from year to year to best fit in with the available power and water levels in the Columbia River Reservoir for that year, it has been assumed in these studies that the Grand Coulee Reservoir stages would vary as outlined above for each year. Based on the above discussion and the irrigation demands set forth in table no. 2, the net amount of water to be pumped from the Columbia River Reservoir and the elevations to which such water must be pumped are set out in table no. 3.

TABLE NO. 3.—*Net irrigation demands on Columbia River for fully developed Columbia Basin project*

[Units, 1,000 acre-feet]

Month	Irrigation demand at Grand Coulee Reservoir [1]	Losses from Grand Coulee Reservoir [2]	Storage content of Grand Coulee Reservoir at end of month	Water pumped from Columbia River to Grand Coulee Reservoir	Elevation to which water must be pumped, feet [3]
January	0	61	1,050	61	1,570
February	0	56	1,050	56	1,570
March	0	61	1,050	61	1,570
April	633	60	721	364	[4] 1,563
May	772	61	872	[5] 984	[4] 1,563
June	852	60	912	[5] 952	1,564
July	875	61	960	[5] 984	1,566
August	817	61	1,050	968	1,570
September	633	60	1,050	693	1,570
October	403	61	1,050	464	1,570
November	0	60	1,050	60	1,570
December	0	61	1,050	61	1,570
Total	4,985	723	------------	5,708	------------

[1] From table no. 2.
[2] Estimated at 1,000 second-feet.
[3] Corresponds to elevation of W.S. in Grand Coulee Reservoir, except as noted.
[4] Minimum elevation to which water must be pumped fixed by conditions at outlet of pump discharge pipe.
[5] Pumps operated at full capacity of 16,000 second-feet.

Preliminary studies show that a dam in Grand Coulee, 10 feet higher than contemplated herein, would furnish additional storage which could be used to further reduce the pumping requirements from Columbia River during the winter months and thereby increase the firm power available at that site from 800,000 to 840,000 kilowatts. However, in order to accomplish this, about 1,000 second-feet of additional pumping capacity and a corresponding increase in the power installation would be required at the Columbia River Dam to care for the additional pumping requirements to insure filling the reservoir during the period May to August when a surplus of water is available in the Columbia River. In addition, raising of the water level in the Grand Coulee Reservoir would tend to increase the possibilities for leakage of such reservoir. Before final plans are made for this reservoir more detailed studies should be made to determine the best capacity to which it can be developed safely and economically.

Columbia River Reservoir.—The determination of the economic height for the Columbia River Dam requires the proper balancing of the costs for pumping into the Grand Coulee Reservoir, the costs of power for pumping, the cost and value of power for commercial uses, the value of lands and power sites submerged by the reservoir and other important factors.

Based on preliminary studies of these factors the "high dam" as proposed in the Army report was tentatively adopted and the studies reported herein are based on this dam, which will raise the water level to elevation 1,287.6 feet and create a reservoir in the stream channel about 150 miles long, with a water area of about 120 square miles (77,000 acres). The plan as outlined herein contemplates that in the winter time the reservoir will be drawn down a maximum of 80 feet, thereby making available 5,028,000 acre-feet of storage in years of low run-off for the production of firm power.

Evaporation losses from this reservoir would occur largely in the period from May to September, inclusive, when there is always more than enough water to fully meet irrigation and power requirements, hence no allowance has been made for evaporation losses in the operation studies of this reservoir.

Very little information is available upon which to determine the extent of seepage losses from the Columbia River Reservoir. The fact that the reservoir would occupy the river channel, which is largely cut into indurated rocks, indicates that seepage losses from the reservoir would be negligible and they have been so assumed in this study.

The tailwater elevation below the proposed power plant at the dam has been assumed to vary with the discharge as at present and ranges from about elevation 933.5 feet with a discharge of 19,000 second-feet to about elevation 981 feet with a discharge of 450,000 second-feet.

Power output.—A study of reservoir operations using monthly estimates of inflow and outflow during the critical periods of low run-off such as occurred in the winters of 1919–20 and 1929–30 shows that with the reservoir drawn down 80 feet there would be sufficient flow to maintain a uniform power output of 920,000 kilowatts, if there were no irrigation and pumping demands for the Columbia Basin project. Further study shows that with the irrigation project fully developed, pumping requirements would reduce the firm power output to 800,000 kilowatts. In this study the over-all efficiency of the power plant was taken as 83 percent and that of the pumping plant as 73 percent.

A study was made of the joint operations of the Grand Coulee and Columbia River Reservoirs with stream flows as estimated for the period April 1913 to March 1931, inclusive. The results of this study are shown graphically on drawing 222-D-5.[31] In this study, whenever the Columbia River Reservoir was full, it was assumed that all water, in excess of that pumped to the Grand Coulee Reservoir, to the extent of the power-plant capacity (1,575,000 kilowatts), would be passed through the power plant for the production of secondary energy. When the reservoir was not full the releases through the power plant were limited to the water required for the production of firm power and power required for pumping.

[31] Not printed.

The average amounts of the various kinds of power available each year are as follows:

TABLE No. 4.—*Various kinds of power available each year*

Year Apr. 1 to Mar. 31	Total power, millions of kilowatt-hours			Months in which secondary power is available [1]
	Firm power	Power required for pumping	Secondary power available for sale [1]	
1913–14	7,008	2,280	1,840	May to March.
1914–15	7,008	2,230	2,460	April to December.
1915–16	7,027	2,240	2,150	April to December and March.
1916–17	7,008	2,230	1,780	April to November.
1917–18	7,008	2,260	2,460	May to March.
1918–19	7,008	2,230	2,280	April to March.
1919–20	7,027	2,260	1,460	April to September.
1920–21	7,008	2,330	2,820	June to March.
1921–22	7,008	2,230	1,890	April to December.
1922–23	7,008	2,250	1,120	May to November.
1923–24	7,027	2,250	1,040	May to September.
1924–25	7,008	2,250	2,210	May to March, except October.
1925–26	7,008	2,230	1,450	April to September.
1926–27	7,008	2,250	2,320	May to March.
1927–28	7,027	2,240	3,850	April to March.
1928–29	7,008	2,230	1,620	April to November.
1929–30	7,008	2,320	700	June to September.
1930–31	7,008	2,330	890	May to September.
Mean	7,013	2,260	1,910	

[1] Available only when reservoir is full. Reservoir spills every year so that if a market should arise for such power in the future more could be generated by providing a larger power-plant capacity.

COLUMBIA RIVER DAM

Scope of investigations.—The geological conditions at the site have been studied by Geologist Kirk Bryan and are covered in his report which is included in the Gault Report of 1924. Between July 9, 1921 and January 9, 1922, 14 diamond-drill holes were put down at this site by the Columbia Basin Survey Commission. Two additional drill holes were put down in 1930 by the Corps of Engineers, United States Army. The geological report and the record and interpretation of drill holes form the basis for present assumptions as to foundation conditions. The foundation area is so extensive and there is such a deep covering over bedrock that there is much uncertainty as to the actual foundation conditions. A large amount of additional testing is necessary to make a reasonably complete exploration of the foundations. The purpose of additional drilling and testing would be to define the surface of the bedrock more completely over the whole area comprising the foundation of the dam and power plant, to determine the depth of unsound rock necessary to remove and to determine the presence of major seams or fault zones within the area. To obtain the necessary additional information, the following program of further diamond drilling and testing has been proposed.

Drilling 48 vertical holes, 8,400 linear feet.
Drilling 10 inclined holes, 8,000 linear feet.
Trenching 550-linear-foot open trench.
Excavating 4 test pits, average 150 feet deep.

Estimated cost of additional foundation exploration necessary is $150,000.

Highways.—The Columbia River dam site can be reached by unimproved roads from Mansfield 35 miles west, from Almira about 20 miles southeast on the Sunset National Highway (U.S. 10); and also by a gravel-surfaced county highway going north through Grand Coulee from Coulee City, located approximately 30 miles southwest of the dam site.

Construction railroad.—No location surveys for a construction railroad have been made. However, there appears to be two feasible routes to the dam site, one connecting with the Great Northern Railroad at Mansfield, 35 miles west, and the other connecting with the Northern Pacific Railroad near Coulee City. A construction cost estimate of a railroad following the latter route was prepared from incomplete United States Geological Survey topography. In addition to providing transportation for the construction of the Columbia River Dam, the Grand Coulee route will also pass near the sites of the proposed North and South Grand Coulee Dams of the proposed Grand Coulee Reservoir. This route will also provide for transportation of concrete aggregates from deposits of this material already accessible by railroad between Coulee City and Hartline, and north of Adrian.

The proposed line, approximately 30 miles in length, will branch from the main line of the Northern Pacific Railroad, near Coulee City junction, and follow the east side of Grand Coulee at an elevation slightly above the flow line of the proposed Grand Coulee Reservoir to a point opposite the North Grand Coulee Dam, from where the line descends to the west end of the Columbia River Dam.

Transportation of concrete aggregates.—For the purpose of estimating the delivered cost of concrete aggregates, it was assumed that the contractor would continue the construction of the railroad down the canyon from the switchback location to a point approximately 2 miles below the dam where the river would be bridged and the railroad constructed upstream to gravel deposits on the east side of the river. It is also practicable to transport concrete aggregates to the mixing plant by an aerial tramway system consisting of several units or lines.

Construction power.—An ample supply of electric power for construction purposes is available from transmission lines of the Washington Water Power Co. which pass through Coulee City. A 60,000-volt branch line to Spokane runs parallel to the tracks of the Northern Pacific Railroad, which at a point west of Almira and directly south of the dam site, is but 16 miles distant across the Hartline Plateau.

Concrete materials.—With the cooperation of the district engineer, Corps of Engineers, United States Army, Seattle, Wash., preliminary field investigations were made of sand and gravel deposits immediately adjacent to the dam site and of several deposits more remotely situated. Approximately 100 material samples of about 100 pounds each, after removal of cobbles larger than 6 inches, were obtained from the various deposits and shipped to the Bureau of Reclamation laboratory at Denver for test. Brief descriptions of the deposits, the work performed, and the general findings are given in the following paragraphs.

Deposits at dam site.—Extensive bench deposits are located on the east side of Columbia River, adjacent to the dam site. Eight test pits from 21 to 41 feet deep and 10 side-hill trenches from 35 to 66 feet in vertical projection, covering an area about 1 mile north and one half mile south of the dam center line, were excavated and logs prepared. The average depth of overburden is about 3½ feet. The aggregate material lies in horizontal strata, differing widely in gradation, and interspersed with layers of clay at depths of 21 feet or more. Lime-coated and discolored material is found in one test pit. The material is fairly well rounded and generally dirty. It is composed largely of basalt (70 to 80 percent), with lesser amounts of granite, shale, quartzite, diorite and andesite. A small percentage of the basalt is vesicular. The aggregate is apparently sound with the exception of the shale. A total of 89 test samples were taken.

The deposit at the dam site may prove to be a practicable source of aggregate for the dam. Accessibility, apparent soundness and freedom from organic impurities of the material, and the satisfactory size range and gradation of the coarse aggregate are characteristics in its favor. Thorough washing would be essential for removing excess silt, disposing of the softer pieces of shale, and avoiding the formation of clay balls. The extreme variations in gradation of the sand, even in the same pit, point to the possible need for division of the same into two or three sizes and recombination in desired proportions. Without such separation, the high average fineness modulus of the washed sand would require correction, by one of a number of possible means. While the tabular values for average pit run proportions show a large excess of sand, it is probable that the actual average percentage of sand is materially less, due to the fact that thick layers of coarse material, especially in the trenches, were not samples and had to be disregarded in arriving at the figures stated. Additional investigations would be required to obtain more reliable data and to definitely establish the sufficiency of the deposits.

Mansfield pit.—This pit is located in Sec. 35, T. 30 N., R. 29 E., about 10 miles in direct line northwest of the Columbia River dam site. It is apparently a small deposit containing relatively fine material only. The material is similar in composition and shape of particles to that at the dam site. Only one sample was taken.

The Mansfield deposit, considered alone, is apparently of little value for the purpose, owing to its limited extent, the large proportion and high fineness modulus of the sand, and a pronounced deficiency in the larger sizes of gravel.

Adrian pit.—This is an extensive deposit located along the Northern Pacific Railroad about 1 mile north of Adrian and 42 miles in direct line southwest of the damsite. The face of the deposit is about 600 feet long and 75 feet high, with the lower half covered by talus. The material is apparently clean, structurally sound, and fairly well rounded. It is composed entirely of basalt with vesicles present in 15 to 25 percent of the coarse aggregate. Four samples were taken from the upper half of the face.

The Adrian deposit is handicapped by its distance from the damsite, its excess of sand, and the relatively high fineness modulus of the sand. The deposit is apparently clean and extensive and, with exception of the deposits at the damsite, shows the most favorable gradation of coarse aggregate.

Hartline pit.—This is an extensive deposit located along the Northern Pacific Railroad and the power line of the Washington Water Power Co. about 21 miles in direct line southwest of the damsite. It lies about 6 miles east of Coulee City and 3 miles west of Hartline. The exposed face of the deposit is about 500 feet long and 30 feet high, and the pit is covered with an earth overburden about 4 feet deep. The material is apparently clean, structurally sound, and fairly well rounded. It is composed entirely of basalt with vesicles prominent in 30 to 50 percent of the coarse aggregate. The face of the pit was logged and four samples taken. A second deposit with similar material was found about 1½ miles west.

If the data obtained may be taken as representative, the Hartline deposit, although similar in many respects, is much less favorable than the Adrian deposit by reason of the very high proportion of sand, the exceptionally high fineness modulus of the sand and the lower fineness modulus of the gravel.

Results of tests on aggregates.—Sieve analyses, silt determinations, and calorimetric tests were made in the Denver laboratory on all the above-mentioned samples. Some concrete tests are contemplated. The principal results of the completed tests are tabulated below:

TABLE No. 5.—*Analysis of concrete aggregates*

	At the damsite			Adrian pit	Hartline pit	Mansfield pit
	8 pits	10 trenches	Entire deposit			
Average pit-run proportions:						
Sand to one fourth inch .... percent	36	50.1	42.9	55.6	83.2	70.5
Washed gravel, one fourth inch to 6 inches ... do	64	44.3	52.0	41.7	14.0	26.4
Calorimetric tests, unwashed sand	(1)	(1)	(1)	(1)	(1)	(1)
Silt content, by weight of unwashed sand:						
Minimum .... percent	.9	.9	.9	2.3	3.4	1.9
Maximum .... do	72.4	44.6	72.4	2.8	4.4	1.9
Weighted average .... do	6.1	5.3	5.6	2.7	3.7	1.9
Fines removed in washing sand, by weights: Weighted average .... percent	11.25	10.05	10.6	3.81	3.84	4.21
Fineness modulus of sand, washed:						
Minimum	1.81	1.64	1.64	3.32	4.12	3.73
Maximum	4.57	4.94	4.94	3.68	4.52	3.73
Weighted average	3.17	3.40	3.30	3.38	4.14	3.73
Fineness modulus of gravel:						
Minimum	7.06	6.0	6.0	7.18	7.11	7.25
Maximum	9.17	8.70	9.17	8.39	8.04	7.25
Weighted average	8.32	8.19	8.26	7.78	7.46	7.25
Grading of gravel, weighted average for entire deposit:						
3-inch seive	13.1	7.5	10.5	48.3	9.8	--------
1½-inch sieve	47.5	47.3	47.4	27.70	25.4	7.6
¾-inch sieve	77.4	72.0	74.9	58.60	42.2	39.8
⅜-inch sieve	94.0	92.4	93.2	86.90	68.6	77.5
No. 4 sieve	100.0	100.0	100.0	100.0	100.0	100.0

[1] Favorable.

NOTE.—Depth of layers and proportions of sand and gravel were taken into account in determining "weighted averages" values.

Foundation conditions.—Knowledge of foundation conditions at the dam site is limited to the information secured by a geological examination and the drilling of 16 diamond drill holes. On the basis of this information it is believed that the surface of bedrock lies at approximately elevation 880 across the valley and rises with side slopes of about 1½ to 1 to the elevation of the crest of the dam. The foundation rock over the whole area is described as a medium gray, fine grained, hard, dense granite, with joints at intervals of 2 to 6 feet. There is no shattering or crushing at joints and the presence of the joints will facilitate quarrying and excavating the rock. Open joints were found to depths of 35 feet, but it is believed that these joints can be success-fully sealed by grouting. The cores indicated that 5 to 10 feet of rock was unsound and should be removed from the valley floor and that 10 to 15 feet should be removed from the rock surfaces on the slopes. From 20 to 70 feet of fine-grained clay lies above the bedrock. This is believed to be impervious and it should afford a watertight connection between the sheet piling of the cofferdams and the bedrock. A mixture of clay, sand, and gravel is found above this clay stratum, varying from a few feet up to 100 feet. The presence of the clay just above the granite will undoubtedly simplify the foundation work and aid in keeping water out of the excavation, but at the same time the clay may tend to squeeze out under the weight of the overburden and this condition will affect the design of the cofferdams from the standpoint of stability.

Two depressions in the surface of the bedrock were disclosed in the drilling, one at elevation 790 and another at elevation 780. Sufficient drilling has not yet been done to determine the shape and extent of these depressions but they are believed to be potholes in an old stream bed or else depressions eroded by glacial action. There are no surface indications of faults within the area of the site. The large amount of river deposit over the valley floor necessitates enormous quantities of foundation excavation.

Diversion of river during construction.—The care of the Columbia River during construction of the dam presents a difficult problem owing to the large discharges that must be passed. During the period in which there are records giving the flow at the dam site, the maximum daily average flow is found to be 496,000 c.f.s. In the period of record, 17.83 years, the mean daily maximum flow exceeded 450,000 c.f.s. during three different periods and these aggregate only 42 days.

The diversion works will be carried out in two main stages. The first stage includes the excavating of a diversion channel along the east bank of the river; the driving of a cellular sheet pile cofferdam to rock, parallel to and adjacent to the east bank of the river; and the turning of the river into the diversion channel by means of timber cribs sunk in the main channel between the west bank of the river and the ends of the cellular cofferdam. The upstream cribs will be built to elevation 975, which is estimated to pass 600,000 c.f.s. without overtopping the cofferdam. After completing the excavation within this first cofferdam the concrete will be brought up to elevation 1025, except the alternate blocks across the spillway section which will be left at elevation 950 for the passage of flood water. In addition to these low blocks thirty-one 12-foot diameter temporary openings will be left through the dam for the passage of flood water.

The cofferdams of the second stage of the diversion plan will extend from the east bank of the river to the ends of the sheet pile cellular cofferdam. These will be raised to elevation 1,005, which is estimated to divert 450,000 c.f.s. through the openings left in the west portion of the dam. After the excavation is completed the concrete in the east section of the dam will be poured to elevation 1,025. Fourteen additional temporary 12-foot diameter holes will be placed in this section which, together with the 20 permanent 5-foot 8-inch by 10-foot outlets, will provide enough spillway capacity to pass 50,000 c.f.s. after the 15 holes through the power-house section of the dam have been closed, without overtopping the low blocks at elevation 950. This will give 2 months time at least in the low-water season for raising the low blocks. A number of the low blocks will be kept low at all times until the drum gates are installed.

The temporary 12-foot diameter openings will be utilized until the spillway crest is completed, after which they will be plugged with concrete. A steel bulkhead will be provided for closing each of these openings to facilitate the pouring of the concrete plug.

Description of dam and appurtenances.—The Columbia River Dam is located on the Columbia River near the head of Grand Coulee in section 1, T. 28 N., R. 30 E., and section 6, T. 28 N., R. 31 E. It is a straight concrete gravity dam 450 feet high and 4,100 feet long at the elevation of the roadway on top of the dam.

The spillway consists of an overflow section of the dam, across the river channel, with an over-all length of 1,918 feet. The spillway discharge, assumed to be a maximum of 1,000,000 second-feet, is controlled by fourteen 124- by 28-foot structural steel drum gates. The drum gates will be designed for automatic control, hand-operation, or remote control from the power plant. With 1,000,000 second-feet discharge over the spillway, the water surface in the reservoir will be at elevation 1289.6, causing a 30-foot depth on the crest of the spillway. The energy of the spillway water will be dissipated on a sloping concrete apron. This apron will be designed to create a hydraulic jump at all stages of the tailwater. The final design of this apron will be determined by hydraulic model tests. The spillway will be bridged by 14 concrete arches, providing a 24-foot roadway, these arches being supported on concrete piers 14 feet thick carried up from the overflow crest structure.

Sluiceway openings are placed through the dam on the right side of the spillway at elevations 935, 1050, and 1165 for emergency and diversion purposes. Twenty 5-foot 8-inch by 10-foot 0-inch conduits are shown on the drawing at elevation 935. These conduits have a discharge capacity of 30,000 second-feet with water surface in the reservoir at elevation 965. The drawings also show eight 5-foot 8-inch by 10-foot 0-inch conduits at elevation 1050 and likewise at elevation 1165. All of these sluiceway conduits are controlled by tandem 5-foot 8-inch by 10-foot 0-inch hydraulically operated slide gates.

The Columbia River is the main artery for fish migrations between the tributaries and the Pacific Ocean and for this reason the problem of passing fish through or over the dam is of utmost importance. A mechanical fish elevator, somewhat similar to that used on the Baker Dam, has been tentatively selected as the most practicable type for fish traveling in an upstream direction. This elevator will raise the fish from the head end of a flume, located adjacent to the draft tubes, up to the crest elevation of the dam and will then lower them into the reservoir. The fish elevator consists principally of a flume extending the full width of the tailrace along the downstream side of the power plant together with a fish elevator operating from the head of the flume upward through an inclined shaft to the crest of the dam and downward through a second inclined shaft to the reservoir.

As the possibility of navigation of the Columbia River is very remote, due to the great expense involved in improving the river below the dam, no design or cost for locks has been included in this report.

The meager information available relative to property damage within the reservoir basin does not warrant the preparation of a detailed estimate at this time. This item of cost is included in a general estimate for reservoir right of way.

POWER PLANT

Buildings and structures.—The power house is located on the downstream toe of the dam to the left of the spillway section. The building is a concrete and steel structure 1,028 feet long and 78 feet wide with the 220,000-volt transformer equipment located between the power-house superstructure and the dam. The generator-room floor has been placed at an elevation just above the maximum recorded tailwater elevation, but the entire building is made watertight to an elevation several feet above an assumed maximum flood-water condition.

All low-voltage switching equipment, governor oil-pumping equipment, and the passages for carrying water, oil, and air piping and power busses and cables are located in the substructure of the building. Two house generators are located at the extreme left-hand end of the plant, at which point there is also dismantling space for the units and a machine shop for handling repair work. The building contains two cranes having a combined capacity sufficient to lift the heaviest part of any generating unit.

A control house containing the control equipment for both power house and pumping plant is located apart from the power house adjacent to the left end of the building.

Water is supplied to the turbines through a concrete and steel trash rack structure on the upstream side of the dam. An individual penstock controlled by a stony gate at the upper end is provided for each main generating unit. The penstock openings have their center lines at elevation 1180. The steel penstocks pass through the dam at this elevation and then follow the downstream face of the dam to the turbines in the power house. A Gantry crane is provided on the top of the dam for handling penstock gates and other equipment.

Hydraulic and electrical machinery.—Fifteen main generating units of 105,000-kilowatt capacity each are proposed for the power plant. The turbines are rated at 147,000 horsepower each at 330 feet head and the generators are rated at 120,000 kilovolt-amperes each at 120 revolutions per minute, 22,000 volts, 60 cycles, 87.5 percent power factor. An individual governing system, including actuator, oil pump, and oil tank, is provided for each turbine, and each generator has a direct-connected exciter.

Each generating unit has its own transformer bank for raising the voltage to 220,000, and switching and protection equipment has been included for one outgoing transmission line per generating unit. In addition, five of the generators are equipped with oil circuit breakers, cables, and control equipment for supplying power to the 20 pumps which are proposed for the ultimate installation in the pumping plant.

Annual costs.—The annual cost of operation and maintenance of the power plant has been taken at 50 cents per kilowatt of installed capacity for the ultimate development or $785,000. For the purpose of financial studies it has been assumed that the annual operation and maintenance cost of the initial development consisting of three units will be one third of the cost of the complete development and will increase uniformly as additional units are installed. The annual operation and maintenance cost for the dam has been taken as $150,000.

Depreciation for both dam and power plant has been taken on an assumed average 30-year life for all items considered depreciable. An annuity has then been set up which when invested at 4 percent will accumulate the required amount for replacement at the end of a 30-year period. On this basis the required annuity is 1.78301 percent of the original cost of the depreciable items.

These annual costs are summarized in the following tabulations:

Complete development:	
Depreciation:	
Cost of depreciable items for dam	$9, 911, 685
Cost of depreciable items for power plant	34, 753, 633
Total in dam and power plant	44, 665, 318
Annuity required, at 1.78301 percent	796, 387
Operation and maintenance:	
Dam	150, 000
Power plant, at $0.50 per kilowatt	787, 500
Total	937, 500
Initial development:	
Depreciation:	
Cost of depreciable items for dam	9, 911, 685
Cost of depreciable items for 3 units in power plant	9, 563, 176
Total in dam and power plant	19, 474, 861
Annuity required, at 1.78301 percent	347, 239
Operation and maintenance:	
Dam	150, 000
Power plant, one third of $787,500	262, 500
Total	412, 500

ULTIMATE IRRIGATION DEVELOPMENT

Columbia River pumping plant.—The pumping-plant building is located along the reservoir shore line just upstream from the left abutment of the dam. It is a reinforced concrete structure about 640 feet long by 100 feet wide, with practically all the buildings below water when the reservoir is at maximum elevation. A Gantry crane will travel the entire length on top of the building and will give access to the machinery through removable hatchways placed over the pumping units. Drainage for the interior of the structure is secured by means of a drainage tunnel leading to a gravity outlet in the tailrace below the power plant. This tunnel will also carry the power cables from the power plant to the pumping plant for the operation of the pump motors. A concrete and steel trash-rack structure occupies the entire reservoir side of the building.

Twenty pumping units are proposed for the ultimate installation, each unit consisting of a single-stage pump having a capacity of 800 second-feet when operating under a total head of 370 feet, direct connected to a 33,000-horsepower, 22,000-volt, synchronous motor operating at 200 revolutions per minute. The motor capacity is such that with a full reservoir 1 main generating unit in the power plant has sufficient capacity to operate 4 pumping units, and with a minimum reservoir elevation 1 main generating unit has sufficient capacity for operating 3 pumping units. This coordination of generator and pumping unit capacities allows full independent use of each generating unit for operation of the pumping units, and also permits variation in the speed of the units so as to maintain the pump efficiency at the highest possible point throughout a large variation in pumping head.

A separate steel discharge pipe is provided for each pump and these pipes are supported on concrete foundations and located above ground so that they are accessible for inspection, painting, and other maintenance work. All pipes lead to a common outlet structure at the head of the Grand Coulee Canal and each is equipped with a siphon arrangement containing an automatic air valve to prevent reverse flow of water from the canal when the operation of a pump is stopped.

Repumping.—In order to utilize as fully as practicable the power possibilities on the project and to relieve the demand on Columbia River power, it is proposed to develop power for pumping purposes at those favorable places on the irrigation project where on account of the topography and for other reasons it is advisable to drop the canal grades to lower elevations. Power plants are to be constructed at these drops and the seasonal electricity generated is to be transmitted to a number of pumping plants located at various places along the canals where water will be pumped to a total of 219,090 acres lying above the gravity canals. Transmission lines are to be constructed connecting the various power plants and supply lines will be extended to the pumping plants.

Size of installations.—With 3.25 acre-feet of water delivered at the land during the irrigation season and 15 percent loss in distribution in the canals supplying the pumping areas, the pumping duty is 3.82 acre-feet per acre, or a total seasonal requirement of 836,924 acre-feet for 219,090 acres. With an average pumping head of 70 feet, the acre-feet feet pumped during the season is 58,584,680. The installations required for the various heads and canal capacities are as follows:

50 percent, or 29,292,340 acre-feet feet, 1,000-kilowatt installation.
30 percent, or 17,575,404 acre-feet feet, 500-kilowatt installation.
10 percent, or 5,858,468 acre-feet feet, 250-kilowatt installation.
5 percent, or 2,929,234 acre-feet feet, 100-kilowatt installation.
5 percent, or 2,929,234 acre-feet feet, 10–50-kilowatt installation.

Estimated costs of repumping.—The estimated costs of the repumping installations are as follows:

Transmission lines and transformers:	
180 miles of primary line, 66,000-volt copper, treated wood poles, at $2,800 per mile	$504, 000
150 miles of secondary line, 11,000-volt copper, treated wood poles, at $1,800 per mile	270, 000
26,000 kilowatts in transformer capacity, at $2.50 per kilowatt	65, 000
	839, 000
Power development:	
26,000 kilowatts, at $60	1, 560, 000

Pumping plants:

Buildings, hydraulic equipment pipe lines, and electric equipment, not including step-down transformers:

29,292,340 acre-feet feet, at $0.065 per acre-foot foot	$1, 904, 002
17,575,505 acre-feet feet, at $0.085 per acre-foot foot	1, 493, 909
5,858,458 acre-feet feet, at $0.10 per acre-foot foot	585, 847
2,929,234 acre-feet feet, at $0.14 per acre-foot foot	410, 093
2,929,234 acre-feet feet, at $0.25 per acre-foot foot	732, 308
	5, 126, 159
Total for repumping	7, 525, 159

Grand Coulee Reservoir.—It is proposed to construct earth dams at the north and south ends of the Grand Coulee. Water pumped from the Columbia River will discharge into the Grand Coulee and be controlled as to elevation and use by the dams and regulating works.

The formation of a lake in the Grand Coulee 23 miles long, having an area of 2,300 acres at the maximum water surface elevation of 1,570, eliminates the necessity for a very expensive canal along the steep walls of the Grand Coulee and saves the loss of about 47 feet in the elevation of the water surface at the south end of the Coulee. It also allows a more efficient use of water for power development and irrigation by providing storage for water which can be pumped when the supply in the river is ample, and in turn decreases the amount of power water required for pumping when the river supply is low.

North Grand Coulee Dam.—The North Grand Coulee Dam, located about 1½ miles from the Columbia River Dam on Grand Coulee, together with the South Grand Coulee Dam, located about 4½ miles north of Coulee City, will be constructed to form the Grand Coulee Reservoir, which is an important link in the main canal system. The site of the North Grand Coulee Dam has been explored with six drill holes and the foundation conditions, as revealed thereby, have determined the selection of an earth-fill dam for this site. The dam section has been designed with unusually flat slopes. The upstream two thirds will be constructed as a sprinkled and rolled earth fill while the downstream one third will consist of a gravel fill with a rock-paved slope and a flat downstream toe. The slope on the water side will be protected with 30 inches of rock riprap laid on 12 inches of gravel. A concrete cut-off wall 10 feet high will extend throughout the length of the dam. On the earth parts of the foundation the concrete cut-off wall is set in a cut-off trench 20 feet deep and is built on top of a row of steel-sheet piling. The rock sections of the foundation, together with the basalt abutment and intake canal section, will be drilled and grouted along the line of the cut-off wall. The maximum height of the dam above the original ground surface will be 92 feet. About 10 feet of foundation excavation over the lower parts of the old stream bed is believed to be necessary. An emergency waste way, controlled by a 50 by 50-foot Stoney gate, provides an outlet to the Columbia River. A 12-foot embankment freeboard is provided for this dam, and an additional 3 feet of freeboard against high waves is provided by means of a concrete parapet wall on the crest of the dam.

South Grand Coulee Dam.—Because of uncertainty in the bearing power and watertightness of the earth foundations at this site, an earth-dam section with flat slopes, similar in most respects to the North Grand Coulee Dam section, has been adopted. A gravel fill will be used instead of a rock fill at the downstream toe because there will be only small quantities of excavated rock available from required excavations at this site. A cut-off trench, concrete cut-off wall, and steel-sheet piling are provided on the earth foundation as in the North Grand Coulee Dam. It is estimated that 18 inches of stripping will be required over the earth portion of the foundation area. The height of the maximum section of the dam above the original ground surface will be 97 feet and an embankment freeboard of 12 feet is provided together with a 3-foot concrete parapet wall. A Stoney gate 50 feet wide and 36 feet high controls the outflow into the main canal heading at this dam.

Canals.—There are included under this item all canals having a carrying capacity in excess of 100 c.f.s. The maximum amount of water which they will carry is dependent upon the acreage which they serve and is intended to be sufficient for the period of maximum demand after allowing for leakage and waste. With the exception of the canal supplying Grand Coulee Lake, the capacities are computed as follows:

In excess of 100,000 acres, 1 c.f.s. to 80 acres.
Between 100,000 acres and 50,000 acres, 1 c.f.s to 70 acres.
Between 50,000 acres and 25,000 acres, 1 c.f.s. to 65 acres.
Between 25,000 acres and 6,000 acres, 1 c.f.s to 60 acres.

Larger carrying capacities are provided in the smaller canals than in the larger canals in order to provide a more satisfactory rotation system when necessary.

The capacity of the canal supplying Grand Coulee Lake is greater than the canal leading from the lake in order to provide for the estimated rate of leakage from the Grand Coulee Lake and at the same time supply the maximum irrigation demand. During the times of diminished irrigation demand this extra capacity provided will allow an accumulation of storage in the lake. All canals are to be lined with reinforced concrete varying in thickness from a maximum of 12 inches to a minimum of 4 inches. The classification of materials of excavation on all canal lines is based principally on field inspection. Borings and test pits would give a closer estimate of the classification, but the estimate as made is believed to be reasonably close.

Tunnels.—The capacities of all tunnels are determined in the same manner as the canals above mentioned. They are designed of the horseshoe type with a depth of water at 83 percent of the diameter. The tunnels will be lined throughout with concrete. No reinforcing is provided in the tunnel lining except in the closed transition sections at the inlets and outlets. Tunnel excavations will be mainly in basaltic rock, but provision is made in the estimate for some timbering.

Siphons and penstocks.—It is proposed to carry the required water supply across streams and coulees by means of reinforced concrete pipes where the pressure head and capacities required are relatively small. Where greater capacities and larger diameters are required, steel pressure pipes are proposed. Steel pipes are also proposed for the power penstocks and pump-discharge pipes at those places on the project where drops in the canal grades occur and where repumping is contemplated.

The steel pipes are designed to rest on concrete saddles and to have concrete anchors where necessary. Depreciation is calculated as an annuity that would replace the steel pipes in 30 years at 4 percent or providing a reserve fund in the annual operating and maintenance budget of the irrigation project an amount to be determined by taking 1.78 percent of the original investment in the steel pipes.

Lateral system.—All distributaries of less than 100 c.f.s. capacity are included in the lateral system which is intended to deliver water to each 160-acre farm. Where these ditches are excavated in gravel or other porous material which would allow considerable leakage, it is proposed to line such stretches with reinforced concrete. The lateral system under the Main West Canal is believed to require a relatively small amount of concrete lining and concrete drops and is estimated to cost $21 per acre. Under the Main East Canal the amount of concrete lining will be greater and this portion of the lateral system is estimated at $25 per acre.

Drainage.—There are a number of places on the irrigation project where ditches will have to be constructed to carry off waste and seepage water and to provide outlet channels for wasteways from the canals. Frequently a wasteway channel affords an outlet for drainage ditches. As the wasteways deemed necessary are considered as a separate item and so estimated, although they really act as drainage outlets, the item and estimate of $4 per acre for providing drainage is intended to cover those cases where lateral drains are necessary and to provide additional outlets where necessary.

Wasteways.—Wasteways are necessary on any irrigation project to provide a means of disposing of water during emergencies such as cloudbursts or canal breaks and to afford a means of regulating the water supply close to the land. This allows closer regulation on shorter notice which is important with a long canal system such as the one under consideration. The wasteway channels deemed necessary will, in addition to carrying off waste water occurring by regulation, provide outlets for drainage ditches as mentioned above.

Buildings.—The operation and maintenance of the irrigation project requires a number of permanent buildings such as offices, shops, warehouses, residences for reservoir superintendents and headgate keepers, and the estimate provides an amount to cover their cost. These buildings are in addition to the temporary buildings to be built by the contractors during the construction period. The cost of such temporary buildings are included in the estimates of the various items which necessitate their construction. This item for permanent buildings does not cover the cost of buildings required for the power plant and pumping plant operators as the cost of such buildings are included in the items covering those features.

Telephone system.—The operation and maintenance of the irrigation project will require a great many miles of telephone lines, in order that daily reports of the use and expected demands for water service may be communicated promptly to the employee whose duty is to see that the required amount of water is kept in the canal for prompt and efficient service. The estimate provides for the construction of 400 miles of metallic circuit carried on 25-foot poles with treated butts.

Wells.—A separate estimate is given for this item in order to obviate the necessity for using different prices for the same class of concrete required throughout the project. The cost of the concrete in place is influenced by the availability of the water supply and an estimate is provided for wells in order to make the distance to a water supply practically constant.

Operation and maintenance during construction.—When the water is first turned into the canal there will be items of expense occurring on account of developments which cannot be entirely eliminated beforehand at reasonable expense. After a few years these difficulties are remedied and usually remain so for the life of the project. While these improvements are being made during the operation of the project they are really items of construction and an allowance is made in the construction estimate to cover the cost of such work.

Summary of estimate of cost of Columbia Basin project for ultimate development

Relevant data:	
Power-plant installation, horsepower	2, 100, 000
Primary power, do	1, 067, 000
Pumping plant installation, do	660, 000
Area to be irrigated, acres	1, 200, 000
Capacity primary pump installation, c.f.s.	16, 000
Columbia River Dam	$125, 750, 000
Columbia River power plant	42, 616, 000
Total cost, dam and power plant	168, 366, 000
Primary pumping plant	8, 890, 000
Repumping plants	7, 525, 000
Grand Coulee Lake	8, 703, 000
Canals	79, 307, 000
Tunnels	22, 778, 000
Siphons	37, 595, 000
Lateral system	28, 516, 000
Drainage	4, 800, 000
Buildings	1, 484, 000
Telephones	240, 000
Wasteways	2, 230, 000
Wells	200, 000
Operation and maintenance during construction	5, 997, 000
Total cost of irrigation project	208, 265, 000
Total per acre cost irrigation project	173. 55
Total per acre cost irrigation project per year	4. 34
Total cost Columbia Basin project	376, 631, 000

First Unit Irrigation Development

The development of the first irrigation unit of 150,000 acres, known as the Quincy area, involves the least investment possible in pumping machinery, pipe lines, dams, canals, and structures necessary to give dependable service to the area, but at the same time includes all of the works required in the beginning so that every part of the initial investment, with the possible exception of the small dam and a short length of canal at Coulee City, will be utilized in the ultimate development of the irrigation project. It is proposed to develop this 150,000-acre unit in blocks of 20,000 acres per year, the first 20,000 acres to be irrigated the year following completion of construction of the Columbia River Dam. The character of the construction proposed is described by features which are shown on drawing no. 222-D-14,[31] as follows:

Feature no. 1.—The Columbia River Dam completed to full dimensions is required.

Feature no. 2.—The initial installation of the pumping plant requires the construction of the entire pump house substructure, the

[31] Not printed.

installation of the Gantry crane for handling the pumping machinery, and the installation of four pumping units. Each pumping unit consists of a vertical shaft, double suction, single stage, centrifugal pump of 800 c.f.s. capacity direct connected to a 35,000 horsepower synchronous motor. Each pump will be connected through a manifold to a steel discharge pipe 8½ feet in diameter and 750 feet in length, the upper end of which will discharge into the Grand Coulee Reservoir supply canal or feature no. 3. No repumping is contemplated for the initial irrigation unit.

Feature no. 3.—The canal leading from the end of the pipe line at the Columbia River Dam to the North Grand Coulee Dam in the Grand Coulee is to be constructed to dimensions required for the ultimate capacity of 16,000 c.f.s. and is to be lined throughout with reinforced concrete.

Feature no. 4.—The North Grand Coulee Dam in the Grand Coulee is to be constructed to the height and dimensions required for ultimate development or of height to store water to elevation 1570.

Feature no. 5-A.—At the south end of the Grand Coulee it is proposed to construct a small dam at what is known as the Coulee City dam site. This dam is to be constructed to the height necessary to supply sufficient water depth in the canal to irrigate the Quincy area. The construction of this dam allows the impounding of water in Grand Coulee to elevation 1542.5, and will provide a relatively inexpensive method of testing the watertightness of the Coulee. In case the leakage is found to be negligible with this test dam at Coulee City, the dam can then be enlarged to allow storage of water to elevation 1570 which is the elevation required for ultimate development. In case the water loss in Grand Coulee Reservoir is found to be excessive with the test dam at Coulee City, this site can be abandoned and a dam (feature no. 5) constructed at a site 4 miles further up the Coulee. In this event there will be a loss of $676,000 in the Coulee City Dam, additional right of way and incidental expenses, and a loss of $224,000 in the temporary canal and headworks described hereafter as feature no. 6-B. However, in case the dam at Coulee City proves successful, there will be no need for the more expensive dam further north (feature no. 5) and there will be a saving of $7,496,000 which is the difference between the cost of the upper dam and the longer canal (feature no. 6) leading to it as compared with the cost of the lower dam and its additional requirement for right of way and a shorter length of canal (feature no. 6-A plus feature no. 6-B).

Feature no. 6-B.—A temporary canal about 3,500 feet long branching from the proposed permanent canal (feature no. 6) which latter extends from the proposed permanent South Coulee Dam to Bacon Siphon, is to be constructed of sufficient dimensions without concrete lining to carry the water required (1,875 c.f.s.) to irrigate 150,000 acres.

Feature no. 6-A.—Only that portion of the canal (feature no. 6) will be constructed which extends from Bacon Siphon on the south to the above-mentioned temporary canal (feature no. 6-B) on the north. Feature no. 6-A is to be constructed of full dimensions required for the ultimate development, but the reinforced concrete lining is to be omitted in the initial development.

Feature no. 7.—The Bacon Siphon as proposed for ultimate development consists of two parallel lines of steel pipes supported upon concrete cradles and anchors. It is proposed to construct one line completely. This will give excess carrying capacity for the first unit, but when due consideration is given to the hydraulic properties of the canals required for ultimate development it is not believed that a better arrangement can be provided.

Feature no. 8.—The Bacon Tunnel as proposed for ultimate development consists of two parallel tunnels lined throughout with unreinforced concrete. The route of this tunnel line is through basalt rock. It is proposed to construct one tunnel to full dimensions. No concrete lining is proposed for the first unit and the tunnel will deliver the water required when running about one half full.

Feature no. 9.—The open canal between Bacon Tunnel and Trail Lake Tunnel is to be constructed to dimensions required for ultimate development, but the reinforced concrete lining is to be omitted.

Feature no. 10.—Trail Lake Tunnel as proposed for ultimate development consists of two parallel tunnels. The same plan is proposed for constructing Trail Lake Tunnel for unit development as was mentioned above.

Feature no. 11.—For the ultimate development of the project, a concrete structure is proposed at the point where the main canal branches into two parts, designated the Main West and the Main East Canal. No structure is proposed at this point for the first development as no part of the Main East Canal is to be built and the Main West Canal, which is to be constructed, is merely a continuation of the Main Canal.

Main West Canal.—The Main West Canal is to ultimately serve 371,000 acres. The first unit selected for development lies wholly under the Main West Canal. It is proposed to omit the construction of lateral W-1 and its branches, but lateral W-2 and lateral W-3, and branches of both these laterals, are to be constructed to full dimensions including reinforced concrete lining. The Main West Canal and all tunnels and siphons (features nos. 1 to 7, inclusive) are to be constructed for the ultimate capacity. Construction of the Main West Canal will stop at the point where lateral W-3 branches off the Main West about 7 miles east of Quincy.

As only a part of feature no. 8 is required, that portion which must be constructed to serve the first irrigation unit is designated as feature no. 8-A.

General items.—In the estimate which follows provision is made for the cost of the lateral system, drainage, wasteways, telephones, wells, buildings and operation and maintenance during construction

Summary of estimate of cost of first unit of Columbia Basin project

Relevant date:	
Power-plant installation ____ horsepower __	2, 100, 000
Primary power ____ do ____	1, 067, 000
Pumping-plant installation ____ do ____	132, 000
Area to be irrigated ____ acres __	150, 000
Capacity pump installation ____ cubic foot-seconds __	3, 200
Columbia River Dam ____	$125, 750, 000. 00
Columbia River power plant ____	42, 616, 000. 00
Total cost, dam and power plant ____	168, 366, 000. 00

Summary of estimate of cost of first unit of Columbia Basin project—Continued

Primary pumping plant	$4,004,000.00
Grand Coulee Lake	3,820,000.00
Canals	13,994,000.00
Tunnels	4,338,000.00
Siphons	3,770,000.00
Lateral system	3,150,000.00
Drainage	600,000.00
Buildings	187,000.00
Telephones	30,000.00
Wasteways	270,000.00
Wells	26,000.00
Operation and maintenance during construction	750,000.00
Total cost of irrigation project	34,939,000.00
Total per acre cost, irrigation project	232.92
Total per acre cost, irrigation project per year	5.82
Total cost, Columbia Basin project	203,305,000.00

Estimates showing comparison of costs of different plans of Grand Coulee Reservoir together with the costs of changes in canals and headgates required for the various plans

Plan no. 1, using test dam at Coulee City:	
North Grand Coulee Dam	[33] $2,070,000
Right of way	[33] 1,274,000
Additional right of way required for test dam	[33] 275,000
Coulee City test dam	[33] 201,000
Raising Coulee City test dam	1,634,000
Temporary canal and headgate, feature no. 6-B	[34] 224,000
Shorter length of main canal used (feature no. 6-A) with test dam	[34] 1,926,000
Concrete lining temporary canal and larger headgate for ultimate capacity if test dam proves satisfactory	436,000
Total cost	5,970,000
Plan no. 2, using dam 4 miles above the test dam without first using test dam:	
North Grand Coulee Dam	2,070,000
Right of way	1,274,000
Upper south dam in Grand Coulee	4,683,000
Canal headgate (feature no. 6) leading to upper south dam	5,439,000
Total cost	13,466,000
Plan no. 3, using dam 4 miles above the test dam after first building the low-test dam of Coulee City and in case it proves unsatisfactory:	
North Grand Coulee Dam	[33] 2,070,000
Right of way	[33] 1,274,000
Additional right of way purchased for Coulee City test dam	[33] 275,000
Coulee City test dam	[33] 201,000
Temporary canal and headgate (feature no. 6-B)	[34] 224,000
Emptying reservoir below elevation 1520 by pumping	[33] 200,000
Upper South Dam in the Coulee	[33] 4,683,000
Canal and headgate (feature no. 6) leading to upper south dam	[34] 5,439,000
Total cost	14,366,000

[33] These items make up the total Grand Coulee Lake cost for ultimate development.
[34] These items are included in cost of canals for ultimate development.
If test dam and its enlargement is satisfactory, the saving over plan no. 2 is $7,496,000.
If the test dam is unsatisfactory, the extra expense involved is shown by the difference between plan no. 2 and plan no. 3, or $900,000.

Annual costs.—The annual depreciation, operation, and maintenance costs for the primary pumping plant have been set up on the same basis as for the power plant, using a 30-year average life for the depreciable items and 50 cents per kilowatt of capacity installed for operation and maintenance. The costs are summarized in the following tabulations:

FULL DEVELOPMENT

Depreciation:	
Cost of depreciable items	$5, 896, 597
Annuity required at 1.78301 percent	105, 137
Operation and maintenance: 500,000 kilowatts at $0.50	250, 000

INITIAL DEVELOPMENT

Depreciation:	
Cost of depreciable items	1, 442, 639
Annuity required at 1.78301 percent	25, 722
Operation and maintenance: One third of ultimate $250,000	83, 300

OPERATION AND MAINTENANCE COSTS

The following gives an analysis of the estimated annual operation and maintenance expense of the irrigation project and includes items for depreciation reserves to replace steel pipes, etc.:

Depreciation:	
Primary pumping plant and pipe line,[35] 1.78 percent of $5,896,597	$105, 137
Repumping power plants, pumping plants,[35] 1.78 percent of $7,525,159 and transmission lines	133, 747
Depreciation on buildings, 5 percent per annum on $1,499,000	74, 950
Depreciation on telephones,[35] 1.78 percent of $240,000	4, 272
Depreciation on pipe siphons and penstocks,[35] 1.78 percent of $22,538,800	401, 190
Total depreciation	719, 296
Total depreciation per acre	. 60
Operation and maintenance:	
Primary pumping plant at 50 cents per kilowatt	250, 000
Secondary power plants at $2 per kilowatt (26,000)	52, 000
Secondary pumping plants at $3 per kilowatt (26,000)	78, 000
Transmission lines at $50 per mile (330 miles)	16, 500
Telephone lines at $25 per mile (330 miles)	10, 000
Total operation and maintenance exclusive of irrigation distribution system	406, 500
Total operation and maintenance exclusive of irrigation distribution system, per acre	. 34
Total of depreciation and operation and maintenance exclusive of irrigation distribution system	1, 125, 796
Per acre for 1,199,430 acres	. 94
Purchase of electricity for primary pumping at $1 per acre per annum	1. 00
Operation and maintenance of irrigation distribution system per acre	1. 25
Total annual charges exclusive of construction repayment	3. 19

[35] Assuming 30-year life and an annuity set aside at 4 percent, requires 1.78 percent per annum on depreciable item.

ANNUAL CONSTRUCTION REPAYMENTS

In the financial study (table no. 6) to determine how the investment is to be repaid it has been estimated that the land, beginning 4 years after the completion of the Columbia River Dam and power plant, and 4 years after the beginning of irrigation of each completed division, will pay $2 per acre per year for 4 years and thereafter pay $2.50 per acre per year for 32 years. In this manner each division or block of and irrigated will pay out in 40 years an amount which, when added to the estimated proportional power surplus, will liquidate its proportionate share of the irrigation investment.

TABLE No. 6.—*Financial operation of irrigation development*

Year after completion of dam	Acres settled	Repayments from lands: Fifth to eighth year after settlement at $2 per acre	Repayments from lands: Ninth to fortieth year after settlement at $2.50 per acre	Repayment from power surplus at 2.25 mills per kilowatt-hour	Total repayment for year	Total cost of irrigation construction at beginning of year
1	20,000					$33,822,000
2	40,000					34,605,000
3	60,000					35,354,000
4	80,000					36,269,000
5	100,000	$40,000			$40,000	37,244,000
6	120,000	80,000			80,000	38,175,000
7	140,000	120,000			120,000	38,712,000
8	160,000	160,000			160,000	40,018,000
9	180,000	160,000	$50,000		210,000	41,602,000
10	200,000	160,000	100,000		260,000	41,886,000
11	220,000	160,000	150,000		310,000	45,213,000
12	240,000	160,000	200,000	$524,958	884,958	48,540,600
13	260,000	160,000	250,000	1,399,259	1,809,259	51,868,200
14	280,000	160,000	300,000	2,470,009	2,930,009	55,195,800
15	300,000	160,000	350,000	3,540,759	4,050,759	58,523,400
16	320,000	160,000	400,000	3,560,759	4,120,759	61,851,000
17	340,000	160,000	450,000	3,580,759	4,190,759	65,178,600
18	360,000	160,000	500,000	3,600,759	4,260,759	68,506,200
19	380,000	160,000	550,000	3,620,759	4,330,759	71,833,800
20	400,000	160,000	600,000	3,640,759	4,400,759	75,161,400
21	420,000	160,000	650,000	3,660,759	4,470,759	78,489,000
22	440,000	160,000	700,000	3,680,759	4,540,759	81,816,600
23	460,000	160,000	750,000	3,700,759	4,610,759	85,144,200
24	480,000	160,000	800,000	3,720,759	4,680,759	88,471,800
25	500,000	160,000	850,000	3,740,759	4,750,759	91,799,400
26	520,000	160,000	900,000	3,760,759	4,820,759	95,127,000
27	540,000	160,000	950,000	3,780,759	4,890,759	98,454,600
28	560,000	160,000	1,000,000	3,800,759	4,960,759	101,782,200
29	580,000	160,000	1,050,000	3,820,759	5,030,759	105,109,800
30	600,000	160,000	1,100,000	3,840,759	5,100,759	108,437,400
31	620,000	160,000	1,150,000	3,860,759	5,170,759	111,765,000
32	640,000	160,000	1,200,000	3,880,759	5,240,759	115,092,600
33	660,000	160,000	1,250,000	3,900,759	5,310,759	118,420,200
34	680,000	160,000	1,300,000	3,920,759	5,380,759	121,747,800
35	700,000	160,000	1,350,000	3,940,759	5,450,759	125,075,400
36	720,000	160,000	1,400,000	3,960,759	5,520,759	128,403,000
37	740,000	160,000	1,450,000	3,980,759	5,590,759	131,730,600
38	760,000	160,000	1,500,000	4,000,759	5,660,759	135,058,200
39	780,000	160,000	1,550,000	4,020,759	5,730,759	138,385,800
40	800,000	160,000	1,600,000	3,793,990	5,553,990	141,713,400
41	820,000	160,000	1,600,000		1,760,000	145,041,000
42	840,000	160,000	1,600,000		1,760,000	148,368,600
43	860,000	160,000	1,600,000		1,760,000	151,696,200
44	880,000	160,000	1,600,000		1,760,000	155,023,800
45	900,000	160,000	1,600,000		1,760,000	158,351,400
46	920,000	160,000	1,600,000		1,760,000	161,679,000
47	940,000	160,000	1,600,000		1,760,000	165,006,600
48	960,000	160,000	1,600,000		1,760,000	168,334,200
49	980,000	160,000	1,600,000		1,760,000	171,661,800
50	1,000,000	160,000	1,600,000		1,760,000	174,989,400
51	1,020,000	160,000	1,600,000		1,760,000	178,317,000
52	1,040,000	160,000	1,600,000		1,760,000	181,644,600
53	1,060,000	160,000	1,600,000		1,760,000	184,972,200
54	1,080,000	160,000	1,600,000		1,760,000	188,299,800
55	1,100,000	160,000	1,600,000		1,760,000	191,627,400
56	1,120,000	160,000	1,600,000		1,760,000	194,955,000
57	1,140,000	160,000	1,600,000		1,760,000	198,282,600
58	1,160,000	160,000	1,600,000		1,760,000	201,610,200
59	1,180,000	160,000	1,600,000		1,760,000	204,937,800
60	1,199,430	160,000	1,600,000		1,760,000	208,265,400
61	1,199,430	160,000	1,600,000		1,760,000	208,265,400
62	1,199,430	160,000	1,600,000		1,760,000	208,265,400
63	1,199,430	160,000	1,600,000		1,760,000	208,265,400
64	1,199,430	158,860	1,600,000		1,758,860	208,265,400
65	1,199,430	118,860	1,600,000		1,718,860	208,265,400
66	1,199,430	78,860	1,600,000		1,678,860	208,265,400
67	1,199,430	38,860	1,600,000		1,638,860	208,265,400
68	1,199,430		1,598,575		1,598,575	208,265,400
69	1,199,430		1,548,575		1,548,575	208,265,400

TABLE No. 6.—*Financial operation of irrigation development*—Continued

Year after completion of dam	Acres settled	Repayments from lands: Fifth to eighth year after settlement at $2 per acre	Repayments from lands: Ninth to fortieth year after settlement at $2.50 per acre	Repayment from power surplus at 2.25 mills per kilowatt-hour	Total repayment for year	Total cost of irrigation construction at beginning of year
70	1,199,430		$1,498,575		$1,498,575	$208,265,400
71	1,199,430		1,448,575		1,448,575	208,265,400
72	1,199,430		1,398,575		1,398,575	208,265,400
73	1,199,430		1,348,575		1,348,575	208,265,400
74	1,199,430		1,298,575		1,298,575	208,265,400
75	1,199,430		1,248,575		1,248,575	208,265,400
76	1,199,430		1,198,575		1,198,575	208,265,400
77	1,199,430		1,148,575		1,148,575	208,265,400
78	1,199,430		1,098,575		1,098,575	208,265,400
79	1,199,430		1,048,575		1,048,575	208,265,400
80	1,199,430		998,575		998,575	208,265,400
81	1,199,430		948,575		948,575	208,265,400
82	1,199,430		898,575		898,575	208,265,400
83	1,199,430		848,575		848,575	208,265,400
84	1,199,430		798,575		798,575	208,265,400
85	1,199,430		748,575		748,575	208,265,400
86	1,199,430		698,575		698,575	208,265,400
87	1,199,430		648,575		648,575	208,265,400
88	1,199,430		598,575		598,575	208,265,400
89	1,199,430		548,575		548,575	208,265,400
90	1,199,430		498,575		498,575	208,265,400
91	1,199,430		448,575		448,575	208,265,400
92	1,199,430		398,575		398,575	208,265,400
93	1,199,430		348,575		348,575	208,265,400
94	1,199,430		298,575		298,575	208,265,400
95	1,199,430		248,575		248,575	208,265,400
96	1,199,430		198,575		198,575	208,265,400
97	1,199,430		148,575		148,575	208,265,400
98	1,199,430		98,575		98,575	208,265,400
99	1,199,430		48,575		48,575	208,265,400
100	1,199,430					208,265,400

Year after completion of dam	Cost of irrigation construction during year	Investment remaining in irrigation development at end of year	Return from power surplus available for other purposes	Accumulated return from power surplus used for repayment of irrigation	Accumulated average return per acre from power surplus for 1,199,430 acres	Accumulated return from power surplus available for other purposes
1	$783,000	$34,605,000				
2	749,000	35,354,000				
3	915,000	36,269,000				
4	975,000	37,244,000				
5	931,000	38,135,000				
6	537,000	38,592,000				
7	1,306,000	39,778,000				
8	1,584,000	41,202,000				
9	284,000	41,276,000				
10	3,327,000	44,343,000				
11	3,327,600	47,360,600				
12	3,327,600	49,803,242		$524,958	$0.44	
13	3,327,600	51,321,583		1,924,217	1.60	
14	3,327,600	51,719,174		4,394,226	3.66	
15	3,327,600	50,996,015		7,934,985	6.62	
16	3,327,600	50,202,856		11,495,744	9.58	
17	3,327,600	49,339,697		15,076,503	12.57	
18	3,327,600	48,406,538		18,677,262	15.57	
19	3,327,600	47,403,379		22,298,021	18.59	
20	3,327,600	46,330,220		25,938,780	21.63	
21	3,327,600	45,187,061		29,599,539	24.68	
22	3,327,600	43,973,902		33,280,298	27.75	
23	3,327,600	42,690,743		36,981,057	30.83	
24	3,327,600	41,337,584		40,701,816	33.93	
25	3,327,600	39,914,425		44,442,575	37.05	
26	3,327,600	38,421,266		48,203,334	40.19	
27	3,327,600	36,858,107		51,984,093	43.34	
28	3,327,600	35,224,948		55,784,852	46.51	
29	3,327,600	33,521,789		59,605,611	49.69	
30	3,327,600	31,748,630		63,446,370	52.90	

TABLE NO. 6.—*Financial operation of irrigation development*—Continued

Year after completion of dam	Cost of irrigation construction during year	Investment remaining in irrigation development at end of year	Return from power surplus available for other purposes	Accumulated return from power surplus used for repayment of irrigation	Accumulated average return per acre from power surplus for 1,199,430 acres	Accumulated return from power surplus available for other purposes
31	$3,327,600	$29,905,471		$67,307,129	$56.12	
32	3,327,600	27,992,312		71,187,888	59.35	
33	3,327,600	26,009,153		75,088,647	62.60	
34	3,327,600	23,955,994		79,009,406	65.87	
35	3,327,600	21,832,835		82,950,165	69.16	
36	3,327,600	19,639,676		86,910,924	72.46	
37	3,327,600	17,376,517		90,891,683	75.78	
38	3,327,600	15,043,358		94,892,442	79.11	
39	3,327,600	12,640,199		98,913,201	82.47	
40	3,327,600	10,413,809	$246,769	102,707,191	85.63	$246,769
41	3,327,600	11,981,409	4,060,759	102,707,191	85.63	4,307,528
42	3,327,600	13,549,009	4,080,759	102,707,191	85.63	8,388,287
43	3,327,600	15,116,609	4,100,759	102,707,191	85.63	12,489,046
44	3,327,600	16,684,209	4,120,759	102,707,191	85.63	16,609,805
45	3,327,600	18,251,809	4,140,759	102,707,191	85.63	20,750,564
46	3,327,600	19,819,409	4,160,759	102,707,191	85.63	24,911,323
47	3,327,600	21,387,009	4,180,759	102,707,191	85.63	29,092,082
48	3,327,600	22,954,609	4,200,759	102,707,191	85.63	33,292,841
49	3,327,600	24,522,209	4,220,759	102,707,191	85.63	37,513,600
50	3,327,600	26,089,809	4,240,440	102,707,191	85.63	41,754,359
51	3,327,600	27,657,409	15,054,113	102,707,191	85.63	56,808,472
52	3,327,600	29,225,009	15,074,113	102,707,191	85.63	71,882,585
53	3,327,600	30,792,609	15,094,113	102,707,191	85.63	86,976,698
54	3,327,600	32,360,209	15,114,113	102,707,191	85.63	102,090,811
55	3,327,600	33,927,809	15,134,113	102,707,191	85.63	117,224,924
56	3,327,600	35,495,409	15,154,113	102,707,191	85.63	132,379,037
57	3,327,600	37,063,009	15,174,113	102,707,191	85.63	147,553,150
58	3,327,600	38,630,609	15,194,113	102,707,191	85.63	162,747,263
59	3,327,600	40,198,209	15,214,113	102,707,191	85.63	177,961,376
60		38,438,209	15,233,543	102,707,191	85.63	193,194,919
61		36,678,209	15,233,543	102,707,191	85.63	208,428,462
62		34,918,209	15,233,543	102,707,191	85.63	223,662,005
63		33,158,209	15,233,543	102,707,191	85.63	238,895,548
64		31,399,349	15,233,543	102,707,191	85.63	254,129,091
65		29,680,489	15,233,543	102,707,191	85.63	269,362,634
66		28,001,629	15,233,543	102,707,191	85.63	284,596,177
67		26,362,769	15,233,543	102,707,191	85.63	299,829,720
68		24,764,194	15,233,543	102,707,191	85.63	315,063,263
69		23,215,619	15,233,543	102,707,191	85.63	330,296,806
70		21,717,044	15,233,543	102,707,191	85.63	345,530,349
71		20,268,469	15,233,543	102,707,191	85.63	360,763,892
72		18,869,894	15,233,543	102,707,191	85.63	375,997,435
73		17,521,319	15,233,543	102,707,191	85.63	391,230,978
74		16,222,744	15,233,543	102,707,191	85.63	406,464,521
75		14,974,169	15,233,543	102,707,191	85.63	421,698,064
76		13,775,594	15,233,543	102,707,191	85.63	436,931,607
77		12,627,019	15,233,543	102,707,191	85.63	452,165,150
78		11,528,444	15,233,543	102,707,191	85.63	467,398,693
79		10,479,869	15,233,543	102,707,191	85.63	482,632,236
80		9,481,294	15,233,543	102,707,191	85.63	497,865,779
81		8,532,719	15,233,543	102,707,191	85.63	513,099,322
82		7,634,144	15,233,543	102,707,191	85.63	528,332,865
83		6,785,569	15,233,543	102,707,191	85.63	543,566,408
84		5,986,994	15,233,543	102,707,191	85.63	558,799,951
85		5,238,419	15,233,543	102,707,191	85.63	574,033,494
86		4,539,844	15,233,543	102,707,191	85.63	589,267,037
87		3,891,269	15,233,543	102,707,191	85.63	604,500,580
88		3,292,694	15,233,543	102,707,191	85.63	619,734,123
89		2,744,119	15,233,543	102,707,191	85.63	634,967,666
90		2,245,544	15,233,543	102,707,191	85.63	650,201,209
91		1,796,969	15,233,543	102,707,191	85.63	665,434,752
92		1,398,394	15,233,543	102,707,191	85.63	680,668,295
93		1,049,819	15,233,543	102,707,191	85.63	695,901,838
94		751,244	15,233,543	102,707,191	85.63	711,135,381
95		502,669	15,233,543	102,707,191	85.63	726,368,924
96		304,094	15,233,543	102,707,191	85.63	741,602,467
97		155,519	15,233,543	102,707,191	85.63	756,836,010
98		56,944	15,233,543	102,707,191	85.63	772,069,553
99		8,369	15,233,543	102,707,191	85.63	787,303,096
100			15,233,543	102,707,191	85.63	802,536,639

TOTAL ANNUAL COST OF IRRIGATION

The total annual cost of irrigation benefits are estimated at $3.19 for the first 4 years, if a depreciation reserve is provided. If no depreciation reserve is provided, the cost is $2.59 per acre.

With $2 per acre for construction beginning the fifth year and continuing to and including the eighth year, the total annual cost for irrigation excluding depreciation will be $4.59 per acre. Continuing thereafter for 32 years the annual cost will be $5.09 per acre.

When the construction payments from the land are added to the proportionate share of the estimated surplus power revenue, the combined receipts from irrigation and power will not only liquidate the investment for each division or block of land irrigated within the 40-year period from the time each division is first irrigated, but there will be sufficient surplus power revenue accruing during the 40 years subsequent to the completion of the Columbia River Dam to liquidate about one half of the entire irrigation investment required for the ultimate project of 1,199,430 acres.

ABILITY OF LAND TO PAY FOR IRRIGATION BENEFITS

The lands to be irrigated on the project are well adapted to the production of alfalfa, sweetclover, potatoes, corn, and small grains. It is expected that the farm production will be largely fed to livestock and converted into beef, pork, and mutton. Dairying and poultry raising will also find a place in the farm program. With a proper rotation program and with a normal price relation between products of the farm marketed and those purchased, it is expected that the land will be able to meet an annual charge of not to exceed $5.25 per acre for irrigation benefits.

PAYMENTS BY OTHER BENEFITED INTERESTS

While the foregoing charges are assumed to be borne entirely by the land and can only be realized by providing interest-free money for the entire irrigation investment and by assuming that about one half of the irrigation investment is repaid from surplus power revenues, there are other interests than irrigation which will be greatly benefited by the proposed development and the charges accruing against the land might be reduced by applying an ad valorem tax to all property benefited within the irrigation district as provided by Washington State law.

POWER MARKET

Market area.—The market area in which the power from the proposed Columbia River development would have to be absorbed includes the area within a radius of approximately 300 miles of the dam site, which includes all of the State of Washington, the northern part of Oregon, the northern part of Idaho, and the western part of Montana. Drawing no. 222-D-23[31] is a map of this area showing the principal power systems operating therein. The most important power market in this territory is the Puget Sound district in western Washington, which is the logical market for a large part of the Colum-

[31] Not printed.

bia River power. Following is a list of the principal power systems serving this territory:

Municipalities:
- City of Seattle.
- City of Tacoma.
- City of Centralia.

Utility companies:
- Puget Sound Power & Light Co.
- The Washington Water Power Co.
- Pacific Power & Light Co.
- Mountain States Power Co.
- Grays Harbor Railway & Light Co.
- Willapa Electric Co.
- Western Washington Electric Light & Power Co.
- Olympic Public Service Co.
- Washington Gas & Electric Co.
- The Montana Power Co.

Manufacturing Companies:
- Crown-Zellerbach Corporation.
- Weyerhaeuser Timber Co.

The city of Seattle has been operating a municipal power system since 1905 and now supplies about 75 percent of the consumers in the city. The city has 4 hydroelectric plants with a total installed capacity of 98,300 kilowatts and 1 steam-electric plant of 30,000 kilowatts capacity, making a total combined capacity of 128,300 kilowatts. The systems of Seattle and Tacoma are interconnected through a 66,000-volt transmission line which has a capacity of approximately 15,000 kilowatts. Power from the city's hydroelectric development on the Skagit River is transmitted to the city over a 165,000-volt transmission line 100 miles in length.

The city of Tacoma has a municipal power system which has been in service since 1893, and this system now serves the entire city. The city's generating facilities consist of 3 hydroelectric plants having a combined installation of 116,000 kilowatts and 2 steam-electric plants having a combined capacity of 34,000 kilowatts, making a total capacity of 150,000 kilowatts. The city's system is interconnected with the city of Seattle and with the Puget Sound Power & Light Co. Power from the city's Lake Cushman hydroelectric development is transmitted at 110,000 volts over a line about 35 miles in length.

The city of Centralia completed the initial installation of 4,000 kilowatts in a hydroelectric power plant in 1930. The ultimate capacity of this development is 11,000 kilowatts. Power is transmitted to the city over a 66,000-volt transmission line 25 miles in length.

The Puget Sound Power & Light Co., which operates under the supervision of Stone & Webster, Inc., serves the western part of Washington, including the cities of Seattle, Bellingham, Everett, Olympia, Chehalis, Bremerton, and Wenatchee. The power system includes 15 hydroelectric plants having a combined installed capacity of 156,735 kilowatts and 7 steam-electric plants having a combined installed capacity of 112,000 kilowatts, making a total installed capacity of 268,735 kilowatts. This system is interconnected with the Washington Water Power Co. on the east and also with the city of Tacoma, the Washington Pulp & Paper Corporation, the Northwestern Electric Co., Western Canada Power Co., Great Northern Railway, Weyerhaeuser Timber Co., and with the United States navy yard at Bremerton. In 1931 the initial installation, consisting of two units of 15,000 kilowatts capacity each, in the new hydroelectric development at Rock Island on the Columbia River was placed in service. This development is planned for an ultimate installation of 150,000 kilowatts. Power is transmitted from this plant to the Puget Sound district over 110,000-volt lines.

The Washington Water Power Co. is controlled by the American Power & Light Co., which in turn belongs to the Electric Bond & Share Co. group of properties. This company operates in eastern Washington and northern Idaho and has 13 hydroelectric power plants with a combined generating capacity of 205,584 kilowatts. The company is interconnected with the Pacific Power & Light Co., the Montana Power Co., Puget Sound Power & Light Co., Mountain States Power Co., Stevens County Power & Light Co., and the Chicago, Milwaukee & St. Paul Railroad. The company has a large hydroelectric plant at Chelan Falls, where two units of 24,000 kilowatts' capacity each are now installed and where an additional 72,000 kilowatts can be developed by the installation of additional units as may be required to meet the growth in load.

The Pacific Power & Light Co. operates in southern Washington, northern Oregon, and northern Idaho. It is controlled by the American Power & Light Co. and belongs to the Electric Bond & Share Co. group of properties. The system comprises 5 hydroelectric plants having a combined installed capacity of 13,500 kilowatts and 2 steam-electric plants having a combined capacity of 3,000 kilowatts, making a total capacity of 16,500 kilowatts. The system is interconnected with the Washington Water Power Co. and with the Northwestern Electric Co.

The Mountain States Power Co. operates in northwestern Washington, western Oregon, and northern Idaho. It is controlled by the Standard Gas & Electric Co., which in turn belongs to the H. M. Byllesby & Co. group of properties. The company has a small power plant at Sandpoint, Idaho, with an installed capacity of 500 kilowatts and obtains most of the energy required on this system from the Washington Water Power Co. over a 66,000-volt interconnection.

The Federal Light & Traction Co., a subsidiary of the Cities Service Co., owns and operates a number of small power systems along the west coast of Washington. These properties include the Grays Harbor Railway & Light Co., the Willapa Electric Co., the Western Washington Electric Light & Power Co., and the Olympic Public Service Co. They have a total generating capacity of 13,186 kilowatts, of which 12,900 kilowatts is steam-electric and 286 kilowatts is Diesel-electric. Additional power is obtained from lumber mills in the immediate vicinity and from the Puget Sound Power & Light Co.

The Washington Gas & Electric Co. operates in the vicinity of Longview, Wash. The company is controlled by the North American Gas & Electric Co. It has a steam-electric plant at Longview having a capacity of 24,000 kilowatts.

The Montana Power Co. is controlled by the American Power & Light Co. and belongs to the Electric Bond & Share group of properties. The western part of the Montana Power Co. system in the extreme western part of the State of Montana is in the territory considered as the market area for the Columbia River power. The Thompson Falls hydroelectric plant, which is located in this territory, has an installed capacity of 35,000 kilowatts. This plant is interconnected with the Washington Water Power Co. on the west and with the main system of the Montana Power Co. on the east through the Chicago, Milwaukee & St. Paul Railway Co.'s lines.

The Crown-Zellerbach Corporation, which is engaged in the paper industry, has 2 hydroelectric plants having a combined capacity of 25,000 kilowatts and 6 steam-electric plants having a combined capacity of 30,150 kilowatts, making a total installed capacity of 55,150 kilowatts. This company has interconnections with the Puget Sound Power & Light Co. The Washington Pulp & Paper Corporation is the largest subsidiary of the Crown-Zellerbach group in Washington.

The Weyerhaeuser Timber Co. is engaged in the lumber industry in the Northwest. It has three important steam-electric generating stations having a total installed capacity of 29,000 kilowatts.

Future increase in power usage.—During the 10-year period ending with 1930 the requirements for power, as shown in table no. 7, in the territory within a radius of 300 miles of the proposed Columbia River development have been increasing at an average rate of 9.5 percent per year, compounded annually. The population of this territory is approximately 3,000,000, or about the same as the northern portion of California, and the energy generated during 1930 was approximately 85 percent of the amount required to supply the Northern California market. A study was made of the Northern California power market in 1928 by Mr. Lester S. Ready, consulting engineer of San Francisco, Calif., in connection with the proposed Kennett Reservoir development on the Sacramento River, a report on which was published as Bulletin No. 20 of Department of Public Works of the State of California. In that report it was estimated that the future growth in load in Northern California would be at a reducing percentage, ranging from approximately 7 percent in 1928 to as low as 4 percent about 1950.

TABLE No. 7.—*Power market*

Data for power market, which includes the area within a 300-mile radius of the proposed damsite, and all of Oregon]

Year	Power output in millions of kilowatt-hours: Market area excluding Oregon	Total for Oregon	Total for market area	Average load in kilowatts	Peak load in kilowatts	Installed capacity in kilowatts
1	2	3	4	5	6	7
1917	[2] 964	[3] 325	[4] 1,289	[5] 147,146	[6] 294,292	[7] 364,987
1920	1,309	476	1,785	203,767	407,534	432,145
1921	1,175	469	1,644	187,671	375,342	437,645
1922	1,294	513	1,807	206,279	412,558	486,245
1923	1,548	594	2,142	244,520	489,040	517,660
1924	1,633	678	2,311	263,813	527,626	535,458
1925	1,701	730	2,431	277,511	555,022	643,868
1926	2,020	831	2,851	325,457	650,914	717,022
1927	2,278	845	3,123	356,507	713,014	768,082
1928	2,569	1,041	3,610	412,100	824,200	829,215
1929	2,705	1,161	3,866	441,324	882,648	921,025
1930	2,811	1,219	4,030	460,046	920,092	974,860

[2] Figures in column 2 were compiled from reports of the Puget Sound Power & Light Co., City of Seattle, City of Tacoma, Washington Pulp & Paper Corporation, Gray's Harbor Railway & Light Co., Pacific Power & Light Co., (the Thompson Falls plant of the Montana Power Co., the Washington Water Power Co. which includes the Lewiston and Grangeville plants in northern Idaho, all associated companies and their predecessor companies).

[3] Figures in column 3 were taken directly from the reports of the U.S. Geological Survey.

[4] Figures in column 4 are the total of those in columns 2 and 3.

[5] Figures in column 5 were derived from those in column 4.

[6] Figures in column 6 were derived from those in column 5 by assuming a 50-percent load factor.

[7] Figures in column 7 were compiled from reports of the companies mentioned in footnote 2, together with data obtained from reports of the U.S. Geological Survey for the State of Oregon.

The Seattle district engineer, Corps of Engineers, United States Army, made a very comprehensive investigation of the power-market situation in the Northwest and in a report on the Columbia River dated July 31, 1931, estimated that the future increase in power requirements would be at a gradually reduced rate of increase starting with a rate of increase of 9.5 percent in 1930, decreasing to 4.75 percent in 1960 and finally reaching zero in 1990. This estimate of load growth is shown graphically by curves A on drawing no. 222-D-6.[31]

For the purposes of this study a somewhat more conservative assumption has been used in regard to future increase in power requirements. A gradually decreasing rate of increase has been assumed beginning with 8 percent in 1930 and decreasing to 4 percent in 1960. This is shown graphically by curves B on drawing no. 222-D-6.[31]

Absorption of Columbia River power.—The installed-generator capacity in the territory in which the power from the proposed Columbia River development would have to be absorbed now amounts to a little over 1,000,000 kilowatts, and if the load continues to increase in the next decade as it has in the past, but at a gradually reduced rate of increase as suggested above, the installed capacity will have to be doubled by 1940 in order to supply the demand. Practically all of the major hydroelectric developments on which construction has been started by the various power companies and municipalities will have been absorbed by 1940, which is the earliest date that power from the Columbia River development could be made available.

Assuming that the power load continues to increase after 1940 in accordance with curves B on drawing no. 222-D-6,[31] there would be required a total of 5,000,000 kilowatts of generating capacity by 1955. The additional generating capacity that would have to be provided during the 15-year period 1940 to 1955 would amount to about 3,000,000 kilowatts, whereas the proposed installation at the Columbia River power plant is 1,500,000 kilowatts. In other words, the proposed installation of 1,500,000 kilowatts would take care of approximately half of the expected increase in power requirements during the 15-year absorption period. The other half of the expected increase would have to be supplied by other hydro or steam development.

The total amount of energy generated in the territory in which the output of the proposed power plant would have to be utilized amounted to 4,030,000,000 kilowatt-hours in 1930. If the energy requirements continue to increase in the future as they have in the past 10 years, but at a gradually reducing rate of increase, as indicated by curves B on drawing no. 222-D-6,[31] the total amount of energy generated will be approximately 8,000,000,000 kilowatt-hours in 1940, and this will have increased to over 20,000,000,000 kilowatt-hours in 1955. The annual energy requirements will have increased 12,000,000,000 kilowatt-hours in the 15-year period from 1940 to 1955, during which it is assumed that the energy output of the Columbia River power plant will be absorbed. The total amount of firm energy which this plant will make available will be 7,000,000,000 kilowatt-hours per year, which amount will be sufficient to meet

[31] Not printed.

more than half the expected increase in the 15-year absorption period. The remainder would have to be supplied from other sources.

With proper cooperation on the part of the various power companies and municipalities which will have to absorb the power output of the proposed Columbia River development, no serious difficulty should arise in connection with the absorption of this large block of power within 15 years after the initial installation is completed, and it might be possible that the full output could be absorbed in a shorter time. The economic feasibility of the project is dependent to a very large degree on the rapidity of absorption of the power, particularly during the early years of operation, when the revenues from power will be insufficient to meet the annual expense and deficits will be inevitable.

COMPETITIVE POWER

The economic limitations of transmission of electric power over high-voltage transmission lines make it necessary that the power to be developed at the proposed Columbia River Dam be utilized within a radius of approximately 300 miles. Under certain special conditions surplus power available at the Columbia River Dam might be used in lieu of power from other sources and thereby release the latter for use elsewhere in more distant markets, but such an arrangement would be used only as a means of utilizing surplus energy and would have little effect on the price of firm power.

The Pacific Northwest is estimated to have 38 percent of the total potential water power in the United States, and quite naturally the present power requirements are supplied largely from hydro sources. The installed generator capacity in this territory is now a little over 1,000,000 kilowatts, of which about 28 percent is in steam plants and the remainder, or about 72 percent, in hydro plants. Previous to 1929 the steam plants produced about 5 percent of the total energy while in 1929, due to low stream flow, the output of the steam plants increased to 14.5 percent, and in 1930 it was about 10.4 percent of the total power generated.

It is probable that a large part of the additional power installations in the Northwest during the next decade will be hydro rather than steam, as all of the large power companies and the municipalities which have power systems have hydro developments planned and partially developed. The Puget Sound Power & Light Co. has the Rock Island development on the Columbia River, where an additional 120,000 kilowatts can be installed; the capacity of the Lake Chelan development of the Washington Water Power Co. can be increased by 70,000 kilowatts by the installation of additional generating units; the Inland Power & Light Co. has a development on the Lewis River where 160,000 kilowatts will be developed ultimately.

The city of Seattle has its Skagit River development under way where some 780,000 kilowatts can be developed ultimately, which is expected to meet the needs of the city during the next 15 years. The city of Tacoma has its Cushman development, the capacity of which can be increased by 100,000 kilowatts. The proposed hydroelectric development which the Montana Power Co. has planned at the outlet of Flathead Lake will add about 100,000 kilowatts to the generating facilities of that system.

Naturally the smaller hydro developments located close to the load centers and which were easy and cheap to construct were undertaken first and up to the present time the tremendous potential resources of the larger rivers have offered blocks of power so large compared to the needs of the systems as to be unfeasible economically. The rapid growth of power demands has now reached a point where the larger developments are economically feasible with the result that such projects as the Rock Island on the Columbia River, the Ariel on the Lewis River, and Diablo on the Skagit River are being undertaken.

By the time the initial installation at the proposed Columbia River Dam is placed in service most of the hydro developments which are now being constructed by the various power companies and municipalities will be completed and the Columbia River power will have to compete in price with power from additional developments which will be more costly than those now under construction and which are located farther from the market and consequently will involve more costly transmission facilities and also with power produced in large modern steam-generating stations located near the load centers and using the cheapest fuel obtainable.

Under present conditions in the Northwest, hydro power can be delivered at load centers at somewhat less cost than steam power as evidenced by the fact that the new developments planned for the immediate future are all hydro, but as the distances that the hydro power must be transmitted become greater and as the cost of construction of the hydro plants becomes greater due to the more difficult and expensive projects being left for later development, coupled with the downward trend of steam-plant costs and the steady improvement in steam-plant efficiencies, the present narrow margin between the cost of hydro and steam power is constantly becoming smaller and it seems probable that by the time power from the proposed development on the Columbia River at the head of Grand Coulee becomes available the cost of steam power rather than the cost of hydro power from other sources will determine the value of the Columbia River power.

Value of power as determined by the cost of steam-electric power.—During recent years there has been a very marked improvement in the efficiency of steam-generating stations and it is to be expected that this trend will continue in the future. Large modern steam plants are now capable of producing 480 kilowatt-hours per barrel of fuel oil when operating at 60 percent load factor which corresponds to a thermal efficiency of about 13,000 B.t.u. per kilowatt-hour. It seems probable that the thermal efficiency may be improved in the near future so that a kilowatt-hour will require not more than 12,000 B.t.u.

There is an ample supply of coal available in the Northwest and several of the smaller steam plants are operating on refuse from the lumber industry. The available supply of natural gas is too limited to make this fuel a factor in determining the cost of steam power. The Shuffleton steam plant of the Puget Sound Power & Light Co. located on Lake Washington, which is the largest and most modern plant in the Northwest, and which is designed so that it can be readily converted to utilize hogged fuel (lumber refuse) or pulverized coal, is now burning fuel oil which, under present conditions, is the cheapest fuel obtainable in sufficient quantities for large central-station use.

The price of fuel is the most important single factor affecting the cost of steam power and the question of future price of fuel oil is impossible of determination for any period of time. At present the average price of fuel oil in southern California fields is 70 to 80 cents per barrel. The cost of transporting fuel oil in tankers from southern California to Puget Sound ports amounts to about 25 cents per barrel and the cost delivered is about $1 per barrel or slightly less. This is less than the present cost of the equivalent quantity of coal.

The California conservation law which went into effect during the summer of 1929 requires the beneficial use of natural gas as a condition to the production of oil and this has resulted in marked reductions in the price of gas, in some instances down to the equivalent of oil at about 50 cents per barrel. Naturally, this low price for natural gas has had considerable effect on the price of fuel oil. It seems fair to assume that the condition of over-production and consequent low price of fuel oil will prove to be temporary and it is the general consensus of opinion that over a long period of time the price of fuel oil will increase rather than decrease. The depletion of nearby oil fields and natural-gas supplies, improvements in the processes for obtaining gasoline from fuel oil which will have a tendency to decrease the fuel-oil residue, together with the general governmental policy of conservation and restriction of production, will all tend toward this end.

Considering the present price of fuel oil and that as noted above, these prices are more likely to increase rather than decrease; a price of $1 per barrel delivered at Puget Sound ports has been used as a basis for determining the cost of steam power.

The largest and most efficient steam-power plant on the West coast is the Long Beach no. 3 plant of the Southern California Edison Co. which is designed for an ultimate installation of four units of 100,000-kilowatt capacity each. This plant is equipped for using either natural gas or fuel oil and is arranged so that coal-burning equipment can be installed later if it should develop that such fuel is more economical. The steam pressure is 400 pounds and the temperature of the steam is 700° F. At 100 percent load factor this plant produces a little better than 490 kilowatt-hours net per barrel of fuel oil, corresponding to a fuel economy of 12,674 B.t.u. per kilowatt-hour. The cost of this power plant will be $77.50 per kilowatt of installed capacity when the ultimate installation of four units is completed. The Los Angeles Gas & Electric Corporation has a smaller steam plant located at Seal Beach near Los Angeles which is reported to have cost $78.20 per kilowatt of installed capacity. The Shuffleton steam plant recently constructed by the Puget Sound Power & Light Co. is reported to have cost $105 per horsepower or $140 per kilowatt of installed capacity.

For the purposes of this study the following assumptions have been used to determine the cost of competitive steam power based on the cost and performance of the Long Beach no. 3 plant of the Southern California Edison Co.

Steam generating station data

Capital cost—$77.50 per kilowatt of installed capacity.
Fuel consumption—0.002 barrel per kilowatt-hour generated, plus 0.55 barrel per kilowatt of installed capacity per year.
Operation and maintenance—$2.25 per kilowatt of required capacity.
Required capacity=peak load.
Installed capacity=110 percent of required capacity.

	Public development	Private development
	Percent	*Percent*
Rate of return on investment	0	7.0
Rate of interest	4.75	0
Amortization	.88	0
Depreciation	2.25	2.25
Taxes	0	1.50
General expense (percent of total cost other than fuel and taxes)	3.0	3.0

Tables 8 and 9 show the cost of steam-generated energy under the above assumptions for public and privately owned steam plants, with the price of fuel oil varying from 75 cents to $1.50 per barrel delivered and for various load factors from 40 to 80 percent.

Drawing no. 222-D-7 [31] shows graphically the cost of steam-generated energy for both public and privately owned and operated steam plants with various prices of fuel oil and various load factors.

TABLE No. 8.—*Estimated cost of steam-generated energy—public development*

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent				
Kilowatt-hours generated per year per kilowatt capacity, 3,504.				
Barrels of fuel oil per year per kilowatt capacity, 7.613.				
Kilowatt-hours per barrel of fuel oil, 460.				
Interest, depreciation, amortization, and operation and maintenance	$8.968	$8.968	$8.968	$8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	5.710	7.613	9.516	11.419
Total annual cost per kilowatt required	14.947	16.850	18.753	20.656
Cost per kilowatt-hour, mills	4.266	4.809	5.352	5.895
Load factor, 50 percent				
Kilowatt-hours generated per year per kilowatt capacity, 4,380.				
Barrels of fuel oil per year per kilowatt capacity, 9.365.				
Kilowatt-hours per barrel of fuel oil, 468.				
Interest, depreciation, amortization, and operation and maintenance	8.968	8.968	8.968	8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	7.024	9.365	11.706	14.047
Total annual cost per kilowatt required	16.261	18.602	20.943	23.284
Cost per kilowatt-hour, mills	3.712	4.247	4.781	5.316
Load factor, 60 percent				
Kilowatt-hours generated per year per kilowatt capacity, 5,256.				
Barrels of fuel oil per year per kilowatt capacity, 11.117.				
Kilowatt-hours per barrel of fuel oil, 473.				
Interest, depreciation, amortization, and operation and maintenance	8.968	8.968	8.968	8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	8.338	11.117	13.896	16.675
Total annual cost per kilowatt required	17.575	20.354	23.133	25.912
Cost per kilowatt-hour, mills	3.344	3.872	4.401	4.930

[31] Not printed.

TABLE NO 8.—*Estimated cost of steam-generated energy—public development*—Continued

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 70 percent				
Kilowatt-hours generated per year per kilowatt capacity, 6,132.				
Barrels of fuel oil per year per kilowatt capacity, 12.869.				
Kilowatt-hours per barrel of fuel oil, 476.				
Interest, depreciation, amortization, and operation and maintenance	$8.968	$8.968	$8.968	$8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	9.652	12.869	16.086	19.303
Total annual cost per kilowatt required	18.889	22.106	25.323	28.540
Cost per kilowatt-hour, mills	3.080	3.605	4.130	4.654
Load factor, 80 percent				
Kilowatt-hours generated per year per kilowatt capacity, 7,008.				
Barrels of fuel oil per year per kilowatt capacity, 14.621.				
Kilowatt-hours per barrel of fuel oil, 479.				
Interest, depreciation, amortization, and operation and maintenance	8.968	8.968	8.968	8.968
General expenses, 3 percent of above	.269	.269	.269	.269
Cost of fuel oil per year per kilowatt capacity	10.966	14.621	18.276	21.931
Total annual cost per kilowatt required	20.203	23.858	27.513	31.168
Cost per kilowatt-hour, mills	2.883	3.404	3.926	4.447

TABLE NO. 9.—*Estimated cost of steam generated energy—Private development*

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent				
Kilowatt-hours generated per year per kilowatt capacity, 3,504.				
Barrels of fuel oil per year per kilowatt capacity, 7.613.				
Kilowatt-hours per barrel of fuel oil, 460.				
Depreciation, return on investment, and operation and maintenance	$10.136	$10.136	$10.136	$10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	5.710	7.613	9.516	11.419
Total annual cost per kilowatt required	17.429	19.332	21.235	23.138
Cost per kilowatt-hour, mills	4.974	5.517	6.060	6.603
Load factor, 50 percent				
Kilowatt-hours generated per year per kilowatt capacity, 4,380.				
Barrels of fuel oil per year per kilowatt capacity, 9.365.				
Kilowatt-hours per barrel of fuel oil, 468.				
Depreciation, return on investment, and operation and maintenance	10.136	10.136	10.136	10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	7.024	9.365	11.706	14.047
Total annual cost per kilowatt required	18.743	21.084	23.425	25.766
Cost per kilowatt-hour, mills	4.279	4.814	5.348	5.883
Load factor, 60 percent				
Kilowatt-hours generated per year per kilowatt capacity, 5,256.				
Barrels of fuel oil per year per kilowatt capacity, 11.117.				
Kilowatt-hours per barrel of fuel oil, 473.				
Depreciation, return on investment, and operation and maintenance	10.136	10.136	10.136	10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	8.338	11.117	13.896	16.675
Total annual cost per kilowatt required	20.057	22.836	25.615	28.394
Cost per kilowatt-hour, mills	3.816	4.345	4.873	5.402

TABLE NO. 9.—*Estimated cost of steam generated energy—Private development*—Continued

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 70 percent				
Kilowatt-hours generated per year per kilowatt capacity, 6,132.				
Barrels of fuel oil per year per kilowatt capacity, 12.869.				
Kilowatt-hours per barrel of fuel oil, 476.				
Depreciation, return on investment, and operation and maintenance	$10.136	$10.136	$10.136	$10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	9.652	12.869	16.086	19.303
Total annual cost per kilowatt required	21.371	24.588	27.805	31.022
Cost per kilowatt-hour, mills	3.485	4.010	4.534	5.059
Load factor, 80 percent				
Kilowatt-hours generated per year per kilowatt capacity, 7,008.				
Barrels of fuel oil per year per kilowatt capacity, 14.621.				
Kilowatt-hours per barrel of fuel oil, 479.				
Depreciation, return on investment, and operation and maintenance	10.136	10.136	10.136	10.136
General expenses, 3 percent of above	.304	.304	.304	.304
Taxes	1.279	1.279	1.279	1.279
Cost of fuel oil per year per kilowatt capacity	10.966	14.621	18.276	21.931
Total annual cost per kilowatt required	22.865	26.340	29.995	33.650
Cost per kilowatt-hour, mills	3.263	3.758	4.280	4.802

TRANSMISSION OF COLUMBIA RIVER POWER

Cost of transmission facilities.—At present, 220,000 volts is the practical limit for high-voltage, high-power, long-distance transmission. Higher voltages are being investigated, but considering the greater first cost of transmission lines designed and built for such higher voltages, it seems doubtful if any marked reduction in the cost of transmitting energy would be affected and at the present state of the art it would not be conservative to assume that power from the proposed Columbia River development would be transmitted at a voltage of more than 220,000.

The area in the vicinity of Puget Sound offers the largest market for Columbia River power within economic transmission distance, and it is assumed that a large part of the power will be utilized in that territory ultimately. The distance that the power would have to be transmitted to reach this market would be approximately 170 miles.

As a basis for determining the cost of transmitting electrical energy to this market, it is assumed that four 220,000-volt circuits would be provided, each capable of delivering 127,000 kilowatts under normal operating conditions with a reasonable factor of safety against instability at times of system disturbances. Each circuit would be capable of carrying up to 146,000 kilowatts under emergency conditions when one of the other circuits is out of service. Synchronous condensers would be provided as part of the terminal substation equipment in the ratio of 0.59 kilovolt-ampere of condenser capacity per kilowatt of delivered power, for regulation of power factor and voltage.

The cost of the transmission lines including terminal substations and right of way is estimated as follows:

340 miles double circuit 220-kilovolt line	$8,950,000
Terminal substations, including synchronous condenser equipment	5,458,000
Right of way	1,510,000
Total	15,918,000

Estimated annual cost of transmission lines including terminal substations is as follows:

	Public development	Private development
Fixed charges:		
Interest, 4.75 percent	$756,000	----------
Return on investment, 7 percent	----------	$1,114,000
Amortization, 0.88 percent	140,000	----------
Taxes, 1.5 percent	----------	239,000
Depreciation exclusive of right of way, 2.25 percent	324,000	324,000
Operation and maintenance:		
Line, $125 per circuit mile	85,000	85,000
Terminal substation, 2 percent of cost	109,000	109,000
Subtotal	1,414,000	1,871,000
General expense, 2 percent of above	28,000	37,000
Total annual cost	1,442,000	1,908,000

In order to provide reliable and satisfactory service over long-distance power-transmission circuits, it is generally considered necessary to provide sufficient steam-standby generating capacity at the terminal end which, together with the overload capacity of the circuits remaining in service, will carry the full load with one of the circuits out of service. On this basis there would be required 70,000 kilowatts of steam-standby capacity to supplement the delivery of power over the four 220,000-volt circuits contemplated for delivering power to the Puget Sound area, at times when one of the four circuits is out of service.

The assumptions used and the estimated annual cost of providing steam stand-by are shown in table 10 and the annual cost of steam stand-by in dollars per kilowatt of capacity for various prices of fuel oil and for both public and private developments are shown graphically on drawing no. 222-D-8.[31]

Cost of transmitting energy.—The total cost in mills per kilowatt hour for transmitting energy from the Columbia River power plant to the load center for various load factors and prices of fuel oil, and for both public and private developments, are shown by tables nos. 11, 12, and 13, and by graphs on drawings[31] nos. 222-D-9 and 222-D-10.

These costs were determined by the following formulas:

$$C = \frac{T}{1{,}000K}$$

and

$$C_s = \frac{T+S}{1{,}000K}$$

where

C = Cost in mills per kilowatt-hour for transmitting energy from the Columbia River power plant to the load center, without steam stand-by.

C_s = Same as C except with steam stand-by.

T = Annual cost, in dollars, of transmission from the Columbia River power plant to the load center (for the various load factors and for public and private developments as show in item b of table no. 14).

S = Annual cost, in dollars, of steam stand-by (for the corresponding load factors, for public and private developments, and for the various fuel costs, as shown in item d of table no. 14).

K = Total energy generated at the Columbia River power plant in millions of kilowatt-hours (for the corresponding load factors as shown in table no. 14).

[31] Not printed.

TABLE No. 10.—*Estimated yearly cost of steam stand-by, public and private developments*

Assumptions:

Capital cost per kilowatt of installed capacity	$77.50
Depreciation (percent)	2.25
Operation and maintenance per kilowatt	$1.75
Fuel oil—barrels per kilowatt	1.00
General expenses—3 percent of costs other than oil and taxes:	
Return on investment for private development (percent)	7.0
Taxes on investment for private development do	1.5
Rate of interest for public development do	4.75
Amortization for public development (40-year sinking fund, at 4¾ percent) (percent)	0.88

ANNUAL COST PER KILOWATT

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Private development:				
Depreciation, return on investment, and operation and maintenance	$8.919	$8.919	$8.919	$8.919
General expenses	.267	.267	.267	.267
Fuel oil	.75	1.00	1.25	1.50
Taxes	1.162	1.162	1.162	1.162
Cost per kilowatt per annum	11.098	11.348	11.598	11.848
Public development:				
Interest, depreciation, amortization, and operation and maintenance	7.857	7.857	7.857	7.857
General expenses	.235	.235	.235	.235
Fuel oil	.75	1.00	1.25	1.50
Cost per kilowatt per annum	8.842	9.092	9.342	9.592

TABLE No. 11.—*Cost of transmitting energy to load center public and private developments without steam stand-by*

	Public development	Private development
Load factor, 40 percent:		
T	1,442,800	1,908,800
K	1,967	1,967
C	0.734	0.970
Load factor, 50 percent:		
T	1,442,800	1,908,800
K	2,459	2,459
C	0.587	0.776
Load factor, 60 percent:		
T	1,442,800	1,908,800
K	2,950	2,950
C	0.489	0.647
Load factor, 70 percent:		
T	1,442,800	1,908,800
K	3,442	3,442
C	0.419	0.555
Load factor, 80 percent:		
T	1,442,800	1,908,800
K	3,934	3,934
C	0.367	0.485

T=Annual cost, in dollars, of transmission from Columbia River to load center.
K=Total energy generated at Columbia River in millions of kilowatt-hours.
C=Cost in mills per kilowatt-hour for transmitting energy from Columbia River to load center, without steam stand-by.

TABLE No. 12.—*Cost of transmitting energy to load center public development with steam stand-by*

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	1,967	1,967	1,967	1,967
Cs	1.048	1.057	1.066	1.075
Load factor, 50 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	2,459	2,459	2,459	2,459
Cs	.838	.846	.853	.860
Load factor, 60 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	2,950	2,950	2,950	2,950
Cs	.699	.705	.711	.717
Load factor, 70 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	3,442	3,442	3,442	3,442
Cs	.599	.604	.609	.614
Load factor, 80 percent:				
T	1,442,800	1,442,800	1,442,800	1,442,800
S	618,900	636,400	653,900	671,400
T+S	2,061,700	2,079,200	2,096,700	2,114,200
K (millions of kilowatt-hours)	3,934	3,934	3,934	3,934
Cs	.524	.529	.533	.537

T=annual cost, in dollars, of transmission from Columbia River to load center.
S=annual cost, in dollars, of steam stand-by.
K=total energy generated at Columbia River in millions of kilowatt-hours.
Cs=cost, in mills per kilowatt-hour, of transmitting energy from Columbia River to load center, with steam stand-by.

TABLE No. 13.—*Cost of transmitting energy to load center private development with steam stand-by*

Cost of fuel oil per barrel	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K (millions of kilowatt-hours)	1,967	1,967	1,967	1,967
Cs	1.365	1.374	1.383	1.392
Load factor, 50 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K (millions of kilowatt-hours)	2,459	2,459	2,459	2,459
Cs	1.092	1.099	1.106	1.114
Load factor, 60 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K (millions of kilowatt-hours)	2,950	2,950	2,950	2,950
Cs	.910	.916	.922	.928
Load factor, 70 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K millions of kilowatt-hours)	3,442	3,442	3,442	3,442
Cs	.780	.785	.790	.796
Load factor, 80 percent:				
T	1,908,800	1,908,800	1,908,800	1,908,800
S	776,900	794,400	811,900	829,400
T+S	2,685,700	2,703,200	2,720,700	2,738,200
K (millions of kilowatt-hours)	3,934	3,934	3,934	3,934
Cs	.683	.687	.692	.696

T=annual cost, in dollars, of transmission from Columbia River to load center.
S=annual cost, in dollars, of steam stand-by.
K=total energy generated at Columbia River in millions of kilowatt-hours.
Cs=cost, in mills per kilowatt-hour, of transmitting energy from Columbia River to load center, with steam stand-by.

TABLE NO. 14.—*Estimated annual value of energy at the Columbia River power plant with and without steam stand-by, assuming load center 170 miles transmission distance*

Assumptions: Peak kilowatts generated at Columbia River hydro plant, 561,300.
Peak kilowatts delivered from terminal substation, 508,000.
Number of 220-kilovolt, 3-phase, double circuit lines, 2.

	Public development				Private development			
Cost of fuel oil per barrel, dollars	$0.75	$1.00	$1.25	$1.50	$0.75	$1.00	$1.25	$1.50
Load factor, 40 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 1,967.								
(*a*) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	7,593,100	8,559,800	9,526,500	10,493,200	8,853,900	9,820,700	10,787,400	11,754,100
(*b*) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(*c*) Annual value of power at Columbia River power plant without steam stand-by	6,150,300	7,117,000	8,083,700	9,050,400	6,945,100	7,911,900	8,878,600	9,845,300
(*d*) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(*e*) Annual value of power at Columbia River power plant with steam stand-by	5,531,400	6,480,600	7,429,800	8,379,000	6,168,200	7,117,500	8,066,700	9,015,900
(*f*) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	3.127	3.618	4.110	4.601	3.531	4.022	4.514	5.005
(*g*) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.812	3.294	3.777	4.260	3.136	3.618	4.101	4.584
Load factor, 50 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 2,459.								
(*a*) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	8,260,600	9,449,800	10,639,000	11,828,300	9,521,400	10,710,700	11,899,900	13,089,100
(*b*) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(*c*) Annual value of power at Columbia River power plant without steam stand-by	6,817,800	8,007,000	9,196,200	10,385,500	7,612,600	8,801,900	9,991,100	11,180,300
(*d*) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(*e*) Annual value of power at Columbia River power plant with steam stand-by	6,198,900	7,370,600	8,542,300	9,714,100	6,835,700	8,007,500	9,179,200	10,350,900
(*f*) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	2.773	3.256	3.740	4.224	3.096	3.579	4.063	4.547
(*g*) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.521	2.997	3.474	3.950	2.780	3.256	3.733	4.209

TABLE NO. 14.—*Estimated annual value of energy at the Columbia River power plant with and without steam stand-by, assuming load center 170 miles transmission distance*—Continued

	Public development				Private development			
Cost of fuel oil per barrel, dollars	$0.75	$1.00	$1.25	$1.50	$0.75	$1.00	$1.25	$1.50
Load factor, 60 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 2,950.								
(*a*) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	8,928,100	10,339,800	11,751,600	13,163,300	10,189,000	11,600,700	13,012,400	14,424,200
(*b*) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(*c*) Annual value of power at Columbia River power plant without steam stand-by	7,485,300	8,897,000	10,308,800	11,720,500	8,280,200	9,691,900	11,103,600	12,515,400
(*d*) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(*e*) Annual value of power at Columbia River power plant with steam stand-by	6,866,400	8,260,600	9,654,900	11,049,100	7,503,300	8,897,500	10,291,700	11,686,000
(*f*) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	2.537	3.016	3.495	3.973	2.807	3.285	3.764	4.243
(*g*) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.328	2.800	3.273	3.745	2.543	3.016	3.489	3.961
Load factor, 70 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 3,442.								
(*a*) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	9,595,600	11,229,800	12,864,100	14,498,300	10,856,500	12,490,700	14,124,900	15,759,200
(*b*) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(*c*) Annual value of power at Columbia River power plant without steam stand-by	8,152,800	9,787,000	11,421,300	13,055,500	8,947,700	10,581,900	12,216,100	13,850,400
(*d*) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(*e*) Annual value of power at Columbia River power plant with steam stand-by	7,533,900	9,150,600	10,767,400	12,384,100	8,170,800	9,787,500	11,404,200	13,021,000
(*f*) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	2.369	2.843	3.318	3.793	2.600	3.074	3.549	4.024
(*g*) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.189	2.659	3.128	3.598	2.374	2.844	3.313	3.783

Load factor, 80 percent								
Millions of kilowatt-hours generated annually at Columbia River power plant, 3,934.								
(*a*) Annual cost of equivalent steam plant at load center (508,000 kilowatts required, 558,800 kilowatts installed)	10,263,100	12,119,900	13,976,600	15,833,300	11,615,400	13,380,700	15,237,500	17,094,200
(*b*) Annual cost of transmission from power plant to load center (2 double circuit lines)	1,442,800	1,442,800	1,442,800	1,442,800	1,908,800	1,908,800	1,908,800	1,908,800
(*c*) Annual value of power at Columbia River power plant without steam stand-by	8,820,300	10,677,100	12,533,800	14,390,500	9,706,600	11,471,900	13,328,700	15,185,400
(*d*) Annual cost of steam stand-by (70,000 kilowatts)	618,900	636,400	653,900	671,400	776,900	794,400	811,900	829,400
(*e*) Annual value of power at Columbia River power plant with steam stand-by	8,201,400	10,040,700	11,879,900	13,719,100	8,929,700	10,677,500	12,516,800	14,356,000
(*f*) Value of power at Columbia River power plant in mills per kilowatt-hour without steam stand-by	2.242	2.714	3.186	3.658	2.467	2.916	3.388	3.860
(*g*) Value of power at Columbia River power plant in mills per kilowatt-hour with steam stand-by	2.085	2.552	3.020	3.487	2.270	2.714	3.182	3.649

VALUE OF ENERGY AT POWER PLANT

It is assumed that the Columbia River power plant will be constructed and operated by the Government; that the energy generated will be sold at the high-voltage side of the transformers at the power plant; and that the transmission lines will be constructed and operated by the agencies which purchase the energy. Under these conditions the value of energy at the power plant will be determined by the cost of an equivalent amount of substitute energy delivered at the terminal substations located at the load centers, less the cost of transmitting energy from the Columbia River power plant to the same load centers.

Drawing no. 222-D-7[31] shows graphically the estimated cost in mills per kilowatt-hour of energy generated by a steam-electric plant for various load factors and prices of fuel oil and for both public and private steam plants. Drawings nos. 222-D-9 [31] and 222-D-10 [31] show the estimated cost of transmitting energy from the Columbia River power plant to the load center for various load factors and for both public and private transmission.

Table 14 shows the value of energy at the Columbia River power plant for various load factors, various prices of fuel oil and for both publicly and privately owned and operated substitute steam plants and transmission lines, both with and without steam stand-by to supplement delivery of power over long-distance transmission lines. The value of energy at the Columbia River power plant under the same conditions is shown graphically by the curves on drawings nos. 222-D-11 [31] and 222-D-12.[31]

These curves indicate that with fuel oil costing $1 per barrel delivered, the value of energy at the Columbia River power plant would vary from 2.55 mills per kilowatt-hour for public ownership and operation of a substitute steam-electric plant and transmission facilities to 2.92 mills per kilowatt-hour for a privately owned and operated substitute steam-electric plant and transmission lines, both on the assumption that steam stand-by is included and that the load factor is 80 percent.

Some margin should be allowed between the cost of substitute power from other sources and the price of Columbia River power so as to induce the various power companies and municipalities to utilize the Columbia River power in preference to power from other sources and to expedite the absorption of the Columbia River power as rapidly as possible which is a very important factor in the financial success of the proposed power development. Based on the cost of equivalent substitute power obtained from steam-electric generating stations located at load centers and with fuel oil at $1 per barrel, the value of energy at the Columbia River power plant would be somewhere between 2.5 and 3.6 mills per kilowatt-hour, depending on load factor and whether public or private agencies purchase the power. A price of 2.25 mills per kilowatt-hour should be sufficiently attractive to induce the power companies and municipalities to purchase energy in lieu of constructing additional power plants, either steam or hydroelectric, of their own and to insure that the Columbia River power will be absorbed as rapidly as the growth of load will permit.

[31] Not printed.

FINANCIAL RESULTS

Studies have been made of the financial operation of the proposed Columbia River development based on the following assumptions:

(*a*) The firm power amounting to 800,000 kilowatts of continuous power is absorbed in 15 years which corresponds to a rate of 53,300 kilowatts, or 467,000,000 kilowatt-hours per year.

(*b*) The firm energy is sold at 2.25 mills per kilowatt-hour.

(*c*) Irrigation development and settlement proceeds at the rates of 20,000 acres per year.

(*d*) Secondary power for pumping purposes is paid for at the rate of $1 per acre per year, which is equivalent to approximately 0.5 mill per kilowatt-hour.

(*e*) Operation of the power plant by Government forces in order to take full advantage of secondary power for irrigation pumping and thus secure the maximum returns from the installation.

Based on the above assumptions, the revenue would be sufficient to repay the cost of the Columbia River Dam and power plant with interest at 4 percent per annum within 50 years, in addition to providing for the operation, maintenance, and depreciation of the dam and power plant and also provide a surplus of approximately $144,000,000 which would be available for repayment of the cost of the irrigation development and other purposes. This financial operation is shown by table 15 and graphically by drawing no. 13.[31]

The absorption of the 800,000 kilowatts of continuous firm power should be accomplished within a period of 15 years without serious difficulty provided the power companies and municipalities will all cooperate to the fullest possible extent and if the requirement for power in the Pacific Northwest continues to increase in the future.

[31] Not printed.

TABLE No. 15.—*Financial operation*

[Power sold at 2¼ mills per kilowatt-hour—Land settled at rate of 20,000 acres per year. Power absorption period, 15 years]

Year after completion of dam	Number units installed at beginning of year	Millions of kilowatt-hours sold, exclusive of pumping uses	Cost, including interest during construction at beginning of year	Investment, including interest during construction and accumulated deficit at beginning of year	Revenue from power for pumping at $1 per acre	Revenue from sale of commercial power at 2.25 mills per kilowatt-hour	Total gross revenue	Operation and maintenance	Depreciation reserve funded at 4 percent	Interest on investment	Payment for retirement of investment	Total annual expense	Deficit	Surplus available for irrigation repayment or other purposes
1	3	467	$158,577,792	$158,577,792	$20,000	$1,050,750	$1,070,750	$412,500	$347,239	$6,343,112		$7,102,851	$6,032,101	
2	4	934	160,853,863	166,885,964	40,000	2,101,500	2,141,500	456,250	384,668	6,675,439		7,516,357	5,374,857	
3	5	1,402	163,129,934	174,536,892	60,000	3,154,500	3,214,500	500,000	422,097	6,981,476		7,903,573	4,689,073	
4	6	1,869	165,406,005	181,502,036	80,000	4,205,250	4,285,250	543,750	459,526	7,260,081		8,263,357	3,978,107	
5	7	2,336	167,682,076	187,756,214	100,000	5,256,000	5,356,000	587,500	496,955	7,510,249		8,594,704	3,238,704	
6	8	2,803	169,958,147	193,270,989	120,000	6,306,750	6,426,750	631,250	534,384	7,730,840		8,896,474	2,469,724	
7	9	3,270	172,234,218	198,016,784	140,000	7,357,500	7,497,500	675,000	571,813	7,920,671		9,167,484	1,669,984	
8	10	3,738	174,510,289	201,962,839	160,000	8,410,500	8,570,500	718,750	609,242	8,078,514		9,406,506	836,006	
9	11	4,205	176,786,360	205,074,916	180,000	9,461,250	9,641,250	762,500	646,671	8,202,997	$29,082	9,641,250		
10	12	4,672	179,062,431	207,321,905	200,000	10,512,000	10,712,000	806,250	684,100	8,292,876	928,774	10,712,000		
11	13	5,139	181,338,502	208,669,202	220,000	11,562,750	11,782,750	850,000	721,529	8,346,768	1,864,453	11,782,750		
12	14	5,606	183,614,573	209,080,820	240,000	12,613,500	12,853,500	893,750	758,958	8,363,233	2,312,601	12,328,542		$524,958
13	15	6,074	185,890,644	209,044,290	260,000	13,666,500	13,926,500	937,500	796,387	8,361,772	2,431,582	12,527,241		1,399,259
14	15	6,541	185,890,644	206,612,708	280,000	14,717,250	14,997,250	937,500	796,387	8,264,508	2,528,846	12,527,241		2,470,009
15	15	7,008	185,890,644	204,083,862	300,000	15,768,000	16,068,000	937,500	796,387	8,163,354	2,630,000	12,527,241		3,540,759
16	15	7,008	185,890,644	201,453,862	320,000	15,768,000	16,088,000	937,500	796,387	8,058,154	2,735,200	12,527,241		3,560,759
17	15	7,008	185,890,644	198,718,662	340,000	15,768,000	16,108,000	937,500	796,387	7,948,746	2,844,608	12,527,241		3,580,759
18	15	7,008	185,890,644	195,874,054	360,000	15,768,000	16,128,000	937,500	796,387	7,834,962	2,958,392	12,527,241		3,600,759
19	15	7,008	185,890,644	192,915,662	380,000	15,768,000	16,148,000	937,500	796,387	7,716,626	3,076,728	12,527,241		3,620,759
20	15	7,008	185,890,644	189,838,934	400,000	15,768,000	16,168,000	937,500	796,387	7,593,557	3,199,797	12,527,241		3,640,759
21	15	7,008	185,890,644	186,639,137	420,000	15,768,000	16,188,000	937,500	796,387	7,465,565	3,327,789	12,527,241		3,660,759
22	15	7,008	185,890,644	183,311,348	440,000	15,768,000	16,208,000	937,500	796,387	7,332,454	3,460,900	12,527,241		3,680,759
23	15	7,008	185,890,644	179,850,448	460,000	15,768,000	16,228,000	937,500	796,387	7,194,018	3,599,336	12,527,241		3,700,759
24	15	7,008	185,890,644	176,251,112	480,000	15,768,000	16,248,000	937,500	796,387	7,050,044	3,743,310	12,527,241		3,720,759
25	15	7,008	185,890,644	172,507,802	500,000	15,768,000	16,268,000	937,500	796,387	6,900,312	3,893,042	12,527,241		3,740,759
26	15	7,008	185,890,644	168,614,760	520,000	15,768,000	16,288,000	937,500	796,387	6,744,590	4,048,764	12,527,241		3,760,759
27	15	7,008	185,890,644	164,565,996	540,000	15,768,000	16,308,000	937,500	796,387	6,582,640	4,210,714	12,527,241		3,780,759
28	15	7,008	185,890,644	160,355,282	560,000	15,768,000	16,328,000	937,500	796,387	6,414,211	4,379,143	12,527,241		3,800,759
29	15	7,008	185,890,644	155,976,139	580,000	15,768,000	16,348,000	937,500	796,387	6,239,046	4,554,308	12,527,241		3,820,759
30	15	7,008	185,890,644	151,421,831	600,000	15,768,000	16,368,000	937,500	796,387	6,056,873	4,736,481	12,527,241		3,840,759
31	15	7,008	185,890,644	146,685,350	620,000	15,768,000	16,388,000	937,500	796,387	5,867,414	4,925,940	12,527,241		3,860,759
32	15	7,008	185,890,644	141,759,410	640,000	15,768,000	16,408,000	937,500	796,387	5,670,376	5,122,978	12,527,241		3,880,759

33	15	7,008	185,890,644	136,636,432	660,000	15,768,000	16,428,000	937,500	796,387	5,465,457	5,327,897	12,527,241		3,900,759
34	15	7,008	185,890,644	131,308,535	680,000	15,768,000	16,448,000	937,500	796,387	5,252,341	5,541,013	12,527,241		3,920,759
35	15	7,008	185,890,644	125,767,522	700,000	15,768,000	16,468,000	937,500	796,387	5,030,701	5,762,653	12,527,241		3,940,759
36	15	7,008	185,890,644	120,004,869	720,000	15,768,000	16,488,000	937,500	796,387	4,800,195	5,993,159	12,527,241		3,960,759
37	15	7,008	185,890,644	114,011,710	740,000	15,768,000	16,508,000	937,500	796,387	4,560,468	6,232,886	12,527,241		3,980,759
38	15	7,008	185,890,644	107,778,824	760,000	15,768,000	16,528,000	937,500	796,387	4,311,153	6,482,201	12,527,241		4,000,759
39	15	7,008	185,890,644	101,296,623	780,000	15,768,000	16,548,000	937,500	796,387	4,051,865	6,741,489	12,527,241		4,020,759
40	15	7,008	185,890,644	94,555,134	800,000	15,768,000	16,568,000	937,500	796,387	3,782,205	7,011,149	12,527,241		4,040,759
41	15	7,008	185,890,644	87,543,985	820,000	15,768,000	16,588,000	937,500	796,387	3,501,759	7,291,595	12,527,241		4,060,759
42	15	7,008	185,890,644	80,252,390	840,000	15,768,000	16,608,000	937,500	796,387	3,210,096	7,583,258	12,527,241		4,080,759
43	15	7,008	185,890,644	72,669,132	860,000	15,768,000	16,628,000	937,500	796,387	2,906,765	7,886,589	12,527,241		4,100,759
44	15	7,008	185,890,644	64,782,543	880,000	15,768,000	16,648,000	937,500	796,387	2,591,302	8,202,052	12,527,241		4,120,759
45	15	7,008	185,890,644	56,580,491	900,000	15,768,000	16,668,000	937,500	796,387	2,263,220	8,530,134	12,527,241		4,140,759
46	15	7,008	185,890,644	48,050,357	920,000	15,768,000	16,688,000	937,500	796,387	1,922,014	8,871,340	12,527,241		4,160,759
47	15	7,008	185,890,644	39,179,017	940,000	15,768,000	16,708,000	937,500	796,387	1,567,161	9,226,193	12,527,241		4,180,759
48	15	7,008	185,890,644	29,952,824	960,000	15,768,000	16,728,000	937,500	796,387	1,198,113	9,595,241	12,527,241		4,200,759
49	15	7,008	185,890,644	20,357,583	980,000	15,768,000	16,748,000	937,500	796,387	814,303	9,979,051	12,527,241		4,220,759
50	15	7,008	185,890,644	10,378,532	1,000,000	15,768,000	16,768,000	937,500	796,387	415,141	10,378,532	12,527,560		4,240,440
51	15	7,008	185,890,644		1,020,000	15,768,000	16,788,000	937,500	796,387			1,733,887		15,054,113
52	15	7,008	185,890,644		1,040,000	15,768,000	16,808,000	937,500	796,387			1,733,887		15,074,113
53	15	7,008	185,890,644		1,060,000	15,768,000	16,828,000	937,500	796,387			1,733,887		15,094,113
54	15	7,008	185,890,644		1,080,000	15,768,000	16,848,000	937,500	796,387			1,733,887		15,114,113
55	15	7,008	185,890,644		1,100,000	15,768,000	16,868,000	937,500	796,387			1,733,887		15,134,113
56	15	7,008	185,890,644		1,120,000	15,768,000	16,888,000	937,500	796,387			1,733,887		15,154,113
57	15	7,008	185,890,644		1,140,000	15,768,000	16,908,000	937,500	796,387			1,733,887		15,174,113
58	15	7,008	185,890,644		1,160,000	15,768,000	16,928,000	937,500	796,387			1,733,887		15,194,113
59	15	7,008	185,890,644		1,180,000	15,768,000	16,948,000	937,500	796,387			1,733,887		15,214,113
60	15	7,008	185,890,644		1,199,430	15,768,000	16,967,430	937,500	796,387			1,733,887		15,233,543