543. *Condition* (*a*).—Open river with no further improvement. (See par. 532.) For the open-river navigation a self-propelled freight boat of 500-ton freight capacity, with a speed of 14 miles per hour in still water, was assumed. The operating cost of one boat of this type is estimated at $73,000 per annum, which includes interest, depreciation, insurance, operation, and maintenance. Based on use for 300 days annually, the cost becomes $243 per day. The number of days required to make one trip between Portland and the various terminals, including traveling time, loading, unloading, going through canals, delays, winds, nights, etc., was estimated for each of the various terminals. Using the costs of trips and the lengths of trips and assuming a 100 percent load downstream and 25 percent load upstream, the rate per ton-mile was determined for each terminal. It was assumed that the average speed downstream would be 10 miles per hour and the average speed upstream would be 6 miles per hour, exclusive of time for lockage. Plates 44 [2] and 45 [2] show detailed application of this method to the rail tonnage. Based upon the above method the average cost of operating boats with present open-river navigation is $0.013 per ton-mile, including 10 percent for added distance of boat haul over rail haul. This covers cost of boat operation only and does not include terminal or overhead charges.

544. *Condition* (*b*).—Open river with some improvements. (See par. 533.) With such conditions, it is assumed that, while currents will not be materially changed, the removal of hazards and the straightening of channels will enable greater speed and safety in navigating the rapids and dangerous points, hence it is probable that open-river navigation costs could be reduced 10 percent under the costs estimated for condition (*a*) (par. 532). The cost would then be $0.012 per ton-mile, not including terminal or overhead charges.

545. *Condition* (*c*).—Lateral canals. (See par. 534.) With a lateral canal from Warrendale to head of Cascades Gorge, an extension of The Dalles-Celilo Canal downstream to foot of Three Mile Rapids, and open-river improvement from The Dalles-Celilo Canal to mouth of Snake River, slack-water conditions would exist from Vancouver to Celilo, and open-river conditions from Celilo to mouth of Snake River. Boat operating costs for the section from Portland to Celilo would be as estimated under condition (*d*) below; and for the section from Celilo Canal to Snake River as under condition (*b*) preceding. The combined average cost of operating boats is estimated at $0.010 per ton-mile, not including terminal or overhead charges.

546. *Condition* (*d*).—Slack-water navigation. For slack-water conditions, made possible by construction of high power dams, six 800-ton steel barges, towed by one tug, comprise the unit selected. Loads of 100 percent downstream and 25 percent upstream were assumed. Annual costs of operation for six 800-ton barges and one towboat were estimated to be $270,000. This includes interest, depreciation, operation, and maintenance. Based on a navigation period of 300 days per year, the daily cost of the above fleet would be $900. Assuming that the average speed downstream would be 10 miles per hour and upstream 4 miles per hour, the average number of days to make trips from Portland to the various terminals was computed as in the case of open-river navigation and the costs

[2] Not printed.

per ton-mile arrived at. Plates[1] 46 and 47[1] show detailed application of this method to the railroad tonnage. The average cost per ton-mile on all commodities for operation of boats, based on the above method, is $0.006 for slack-water navigation, including 10 percent for added distance of boat haul over rail haul. This does not include terminal charges or overhead.

547. In the case of the construction of high dams for power, it would be necessary to provide means for handling the water-borne traffic during the construction of the dams. This could be done by portage railroads around the dam sites. The transfer of freight from boat to rail and from rail to boat would cost about 60 cents per ton, not including the first cost of the construction of the portage railroads and the necessary railroad rolling stock. This cost should be charged to the construction of the dams and not to the shipper. It is probable that the tonnage carried on the river would not be very large during the next 10 years, so that the cost of transferring freight around the dam sites would be only a small percentage of the total cost of the dams.

548. *Terminal charges.*—Wheat is the principal commodity and constitutes about 50 percent of the total tonnage. In conditions (*a*), (*b*), and (*c*), wheat has been considered as sacked. Should it be handled in bulk, the terminal cost for conditions (*a*), (*b*), and (*c*) would be as condition (*d*). In the case of condition (*d*) the wheat has been considered as handled in bulk.

549. The estimated terminal costs per ton are as follows:

| (*a*) (*b*) (*c*) *for sacked wheat* | | (*d*) *for wheat in bulk* | |
|---|---|---|---|
| Terminals | $1.20 | Terminals | $0.80 |
| Maintenance | .05 | Maintenance | .05 |
| Traffic expenses | .08 | Traffic expenses | .08 |
| Loss and damage | .08 | Loss and damage | .08 |
| General expenses | .08 | General expenses | .08 |
| Total | 1.49 | Total | 1.09 |

| (*a*) (*b*) (*c*) *for other commodities* | | (*d*) *for other commodities* | |
|---|---|---|---|
| Terminals | $1.50 | Terminals | $1.50 |
| Maintenance | .05 | Maintenance | .05 |
| Traffic expenses | .08 | Traffic expenses | .08 |
| Loss and damage | .08 | Loss and damage | .08 |
| General expenses | .08 | General expenses | .08 |
| Total | 1.79 | Total | 1.79 |

Average rate per ton, all commodities, $1.64, or $0.008 per ton-mile for average haul of 200 miles.

Average rate per ton, all commodities, $1.44, or $0.007 per-ton mile for average haul of 200 miles.

550. By combining the costs of navigation and terminals the total boat rates per ton-mile, to compare with the average rail rate of $0.025 per ton-mile, are as follows:

| | Per ton-mile |
|---|---|
| Condition (*a*). No further improvement | $0.021 |
| Condition (*b*). Some open-river improvement | .020 |
| Condition (*c*). Lateral canals and open-river improvement | .018 |
| Condition (*d*). Slack-water by high power dams | .013 |

551. The foregoing computations and the resulting costs per ton-mile given in the preceding paragraph take into consideration only

[1] Not printed.

the cost of operating the boats themselves, and the costs due to terminal charges, and overhead. They do not consider the cost of getting the shipments to the water terminals. In other words, only the water-haul and water-terminal charges are considered in order to get the difference between water and rail haul to points along the rivers.

552. As given in the preceding paragraph, the estimated per ton-mile water costs vary from $0.021 with the river in its present condition to $0.013 for slack-water conditions produced by dams for power. The average rail rate is $0.025 per ton-mile between Portland and points on the Columbia River below the mouth of Snake River. There are only a few towns on the river bank so that very little freight would originate there. Hood River (2,757 population) and The Dalles (5,883 population) are the only towns of any size along the river, and they have railroads and highways in addition to the river, as means of transportation. The total population of the towns along the river above tidewater to the mouth of the Snake River does not exceed 11,000 inhabitants and there are only a few farms along the river bank.

553. There is very little tonnage which originates on the river bank or which is delivered to points on the river bank to be used in the immediate vicinity of the towns or railroad stations, so that boats would get very little business if they could handle only the shipments that originate on the river bank or that are destined to points on the river bank. The problem is to get shipments to and from the river terminals. Eastbound freight which originates at Portland would be delivered to the boats by the shipper, and the cost would be the same as delivery to the railroad, except that in the case of carload shipments the cars could be loaded at the warehouse. In case of upriver points, shipments must be delivered to the water terminals (if any exist) and the problem is to get the shipments to the interior points from the water terminal. At the present time there is no physical connection between the railroads and the river, so that the shipments would require hauling by wagon or by truck. The railroads have feeder lines to the farming section and have tracks into the industrial centers of the cities and towns and can make delivery in carload lots to the warehouse. Freight originating in or destined to points off the river, if handled by a boat line, would have to be loaded on trucks and hauled from the water terminal to the inland destination or to the nearest railroad. The former would probably be the cheapest means of getting the shipment to destination.

554. Due to the through rail rates, the cost to the shipper for that portion of the haul carried on the feeder line from the inland point of origin to the main line is not only less than it would be if the local short-haul rate were applied, but it is generally less than it would be if the average main-line rate were applied to the feeder haul. For example, in the case of wheat the rail rate from Umatilla, a point on the main line and a proposed river terminal, to Portland is $3.50 per ton, while the through rail rate from Pendleton, 40 miles inland from Umatilla, to Portland is $3.70 per ton, giving a difference of $0.20 per ton for the additional rail haul of 40 miles. The local rail rate from Pendleton to Umatilla is $2 per ton.

555. In order to get freight from Pendleton to the river for water shipment, it would be necessary under present conditions, either to haul the shipment by rail to Umatilla, load it on trucks at the latter

point, and haul to the river terminal, about one-third mile distant, or to make the entire haul from Pendleton by truck. In the first case the cost would be $2 per ton for local rail freight rates, plus about $1 for the transfer to the boat, or $3 per ton. The truck haul of 40 miles at $0.052 per ton-mile would cost $2.08. This indicates that it would be cheaper to make the entire haul by truck, and freight could be picked up directly from consignor. The railroads have tracks to wheat warehouses and industrial centers, and there is usually only a switching charge to pay for the collection or delivery of freight when shipment is made entirely by rail. In order to make shipments to or from inland points by means of boat lines it would usually be necessary to handle them by railroad or trucks between the river terminal and the inland point of collection or delivery. The only consignments which could be collected by or delivered from the boat lines without this double handling would be those shipments originating at or destined for points located at river terminals.

556. Feeders are very important considerations in arriving at the cost of water transportation. The cost of hauling to inland points must be added to the boat haul, and unless the sum of the two charges is less than the all-rail haul charge, no shipments to and from inland points will go by water. In the study of the traffic carried by the railroads along the river and the probable tonnage that would go by water, if the rate were sufficiently lower than the rail rate to induce shipments by water, it was found that the average haul of wheat to the Columbia River from inland points between The Dalles and the mouth of Snake River would be about 30 miles, and that the roads generally paralleled the branch railroad lines which use the canyons to reach the plateaus along the river. There is no wheat land worthy of mention on the river banks. The grain is raised on the highlands making a long haul over rough ground, and generally over unimproved roads to get down from the highlands to the river. The cost of hauling by trucks was determined to be 5.2 cents per ton-mile, which for 30 miles would amount to $1.56 per ton to get shipments to the river by truck. Assuming the average haul to railroad wheat warehouses or railroad sidings to be 8 miles (from farm to railroad station), it would cost the farmer 41 cents per ton to get the shipment to the feeder line of the railroad. Further assuming that the difference in terminal rates on the railroad for the 22 miles between the point on the feeder line and the point on the main line corresponding to the river terminal would be as much as 2½ cents per ton-mile, or 55 cents, the total cost of transporting the freight from the farm to the main-line junction becomes 96 cents per ton. The estimated cost by truck would be $1.56 for the 30-mile haul, or 60 cents greater than the rail rate. This difference, which amounts to 3 mills per ton-mile for an average water haul of 200 miles, has to be added to the water cost in order to make it comparable with the rate by railroad. Combining the costs of navigation, terminal charges, and truck haul, total costs per ton-mile to the shipper for an average water haul of 200 miles will be as follows:

| | *Per ton-mile* |
|---|---|
| Condition (*a*). No further improvement | $0. 024 |
| Condition (*b*). Some open-river improvement | . 023 |
| Condition (*c*). Lateral canals and open-river improvement | . 021 |
| Condition (*d*). Slack-water by high dams | . 016 |

The average rail rate remains the same, $0.025 per ton-mile.

557. *Probable tonnage.*—There is at present no appreciable amount of navigation on the Columbia River above Camas, Wash. Various estimates have been made as to the probable tonnage which would develop if the river were further improved. It is claimed that under the present conditions navigation is hazardous and barges cannot be used, but that if the narrow channels were widened by the removal of rock pinnacles in the rapids as outlined in paragraph 533, condition (*b*) above, navigation would be easier; barges could be used at least to some extent; and with the promise of business boat companies would be induced to operate.

558. A recent traffic survey made by the Columbia Valley Association and Martin's Shipyard, Inc., resulted in obtaining promises for about 400,000 tons of freight annually, provided river navigation was established with charges 20 percent less than existing freight rates. This is more tonnage than has ever been carried on the river in the past and the estimate would appear too optimistic. The estimate of 400,000 tons includes about 100,000 tons of the Lewiston (Idaho) territory, which is 141 miles up the Snake River, and omitting this tonnage there would remain 300,000 tons as the probable tonnage tributary to the Columbia below the mouth of Snake River. The study made by this office indicates that while boats might handle freight at 20 percent less than existing rail rates to points on the river bank under open-river conditions with some improvement, they cannot do so on shipments consigned to points off the river where a fairly long truck haul is required. It is estimated that not to exceed 50,000 tons could be diverted to the river from areas in which the truck haul to the river terminal would be about the same as the truck haul to the rail-shipping point, and not to exceed an additional 50,000 tons could be diverted from areas where the truck haul to the river, while greater than that to the rail-shipping points, would still permit some savings to be effected to the shipper.

559. If the river were further improved by lateral canals and open-river work, as stated in paragraph 518, above, it is believed that, due to the somewhat cheaper costs of transportation, a greater amount of tonnage than that estimated for purely open-river conditions might result, possibly 200,000 tons. If slack-water conditions could be obtained as in the case of the construction of dams, which would reduce the cost of navigation materially, it is estimated that as much as 600,000 tons might be diverted to the river.

560. *Economic benefits.*—In considering the economic benefits which might be the result of further river improvement, it is necessary to take into account not only the saving to shippers in freight charges, but also the cost of the proposed improvements. The annual cost due to improvements for navigation have been stated in paragraphs 533, 534, and 535, above, as follows:

| | |
|---|---|
| Condition (*b*). Some open-river improvement. Annual costs | $55, 000 |
| Condition (*c*). Partial improvement by lateral canal. Annual costs | 1, 025, 600 |
| Condition (*d*). Slack-water. Annual costs | 884, 000 |

561. Based on the estimates of tonnage that might result from such improvements, the estimated annual river transportation costs are less

than the existing annual railroad freight charges on such tonnage for the various conditions of river improvement by the following amounts:

| | |
|---|---|
| Condition (*b*). Some open-river improvement | $70,000 |
| Condition (*c*). Partial improvement by lateral canal | 160,000 |
| Condition (*d*). Slack-water | 1,080,000 |

562. Taking into consideration the cost of the improvements, annual net economic savings would result in case (*b*) of $15,000; and in case (*d*) of $196,000; but in case (*c*) there would be an economic loss of $865,000 annually. While condition (*b*) shows an economic gain of $15,000 annually after paying all costs of maintenance, operation, and interest on the cost of additional river improvements, the amount invested in the improvement itself would be a loss if high dams for power were constructed a few years after the improvements under (*b*) was completed, so that the benefits under (*b*) would be contingent upon the time of the construction of the power dams.

563. It should be borne in mind, however, that there is no way to determine accurately that such improvements would actually result in continued use of the river, or that the tonnage estimated would actually develop, and it is obvious that economic benefits of river improvement could be estimated at various amounts dependent upon the tonnage which might be assumed to be diverted to the river.

## C. POWER

### (1) Undeveloped

#### 1. GENERAL CONSIDERATIONS

564. The power section of this report covers:

(1) Estimate of power possibilities of Columbia River below the mouth of Snake River, together with plans for developing this power and transmitting it to principal industrial centers of the Pacific Northwest, and the estimated cost of power so delivered.

(2) Summary of undeveloped and developed power of the principal tributaries of Columbia below mouth of Snake.

(3) Study of the market for power in the Pacific Northwest and its probable growth based on expected increase in population and per capita consumption and on trends in industrial expansion.

(4) Presentation of preferred plan of development of power resources in this section of the river.

565. *Earlier investigations.*—Investigations of power sites on Columbia River below mouth of Snake and some of its tributaries in this stretch are covered in the following reports:

(*a*) *Reports covering power on main stream.*

(1) Columbia River Power Project (1915). A report covering power development at The Dalles-Celilo site, by United States Bureau of Reclamation in cooperation with State of Oregon. L. F. Harza, consulting Engineer. (Now out of print.)

(2) Report of Possibility of Power Development at the Cascades of Columbia River. Printed in Bulletin no. 5, Office of State Engineer, Salem, Oreg., entitled "Oregon's Opportunity in National Preparedness," (1916), John H. Lewis, State engineer.

(3) Report on Proposed Power Development at Umatilla Rapids on Columbia River near Umatilla, Oreg. Prepared for Umatilla Rapids Association in cooperation with the States of Oregon and Washington (1921). J. H. Lewis, consulting engineer. (Unpublished.)

(4) Umatilla Rapids Project. Prepared by United States Bureau of Reclamation in cooperation with the State of Oregon (1924). E. R. Crocker, associate engineer. (Unpublished.)

(5) Economic Report Umatilla Rapids Project. United States Bureau of Reclamation, by Andrew Weiss and William W. Johnson (1926). (Unpublished.)

(6) *Brief.*—The Umatilla Rapids Project. Published by Umatilla Rapids Association (1927).

*(b) Reports covering power on tributaries entering Columbia below mouth of Snake.*

(1) Reconnaissance Report of John Day River, Oreg. A United States Bureau of Reclamation report by N. J. Tubbs, engineer, 1922. (Unpublished.)

(2) Uses of Deschutes River, Oreg. A Federal Power Commission report, by D. C. Henny, Col. J. B. Cavanaugh, and F. F. Henshaw, acting as a board of engineers. Published in 1922.

(3) Deschutes Project. Cooperative study by United States Bureau of Reclamation and State of Oregon (1914), also later extensions and revisions, office of State engineer et al.

566. The United States Geological Survey Water-Supply Papers listed below give information relative to water-power resources of streams mentioned. The list does not include the large number of Water-Supply Papers giving stream discharge records:

(4) Water-Supply Paper 253, Klickitat, Lewis, and Toutle Rivers:

(5) Water-Supply Paper 313, Cowlitz River, Wash., 1913.

(6) Water-supply Paper 344, Deschutes River, Oreg., 1914.

(7) Water-Supply Paper 348, Hood and Sandy Rivers, Oreg., 1914.

(8) Water-Supply Paper 349, Middle Fork of Willamette, Clackamas, and Collawash Rivers, Oreg., 1913.

(9) Water-Supply Paper 377, John Day River, Oreg., 1915.

(10) Water-Supply Paper 378, Middle Fork of Willamette River, Oreg.

(11) Water-Supply Paper 637-C, Water Power Resources of McKenzie River, Oreg., 1931.

(12) House Document No. 666, Seventy-first Congress, third session, Cowlitz River, Wash., by Corps of Engineers, 1930.

(13) House Document No. 680, Seventy-first Congress, third session, Lewis River, Wash., by Corps of Engineers, 1930.

Reference is also made to:

(14) Rules and regulations governing Administration of Federal Water Power Act, third revised issue, 1928.

567. *Datum plane for elevations.*—Elevations are expressed in feet above mean sea level, the datum plane used by the United States Geological Survey. Similarly, negative signs indicate elevations below mean sea level.

568. *Natural fall.*—The elevation of water surface of Columbia River at mouth of Snake, 324 miles from the sea, at mean low water, is 313, and at head of tidal reach at Warrendale, Oreg., 140 miles from the sea, 4 feet. A gage height of 4 feet at Warrendale corresponds to a flow of 60,000 second-feet. The total fall, then, in the 184-mile stretch is 309 feet. In this section of the river there are two distinct falls. The upper fall is in The Dalles-Celilo section where the river drops 82 feet in 11 miles at mean low water. The other fall is at Cascades Rapids where there is a concentrated fall at low water of 25 feet, with an additional drop of 12 feet in the 7-mile stretch between Cascades Rapids and Warrendale.

569. As the discharge increases the river rises somewhat more rapidly at Warrendale than at the mouth of Snake with the result that the total fall becomes less. At peak of record flood, June 1894, the water surface at mouth of Snake stood at elevation 342 and at Warrendale 47, giving a record low fall of 295 feet.

570. *Natural flow.*—As stated in paragraph 73, stream flow records for Columbia River at The Dalles, Oreg., extend continuously from 1878 to date. However, as the discharge has shown a downward trend in later years, it has been decided, for purposes of calculating power in this report, to use stream discharge figures for the 17-year period from April 1, 1913, to March 31, 1930. The discharge at Warrendale is increased over that at mouth of Snake by the entrance of several tributary streams, most important of which is the Deschutes. Deschutes River has a relatively constant flow throughout the year. The smaller tributaries which rise in the eastern slope of the Cascade Mountains, both in Oregon and Washington, and enter the Columbia between The Dalles and Warrendale, have a generally well sustained flow during the months of winter when the discharge in the Columbia is lowest. The following tabulation shows the discharge of the Columbia at a point just above the mouth of Deschutes, at The Dalles and at Warrendale for various percents of time, as computed from United States Geological Survey record for 17-year period mentioned. The increment in discharge is so small, especially for low flows, that the figures for the point just above mouth of Deschutes, with small error, may be used for computing power at any site between mouth of Snake and the Deschutes.

*Discharge of Columbia in second-feet, unregulated*

| Percent of time | Just above mouth of Deschutes River | The Dalles | At Warren dale |
|---|---|---|---|
| 100 (lowest day) | 36,000 | 40,000 | 43,000 |
| 99 | 52,000 | 56,000 | 59,000 |
| 98 | 55,000 | 59,000 | 62,000 |
| 90 | 66,000 | 70,700 | 74,000 |
| 50 | 120,500 | 126,000 | 130,000 |
| 35 | 168,000 | 174,000 | 179,000 |
| Mean for period | 179,000 | 185,000 | 190,000 |

571. *Regulated flow.*—Studies have been made of the effect on the flow of the Columbia below mouth of Snake of future ultimate diversions for irrigation and of return flow from irrigation. In this, consideration has been given to the Columbia and its tributaries in the United States and to Snake River and its tributaries. Studies have also been made showing a probable ultimate storage in the interest of power and irrigation on these streams and tributaries of about 26,000,000 acre-feet, not including storage above high dams proposed below mouth of the Snake. Owing to the fact that the regimen of the Columbia below mouth of the Snake differs from that above the mouth and from that of the tributaries, all of this storage would not be available when most needed for regulating the flow of the lower Columbia. A consideration of these several factors, and of the average flow for the 17-year period, 1913–30, results in an estimated ultimate flow in Columbia River at The Dalles and is shown in the following tabulation. This table gives the estimated effect that future regulation would have on flow of Columbia, if the pumping scheme involving the construction of a high dam at the Grand Coulee is used for development of the Columbia Basin irrigation project. (Also see table no. 67, par. 1345.) In computing and applying the

revisions resulting from future irrigation and storage for power, consideration has been given to average monthly discharges only.

*Regulated discharge of Columbia River at The Dalles*

| Percent of time | Second-feet | Percent of time | Second-feet |
|---|---|---|---|
| 100 | 83,000 | 50 | 123,000 |
| 99 | 88,000 | 35 | 154,000 |
| 90 | 97,000 | | |

572. *Flood discharges.*—The annual spring flood in Columbia River generally comes to a peak in June. The maximum flood on record, since 1878, occurred on June 6, 1894, and reached a crest of 1,170,000 second-feet at The Dalles, Oreg. The average for the same day is estimated at 1,160,000 second-feet. This flood marked out a profile roughly 30 to 35 feet above mean low water from mouth of Snake to Celilo, a distance of 123 miles. It stood at 60 feet above mean low water at Big Eddy, 9 miles below Celilo; descended to 50 above low water at the head of Cascades Rapids, 45 miles farther downstream; and dropped in the next 7 miles to 43 feet above mean low water at Warrendale, which marks the head of tidal reach.

573. Flood peaks of more than 800,000 second-feet at The Dalles have occurred 4 times since 1878; 600,000 second-feet or more, 28 times, and over 400,000 second-feet, 47 times. It may be of interest to know that a flood peak of 766,000 second-feet was reached as late as 1928. A flood peak less than 300,000 second-feet has occurred only once during the period of record. This was in 1926 when the maximum discharge for one day was 269,000 second-feet. Paragraphs 1072 to 1084 give detailed information covering recorded facts and probable magnitude, frequency, and duration of Columbia River floods.

574. *Mean low water.*—A study of the yearly minimum flow at The Dalles shows that yearly minima below 75,000 second-feet have occurred 42 times during the 52 years of record since 1878. For those 42 years the average minimum was about 60,000 second-feet. This figure accordingly has been adopted in this report to represent mean low-water flow.

575. *Potential power.*—The Federal Power Commission, for the purpose of fixing fees to be paid by licensees, and the United States Geological Survey, as a basis for estimating the potential power of the country's undeveloped streams, assume an over-all efficiency from head water to tail water of approximately 70 percent and calculate power by the formula:

Horsepower = second-feet available 90 percent of time × head in feet × 0.08.

For power output in kilowatts, this formula becomes: Kilowatts = second-feet × head in feet × 0.06.

Computations based on this formula and average natural discharges in the several sections for the 17-year period between 1913 and 1930 show the Columbia between mouth of Snake and head of tidal reach to have potential power as given in the following tabulation:

| | *Potential power kilowatts* |
|---|---|
| 100 percent time (lowest day) | 717,000 |
| 90 percent time | 1,275,000 |
| 50 percent time | 2,290,000 |
| 35 percent time | 3,170,000 |

576. *Canyon of the Columbia.*—Columbia River, through much of its course from mouth of Snake to head of tidal reach, flows through a rather narrow rock-bordered gorge. What is generally conceived of as a flood plain may be considered as nonexistent and river lowlands along this stretch are very limited in area. Basaltic rock provides adequate foundation and abutment supports for dams up to any reasonable height at a number of sites above Cascades Rapids. Aside from The Dalles and Hood River, there are no towns of importance near water's edge between mouth of Snake and head of tidal reach, and even individual homes are few in number. Unlike the Mississippi, Ohio, and many other streams of the midwest and east which have low banks and far spreading agricultural areas along them, and cities, towns, and many rural homes at slight elevation above river level, the Columbia seems most ideally set by nature and favored by absence of settlement by man for the developing of water power through the construction of high dams. The two features making such a deduction, to some extent, in error, are the railroads, which have been built on both river banks from mouth of Snake River to and through Columbia Gorge.

577. *Railroad on north bank.*—The Spokane, Portland & Seattle Railway, the Great Northern-Northern Pacific system's connection between Spokane and Portland, follows the north bank of the Columbia from a point opposite mouth of Snake River to and past head of tidal reach. It was built in 1905 and 1906 and has a maximum adverse grade of two tenths of 1 percent going east and no adverse grade going west. It is located at all points with a minimum vertical clearance of 4 feet above the highest flood of record, that of June 1894 (par. 572).

578. *Railroad on south bank.*—The Union Pacific line, which follows the south bank of the Columbia from mouth of Snake to and past Warrendale, Oreg., was constructed in the early eighties in accordance with pioneer standards as to grade and alinement. It has been relocated, revised, and rebuilt in large measure and now has a ruling grade of five tenths of 1 percent, both east and west bound. At a few points it still drops below the profile of the 1894 flood.

579. *Accessibility of sites.*—Each of the five major sites proposed is easily accessible from Portland, Oreg., by rail or highway. The Warrendale and The Dalles sites have the additional advantage of river navigation during most of the year. The Spokane, Portland & Seattle Railway on the Washington side and the Union Pacific System on the Oregon side are close to the river for practically the entire distance between Portland and the mouth of the Snake. The Columbia River Highway follows the Oregon shore of the river closely from Portland to Umatilla. On the Washington bank the new Evergreen Highway and other roads parallel the river at some distance back. To gain access to any site for construction purposes only short and inexpensive stretches of railroads or wagon roads would have to be constructed.

580. The Dalles, Oreg., with 6,000 inhabitants, is the largest city in this part of Columbia Valley. It would be necessary to establish construction camps at sites selected for development. The city of Portland would be the principal source of supplies during the construction period.

581. At some sites, as Warrendale and The Dalles, electric power for construction purposes could be obtained from existing hydroelectric plants. Sites upstream from The Dalles would require either long transmission lines or temporary power plants.

582. There is no appreciable difference in accessibility which would warrant preference for any of the sites considered.

583. *Silting of reservoirs.*—For the low-head developments it is planned to utilize the upper few feet in the pools for daily regulation. Similarly for the high-head developments it is planned to utilize but a comparatively small portion of the depth, leaving a large amount of dead storage space below.

584. The Columbia, having its sources in the Continental Divide and other high ranges in the United States and Canada, and flowing between rock and gravel banks through much of its course above the head of tidal reach, carries in suspension a relatively small amount of sand and silt.

585. Wenatchee, Wash., is the only point on Columbia River above mouth of the Snake where records of silt carried have been kept. The city of Wenatchee, which uses Columbia River as the source of its water supply, has made daily determinations of the turbidity for the period from January 1, 1927, to November 19, 1930. An examination of the records shows that the turbidity is noticeable for about 30 days in each year, usually during March. The average monthly turbidity varied from a maximum of 34.2 parts per million, by weight, for March 1927 and 1928, to zero for a total of 25 months in the 4-year period. The average turbidity for year varied from a maximum of 7.44 parts in a million for 1927 to a minimum of 0.45 parts in a million for 1929. The average for the 4-year period of record is 4.7 parts in a million. The average flow per year for the period of record was 89,000,000 acre-feet. Assuming the dry silt to have a weight of 80 pounds, there results an average of 330 acre-feet carried by the river per year.

586. The water in Snake River at its mouth near Pasco does not appear to differ greatly from the Columbia River water. The very slow rate of silting of irrigation and power reservoirs on the Snake gives good reason for assuming that silting will be of small importance in affecting the active capacity of reservoirs on Columbia River.

587. *Ice conditions.*—The winter climate east of the Cascade Range is more severe than to the west, with the result that ice may be expected to form in the river in December, January, or February, and that great quantities of ice may come down from the stretches above. Records kept by the Government at Cascade Locks for the 35-year period between 1896 and 1930 show that there was a total of 14 winters during which there was no closure of the locks on account of ice and that during the remaining 21 years the locks were closed for periods ranging from a few days to a few weeks. The aggregate time of closure amounted to 256 days, or an average of about 7 days per year for the entire 35 years. During 16 years of this same 35-year period, the river at the head of Cascades Rapids was blocked from shore to shore for a total of 283 days, or an average of 8 days per year. As a rule the river continues to flow at normal volume, but occasionally an ice jam forms. However, the volume of water is so great and the channel so contracted that the head against the jam soon forces it on down the stream. After dams have been built, the forming of ice jams would be eliminated. With raised low water levels ice would no longer lodge

against irregularities in the river channel but would float on the pool surface and be carried away through the gate openings.

588. Conditions favorable for formation of anchor ice are not known to exist in the Columbia River below mouth of the Snake and no trouble from such occurrences would be expected.

589. *Exploration drilling.*—Diamond-drill borings have been made at a number of possible dam sites. The material penetrated by the drills is represented on drawings accompanying the descriptions of the several sites in pages following. No attempt was made to continue the drilling to a point which would give all the information required for preparing plans for construction, or even for definitely locating the various structures. One to three holes were put down at each prospective site. This amount of drilling, together with information gained from other sources, was considered sufficient to determine the general nature of the foundation materials and to provide such knowledge of subsurface conditions as would make possible the working up of tentative designs from which to prepare approximate estimates of cost.

590. *Critical height of dams.*—Eliminating from consideration for the present, The Dalles-Celilo and Cascades Rapids sites, at both of which concentrated falls are available, and confining attention to the portion of Columbia River between mouth of the Snake and Celilo, it will be seen that dams made up of low-base structures, piers, and crest gates will be limited in height to about 30 or 35 feet, if the railroad on the north bank is not to be submerged; and several feet lower if the railroad on the south bank is considered. Such a series of dams, if constructed with the pool above each extending to the dam next above, would develop the full power of the stream at low water. With increasing discharges, however, the crest gates would be opened. This would hold the elevation of head water constant while the tail water would rise, until, with the recurrence of a flood equal in volume to that of 1894, the river would flow on virtually as though no dams were present so that no power would be developed. As a matter of fact, the water wheels would fail to rotate at speed required by generator frequency and would cease to deliver power at a river stage several feet below that of the 1894 flood. The minimum height of dams, then, if any power is to be delivered 100 percent of the time, in the portion of the Columbia between mouth of the Snake and Celilo, is roughly 40 feet. Dams of this height will make possible the generation of power at ordinary high water, although at time of great floods no power would be available. To avoid uneconomical multiplication of water wheels and to secure a reasonably effective development, a power dam in the Columbia should provide a mean low water head of not less than 55 or 60 feet.

591. *Spillways.*—To pass the flow at the power dams during floods, two types of spillways have been considered, one with fixed crests, and another with crest gates. If it were not for the railroads along the banks, it would be feasible to build dams with fixed crests up to any reasonable height at many points along the Columbia above Cascades Rapids. Were dams of this type constructed, the head at each would remain roughly constant, the water rising as rapidly below the dam as above it. A comparative estimate, however, shows that it would be more desirable to build dams of the crest gate type

and install additional wheels for maintaining power output during the low-head period occurring annually at time of high water.

592. For crest gates, the roller-type gate has been chosen. The dimensions proposed, although great, are not unprecedented. The largest would be 150 by 24 feet and 130 by 30 feet. Gate manufacturers have given assurance that gates of these sizes are practicable and have given approximate quotations. Piers 16 feet thick would separate and support the roller gates and their operating mechanism as well as a service or highway bridge. Advantages of roller gates are the very wide fairway opened for disposing of floating material such as ice and debris, their reliability in operation in cold weather and the absence of vibration in partially open position. Roller gates are well suited for the conditions prevailing in Columbia River where a great volume of water must pass channels which are comparatively narrow at the dam sites. This results in a shorter spillway than would be possible with gates of other types.

593. Spillways have been designed to pass a discharge of 1,170,000 second-feet, the record flood at The Dalles as of June 1894, at a water level not exceeding the controlled level at low water and to discharge a 25 percent greater flood than the maximum recorded at a level about 3 feet higher. The only exception is the dam at the lowest or Warrendale site where spillway gates have been omitted.

594. *Design of dams.*—The character of the foundation at any given site has determined the type of dam proposed. At most sites investigations have disclosed rock of excellent grade, capable of supporting high masonry dams. At several sites absence of rock at reasonable depth has limited the height proposed and entailed precautionary measures to insure safety. At still other sites, calling for low dams where bedrock is deeply overburdened, earth embankments are proposed for nonoverflow sections.

595. In designing the various types of dams here proposed only standard and generally approved methods have been employed In making assumptions governing the design a conservative policy has been followed throughout.

596. In the design of gravity dams the allowance for uplift, as determined by foundation conditions, greatly affects the dimensions of the section adopted. In most of the projects investigated the dams will be founded on rock, usually a basaltic lava formation. Along the Columbia this is made up of many flows, varying in thickness from a few feet to hundreds of feet. Some of these lie in close contact, while others are separated by layers of softer rock, decomposed sometimes to the consistency of clay. While much of this lava is excellent basalt, some of it is seamed and jointed. Furthermore, since in the majority of cases the greater portion of the dam would be spillway, discharging over 1,000,000 second-feet at extreme floods, sufficient masonry mass must be provided to safeguard against the enormous dynamic forces which may produce vibration at such times.

597. Due to the possible vibration effect from large discharges, all gravity dams proposed in this report have been designed with a downstream slope of 0.85 which provides amply against sliding and uplift. A system of drainage galleries and drain wells has been assumed for the gravity dams, but no reduction in uplift has been allowed on that account.

598. For some of the projects investigated, multiple-arch dams have been proposed for some parts not subject to overflow. The maximum height for such sections has been taken at 150 feet. Center-to-center distance of buttresses has been assumed at 40 feet.

599. Where earth embankments have been proposed they have not been given steeper slopes than three horizontal to one vertical. Where conditions favor a hydraulic-fill dam, that type has been adopted.

600. The single-arch type of dam has been proposed for only one development, The Dalles for the 150- and 183-foot levels. In The Dalles plan the single arch would close the deep channel in the river between Big Eddy Island and the Oregon shore. The arch would be of standard design. Details follow in the description of The Dalles plan.

601. Pressure grouting near upstream face of all masonry dams has been estimated as a safeguard against leakage beneath the body of the dam.

602. Freeboard over controlled water levels has been assumed as 10 feet for all masonry structures and 15 feet for earth embankments.

603. *Model experiments.*—Of late it has been generally recognized that the testing of small-scale models of hydraulic structures renders results directly applicable to the actual structures under consideration. Among conditions not possible of mathematical solution but determinable to a high degree of accuracy in this way is the general shape of the dam profile, size and location of baffles, discharge over dams, scouring below dams and in river channels, the behavior of timber booms, and the passing of ice.

604. The cost of such model experiments has been included in the estimate of each site.

605. *Intakes.*—The intake to each turbine should have trash racks and provision for stop logs and intake gates. A velocity of 2½ feet per second on gross rack area has been taken as the basis to determine intake openings. Structurally the racks and their supporting beams have been designed for full hydrostatic pressure possible during severe winters due to clogging by ice. For such extreme conditions unit stresses allowed approach the elastic limit. Mechanical raking and provision for electric heating during winter have been estimated for each development.

606. One or more sets of stop logs have been estimated for each development for temporary closure of the intakes.

607. Each intake would be provided with structural steel seats for closing by means of gates. Owing to the large-size units proposed for the projects here investigated, it would require a great number of gates to completely close the openings for all the units. In some projects not less than 6 gates to 1 unit would be needed. Considering the infrequency of closing an intake and also the possibility of shutting off the flow by means of the wicket gates on the turbines, gates for individual intake openings have been omitted. Gate guides, however, would be installed in all openings. A number of gates sufficient to close any 1 opening for 1 unit in 10 would be provided. When not in use, these gates would be stored at a convenient place at the end of the intake.

608. A gantry crane, traveling on a track along the top of the dam, would serve to transport, lower, and raise the gates, stop logs, and racks.

609. *Logways.*—There is at this time no driving of loose logs on the Columbia below mouth of Snake. Such timber as is cut from the eastern slope of the Cascades in the vicinity of White Salmon, Hood River, and Lyle and marketed at lower river points is assembled into rafts and towed through Cascades Canal. There is, however, some drift and occasionally, at time of flood, saw logs break away from upriver points, even as far away as British Columbia, and provision for passing these and miscellaneous drift should be made in all dams.

610. *Fishways.*—The Columbia is one of the important salmon fishing streams of the country and the packing of this fish is an industry of great importance on the lower reaches of the stream in both Oregon and Washington. It is the habit of the salmon to come into the Columbia from the sea and pass to the upper reaches and tributaries to spawn. For these reasons it is probable that the United States Bureau of Fisheries will require one or more fishways to be built in connection with any dam up to about 75 feet in height which may be constructed in the Columbia below mouth of the Snake and that tramways or other devices be provided for getting the fish past dams of greater height. In general, two fishways have been covered in the estimate for each low-head site considered in this study, one with lower entrance in the turbulent water at foot of spillway and the other with lower entrance in swift water emerging from the wheels. These would be 20 feet wide in the clear and on a grade of 10 horizontal to 1 vertical. To attract attention, a disappearing gate 20 feet wide would discharge additional water near each fishway. In view of probable requirement by the United States Bureau of Fisheries, estimates also include electric fish screens at the intakes and below the draft tubes to protect both upstream and downstream migrants.

611. *Existing plants.*—There are now no dams or power plants on the main stream of the Columbia River between mouth of the Snake and tidewater.

612. *Installed capacity.*—In order to secure comparable results for the different sites, firm power at each site has been determined from a flow corresponding to that at 99.3 percent of the time. This flow is 55,000 second-feet below the mouth of Deschutes River and 50,000 second-feet above. (See pars. 570 and 620.) The kilowatt output produced by utilizing this flow and corresponding head has been termed firm power. Based on an assumed load factor of 50 percent, the peak load would be twice the firm power. This installation is then increased by the number of units which would be necessary to produce the same peak load at high water when the head is reduced due to a rise in tailwater levels. Manufacturers' estimated turbine efficiencies at varying heads and flows have been used throughout in the computations.

613. In projects including storage reservoirs the effect of storage and draw-down has been given consideration. Storage regulation increases the minimum available discharge as much as 30,000 second-feet.

614. It is realized that the assumed load factor of 50 percent is low. For this reason comparative estimates have been worked out for other load factors up to 100 percent. Graphs showing the cost per kilowatt-hour for load factors between 50 and 100 percent are shown on plates 95 [2] to 100 [2] inclusive.

[2] Not printed.

615. *Turbines.*—For units operating at heads in excess of 68 feet, reaction type wheels are assumed, while at lower heads, varying greatly in all low-head installations considered, adjustable blade propeller type wheels are contemplated. Some plants would be equipped with both types. Physical and economic considerations prompted the assumption of the largest sizes manufacturers are prepared to build, transport, and install. Further information as to turbines is embodied in descriptions of equipment assumed for the several more important sites investigated.

616. *Electrical equipment.*—The principal electrical equipment for the several power houses proposed in this report is planned to conform to the following general specifications:

*Generators.*—The generators will be of the vertical type direct connected to the turbines. Each generator will be capable of producing continuously its full rated output in kilowatts from 100 percent to 80 percent power factor. Each will be designed for 3-phase operation at 60 cycles and 13,800 volts. Each will be furnished with direct-connected exciter and necessary auxiliary equipment suitable for properly regulating the voltage under all operating conditions. There will also be furnished a suitable oil-lubricated, water-cooled thrust bearing and usual device for automatic protection of the unit.

*Transformers.*—The transformers will be of the outdoor type, water cooled, 3-phase, 13,800 volts on low side and 230,000 volts on the high side.

*Generator control.*—A 13,800-volt remote-controlled oil circuit breaker and necessary disconnecting switches will be furnished for each unit. These will include all equipment necessary to provide for automatically synchronizing, controlling, and protecting the generator and exciter. Meters, instrument transformers, relays, etc., will also be provided.

*Bus sectionalizing control.*—There will be provided 13,800-volt remote-controlled oil circuit breakers and necessary disconnecting switches at points where it is desirable to divide the generator bus bars. Provision will also be made for synchronizing the different sections.

*Transformer and line control.*—A 13,800-volt, remote-controlled oil switch and necessary disconnecting switches will control the connection of each bank of transformers to section of low-tension bus. Two banks of transformers will operate in parallel to feed one 220,000-volt transmission line. This will require the installation of two 220,000-volt remote-control nonautomatic oil switches for the transformers and one automatic, quick-opening oil switch for the line. Each will have the necessary disconnecting switches.

*Auxiliary controls.*—These will be provided for control of exciters, house generators and transformers, circuits for panel lighting, power, heating, and miscellaneous purposes.

*Substation.*—The substation at each plant will consist of the usual yard or roof installation as the space at the site may determine.

617. *Transmission lines.*—The transmission-line specification adopted for estimating purposes in this report contemplates steel-tower, double-circuit, steel-aluminum conductor construction. Regulating equipment will be provided. The transmission system includes, in addition to the transmission line, transformers, circuit breakers, and other standard equipment at both ends of the line.

It also includes the substation structure and necessary condenser equipment at the receiving end of the line. A study covering the theory, economics, and costs of constructing and operating high-voltage, high-power transmission lines will be found in part I of this combined report.

618. *Navigation features.*—The Columbia is a navigable stream and it will be necessary to provide for canal and locks from lower to upper pool past any power dam that may be constructed. The general specifications covering this feature call for lock chambers 60 feet by 360 feet, usable dimensions, with 11-foot depth over lower miter sill. Ultimately it is planned to have the locks in pairs (twin locks), which will permit the making of repairs without interruption of traffic. The estimates covering initial installation, however, as given in this report, are to include only the cost of a single flight, but provision is to be made in the location plans for constructing a second flight of locks parallel to the first series, when increase in traffic justifies its construction.

619. It is desirable from a navigation point of view that from the head of tidal reach to the foot of Priest Rapids the maximum surface velocity should not exceed 5 feet per second in channels affected by dams for combined power and navigation at flood stages of 800,000 second-feet. Though this velocity limitation may not be possible of attainment at all points for a flow as high as 800,000 second-feet, an effort has been made to provide for it as a maximum.

620. *Firm and secondary power.*—A tabulation showing daily discharge of Columbia River at The Dalles for the 17-year period 1913 to 1930 gives the following figures:

| | *Second feet* |
|---|---|
| During 2 days discharge was | 40, 000 |
| During 12 days discharge was below | 45, 000 |
| During 31 days discharge was below | 50, 000 |
| During 44 days discharge was below | 55, 000 |

That is, during seven tenths of 1 percent of the time the discharge was less than 55,000 second-feet, or during 99.3 percent of the time the discharge was 55,000 second-feet or more.

621. For the 52-year total period of record there were 102 days, or but fifty-four one-hundredths of 1 percent of the time, during which the discharge fell below 55,000 second-feet, or 99.46 percent of the time during which the discharge was 55,000 second-feet or more.

622. During the 17-year period there were 14 years, and during the 52-year period 46 years, in which the flow did not fall below 55,000 second-feet. For these reasons "firm power" is herein defined as power corresponding to a discharge up to 55,000 second-feet for sites below Deschutes River and to discharges up to 50,000 second-feet for all sites above the Deschutes as far as the mouth of Snake River.

623. The above period of shortage in flow would affect only the low-head series of dams. Should one of these low-head series be adopted for developing the power in the Columbia, the combined pondage effect in the pools thus created would practically make up for this shortage and bring the low flow to a figure very close to 55,000 second-feet at The Dalles. If, furthermore, the uncertainty regarding the extreme low water flows due to ice conditions (see par. 95) is considered, it will be seen that the assumed flows governing firm power are justified.

624. Secondary power is given under "General data" in the description of each project included in series A and D (see par. 641) and is also shown graphically for the same projects.

625. *The average static head* is the average of the heads for each month during the period from April 1, 1913, to March 31, 1930, inclusive; that is, for each month during the above-mentioned period there is a certain average discharge and a corresponding head. The average of these heads is given as the average static head. A constant forebay level has been assumed for all developments except Warrendale.

626. *Proposed hydraulic capacity* is the maximum amount of water passed by all the installed turbines at rated head.

627. *Power capacity* is the capacity in horsepower as defined by the Federal Power Commission and is the continued product of—

A. The factor 0.08 which represents the horsepower at 70 percent efficiency of 1 cubic foot of water per second falling through a head of 1 foot;
B. The average static head in feet, as defined above, and
C. The water supply, in cubic feet per second available from natural flow or from storage, or from both, for 90 percent of the time.

628. This term is used merely to give a means of comparison between the projects under consideration herein and those over which the Federal Power Commission has assumed jurisdiction.

629. *Plant capacity factor* is the ratio between mean plant output for the period under consideration and the installed capacity.

630. *Load factor.*—This is defined as the ratio of average load to maximum load carried by the plant in any stated time.

631. *Carrying charges.*—It is not anticipated that a capacity load will be available at time of completion for any of the power developments considered in following pages. It is reasonable to suppose that, for several years after construction, the return from any large Columbia River power plant will be insufficient to pay interest, depreciation, amortization, operating, and all other charges, and that it will be necessary to make up the deficiency by additional capital investment. This expenditure, here designated as "carrying charge", is as much a part of the cost of the plant as is money expended for construction or equipment and should be included as a part of the investment.

632. In order to compare all sites on the same basis, the carrying charge is calculated on the assumption of each plant coming into operation in 1940 and that 50 percent of the total growth in power demand in the Pacific Northwest, as shown by curve on plate 114,[2] will come to the plant until it is carrying full load.

633. This assumption is conservative, as it is reasonable to suppose that it would be possible to divert to any large new plant constructed at a central point on the Columbia more than 50 percent of the growth in total load. For comparison, estimates also have been prepared on the assumption that 100 percent of the growth in load is absorbed by any one project.

634. *Interest.*—Interest, both during construction and in calculating fixed charges after plant is in operation, is figured at 4 percent per annum for public development and 6 percent per annum for private development.

[2] Not printed.

635. *Depreciation.*—Depreciation is allowed for dams and all structural features, but not for property damages. This is figured on a 4 percent and 6 percent sinking-fund basis for public and private developments, respectively. Dams are estimated as having a useful life of 100 years and all other structural features 30 years. The annual depreciation reserve, expressed as a percent of invested capital, follows:

Dams, 100-year life, 4 percent money, 0.081 percent of invested capital.
Dams, 100-year life, 6 percent money, 0.018 percent of invested capital.
Other features, 30-year life, 4 percent money, 1.78 percent of invested capital.
Other features, 30-year life, 6 percent money, 1.27 percent of invested capital.

636. *Taxes.*—No tax is figured for plants constructed by the public. An item of 1½ percent per annum on invested capital is included among the fixed charges for plants constructed by private capital.

637. *Amortization.*—An item sufficient to retire the invested capital in 40 years, based on 4 percent interest charge, is included as an item in fixed charges for public plants. The annual charge on this basis would amount to 1.05 percent on capital invested. No amortization item is included in the fixed charges for private developments.

638. *Unit prices.*—The following figures show the range of unit prices used in estimating the cost of the several proposed developments on Columbia River below mouth of Snake as regards some principal items.

| | |
|---|---|
| I. Dams: | |
| Excavation above stream level: | |
| 1. Common | 30 to 40 cents per cubic yard. |
| 2. Loose rock | 35 to 45 cents per cubic yard. |
| 3. Solid rock: | |
| *a.* Mass | 80 cents to $1.50 per cubic yard. |
| *b.* Rock excavation for structure | $2 to $3.50 per cubic yard. |
| Excavation below stream level: | |
| 1. Common | 35 to 50 cents per cubic yard. |
| 2. Loose rock | 40 to 55 cents per cubic yard. |
| 3. Solid rock: | |
| *a.* Mass | 80 cents to $1.50 per cubic yard. |
| *b.* Rock excavation for structure | $2 to $3.50 per cubic yard. |
| 4. Cut-off trenches and abutments: | |
| *a.* Common | $2 to $4 per cubic yard. |
| *b.* Rock | $4 to $5 per cubic yard. |
| Drilling and grouting | $3 per linear feet. |
| Dredging: | |
| *a.* Sand and gravel, difficult | 35 to 40 cents per cubic yard. |
| *b.* Suction and large job | As low as 10 cents per cubic yard. |
| Concrete: | |
| 1. Mass concrete, 4 sacks of cement per cubic yard of concrete. | $5 to $8.50 per cubic yard. |
| 2. Mass concrete, 5 sacks of cement per cubic yard of concrete. | $6 to $9.50 per cubic yard. |
| 3. Reinforced concrete in crest and piers (including reinforcement steel). | $12.50 to $15 per cubic yard. |
| 4. Reinforced concrete in power house substructure, used only where the power house is built as an integral part of the dam. | Do. |
| 5. Miscellaneous superstructure (thin walls). | $25 to $50 per cubic yard. |

| | |
|---|---|
| Structural steel: | |
| 1. Spillway gates and fittings | 10 to 15 cents per pound. |
| 2. Gate operating equipment | 20 to 25 cents per pound. |
| 3. Miscellaneous structural steel (including operating bridges). | 7 to 20 cents per pound. |
| 4. Miscellaneous | Listed as needed. |
| II. Power house: | |
| Excavation | Subdivisions and unit prices. (See I.) |
| Concrete | $12.50 to $15 per cubic yard. |
| Trash racks and guides | 10 cents per pound. |
| Gates and seats | 10 to 15 cents per pound. |
| Operating equipment (hoists, crane, mechanical rake). | 20 to 25 cents per pound. |
| Penstock steel | 8 to 12 cents per pound. |
| Power house superstructure | 20 to 35 cents per cubic foot (cubical content of outside dimensions). |
| Hydraulic equipment, including governors and all auxiliary water wheel equipment. | Manufacturers' quotations. |
| Electrical equipment | Do. |
| III. Contingencies | 10 percent. |
| IV. Overhead (engineering, supervision, clerical, legal, insurance, etc.). | 12½ percent of total of all above items. |
| V. Interest during construction | On basis of 4 percent for public development and 6 percent for private development. |
| VI. Carrying charges | Based on 50 and 100 percent of the power market being absorbed by the project. |

## II. RIVER SECTIONS

### (A) GENERAL

639. An orderly setting forth of the power possibilities of that portion of the Columbia below mouth of Snake River, taking into account public interest, earlier investigations, and nature of problems involved, leads to considering the river in sections as follows:

1. Mouth of Snake to Celilo.
2. Celilo to The Dalles, or The Dalles-Celilo section.
3. The Dalles to Warrendale.

640. The first section of the Columbia River is the 123-mile stretch between the mouth of Snake River and Celilo in which the problems of design and construction are largely the same regardless of the particular points selected for development. The second and third are the sections in which concentrated falls occur. Plate 48, "Power site index", shows a plan of the Columbia River from the mouth of Snake to the ocean and a river profile for the same stretch. The sites investigated and other principal points are also shown on that plate.

641. For the complete utilization of the power resources below mouth of Snake five distinct combinations or series of dams are discussed. The following tabulation lists, according to series, each site and its respective upper-pool elevation:

| Series | Site | Pool elevation | Series | Site | Pool elevation |
|---|---|---|---|---|---|
| A | Umatilla | 330 | C | Arlington | 330 |
| | John Day | 258 | | The Dalles | 183 |
| | The Dalles | 150 | | Warrendale | 54 |
| | Warrendale | 54 | D | The Dalles | 330 |
| B | Umatilla | 330 | | Warrendale | 54 |
| | Arlington | 258 | E | John Day | 330 |
| | The Dalles | 183 | | The Dalles | 150 |
| | Warrendale | 54 | | Warrendale | 54 |

642. Each of the series utilizes the full fall in the river from elevation 330, at a point about 15 miles above the mouth of Snake, to tidewater, elevation 4, at Warrendale, making a total natural fall of 326 feet at mean low water. These series are shown on plate 49.

643. It will be noted that the first two series would call for comparatively low dams with pools too small for seasonal storage. In this series the effect of pondage for daily regulation only has been taken into consideration. In the three remaining series storage would raise the firm power not only for the particular project itself but for all those below it.

644. The effect of storage in the upper Columbia after complete regulation of the river is realized as beneficial to any project on the lower river. The extra units to develop the additional power from increased low-water flows have not been included in any of the estimates. The effect on the amount of power available, however, from storage on the upper river has been computed for the comprehensive plan of development, as shown in paragraph 1412.

645. In the following description of each site complete estimates are given only for the projects which are included in the comprehensive plan of development, which is series D, and for the low-head developments as included in series A. All estimates given are based on a 50 percent load factor and on the assumption that 50 percent of the increase in power market in the Pacific Northwest would be absorbed by any of the projects beginning in 1940 (par. 1420). Interest during construction and carrying charges are based on 4 percent money.

646. Estimates, not given in this report, have been prepared for all projects included in the five series where consideration has been given to load factors up to 100 percent; to carrying charges based on a 50 and a 100 percent power market factor and to 4 and 6 percent money. Unit costs in mills per kilowatt-hour have been derived from those estimates and are shown graphically on plates 95[2] to 100[2], inclusive.

647. For projects estimated the cost of transmitting power to Portland, Oreg., as load center, has been given in tabulation following the general estimate.

### (B) Section 1. Mouth of Snake to Celilo

648. *General.*—The confluence of Columbia and Snake Rivers, 324 miles from the mouth of the Columbia, and Celilo 201 miles from the mouth, mark the upper and lower limits of the Snake-Celilo section of Columbia River. The stream, for about one half of its course through this section, flows in a canyon or open gorge. This canyon portion is in two stretches, the upper extending from Wallula, Wash.,

[2] Not printed.

nearly down to Umatilla, Oreg., a distance of about 20 miles, and the lower from the vicinity of Arlington to Celilo, Oreg., a distance of 41.5 miles. Basaltic rock is found almost continuously along the banks and at many points in the channel in these two sections and also appears at several points in the more open sections. Foundation conditions are, therefore, favorable for the building of dams and power plants.

649. *Natural fall.*—The elevation of water surface, at time of mean low water, at mouth of Snake is 313 and at Celilo 127, showing a total fall of 186 feet in 123 miles. The record flood of 1894 stood at elevation 342 at mouth of Snake and 160 at Celilo, showing a fall of 182 feet.

650. *Natural flow.*—A study of the records for the Columbia below mouth of Snake shows that the year of best sustained flow, considering power output, was from April 1, 1927, to March 31, 1928, and that the least favorable year was from April 1, 1929, to March 31, 1930. Tabulation showing natural flow for various percents of time for the 17-year period from April 1, 1913, to March 31, 1930, is given in paragraph 570. The figures apply to a point just above mouth of Deschutes River, but the inflow is so small during much of the year that they may be used, with small error, for computing the power at any site as far up as mouth of Snake.

### 1. EARLIER INVESTIGATIONS

651. *Proposed navigation dams.*—The district engineer, Portland, Oreg., under date of November 29, 1922, submitted to the Chief of Engineers, a report entitled "Columbia River, Celilo Falls to Snake River; Snake River, mouth to Pittsburg Landing; Clearwater River, mouth to Orofino." This report sets forth a plan for securing slack-water navigation, Celilo to mouth of Snake River, by the construction of five dams. The five dam sites considered in the report, listed in order downstream, together with elevations of pools and head available at low water, follow:

| No. | Location | Miles from mouth | Elevation: Lower pool (low water) | Elevation: Upper pool (low water) | Head in feet (low water) |
|---|---|---|---|---|---|
| 1 | Homly Rapids | 318 | 295 | 330 | 35 |
| 2 | Middle Umatilla Rapids | 292 | 254 | 295 | 41 |
| 3 | Canoe Encampment Rapids | 264 | 210 | 254 | 44 |
| 4 | Four O'Clock Rapids | 232 | 165 | 210 | 45 |
| 5 | Biggs Rapids | 207 | 131 | 165 | 34 |

| | |
|---|---|
| Average low-water head ... feet | 40 |
| Total installed capacity ... horsepower | 900, 000 |
| Total estimated cost as for 1922 prices | $98, 988, 000 |

652. As stated in report by district engineer:

> The spillway crests of the five dams would be from 5 to 16 feet above low water, depending upon location of railroads above low water. The pool levels are to be maintained by means of Stoney type sluice gates about 28 feet high and 40 feet wide to give a clear opening of 38 feet between piers of the spillway crest.

653. *Alternate series—Low dams.*—The same report lists a series of proposed low dams, for the most part of fixed crest type, but with limited control gate capacity, planned to secure slack-water navigation at time of low water, from Celilo on Columbia River to Five Mile Rapids in Snake River. The locations of these proposed low dams, together with elevations of pools and head available at low water, follow:

| No. | Location | Miles from mouth | Elevation | | Head in feet (low water) |
|---|---|---|---|---|---|
| | | | Lower pool (low water) | Upper pool (low water) | |
| 1 | Mouth Snake River | 324 | 313 | 328 | 15 |
| 2 | Homly Rapids | 318 | 294 | 311 | 17 |
| 3 | Middle Umatilla Rapids | 292 | 254 | 282 | 28 |
| 4 | Devils Bend | 285 | 236 | 254 | 18 |
| 5 | Alder Creek | 257 | 203 | 225 | 22 |
| 6 | Owyhee Rapids | 239.5 | 174 | 200 | 26 |
| 7 | Squally Hook | 222.5 | 152 | 174 | 22 |
| 8 | Biggs Rapids | 207.0 | 131 | 150 | 19 |

Average low-water head ........ feet .. 21
Total installed capacity ........ horsepower .. 760,000
Total estimated cost as per 1922 prices ........ $117,360,000

2. PRESENT INVESTIGATION

654. *Plans for development.*—The present investigation has included geological examination, exploration drilling, and topographic and hydrographic surveys at the more favorable dam sites in the Columbia between the mouth of Snake and Celilo. The sites at which one or more of these operations were carried on, listed in order downstream, are:

Homly Rapids
Wallula power site
Umatilla Rapids
Canoe Encampment Rapids
Arlington power site
Blalock Rapids
Four O'Clock Rapids
Squally Hook Rapids
John Day Rapids
Biggs Rapids

655. These are taken up in order. A description of the investigation at each is given; and, for the more favorable sites, alternate plans for development and estimates of cost are included.

656. *a. Homly Rapids site—Location.*—Homly Rapids, the first dam site on the Columbia below mouth of Snake River, is 318 miles from mouth of the Columbia. It is 10 miles downstream from the cities of Pasco and Kennewick, Wash., and 225 miles from Portland, Oreg., by the line of the Spokane, Portland & Seattle Railway, which passes close to the river on the west or right bank. The Northern Pacific branch from Pasco, Wash., to Pendleton, Oreg., and the Union Pacific Railroad Co.'s branch from Wallula to Yakima, Wash., pass within about 1 mile of the site on the east or left bank. The elevation of water surface at time of low water is 295 and at time of record flood about 325. A map of this site is shown on plate 50.[2]

657. *Geology and test borings.*—Mr. James Gilluly, geologist of United States Geological Survey, as a study in connection with present investigation, made an examination of Columbia River dam sites

[2] Not printed.

below mouth of Snake in fall of 1929. His report relative to Homly Rapids is quoted as follows:

Excellent foundation bedrock occurs on the west extremity of the proposed site opposite Island No. 7 and will probably be found at moderate depths across the river and on the east bank. However, there is no sign of bedrock at the surface on the east side and it probably does not rise in elevation to the proposed flow line of the dam for a considerable distance, perhaps as much as 2,000 feet back from the bank. This will probably necessitate a long cut-off wall. The present surface is formed by gravel and sand of river deposition proving the existence of a former channel beneath the present bank. However, because of the great width of the valley at the site, it is extremely unlikely that such a channel will be found to be deeper than the present river channel. It will probably prove shallower. It is suggested that holes be drilled on the east bank at intervals of 200 feet until bedrock is found to rise to within 5 to 10 feet of the proposed flowline. The gravel forming the present bank would certainly not hold any great water pressure and would probably not serve as an earth dam except with a cut-off wall to bedrock.

No similar drilling will be necessary on the west bank as bedrock is evident at the surface.

Attention may be appropriately called to the fact that elevating the river surface 30 feet here will affect agricultural lands over a much wider area than that flooded. By raising the permanent water table 30 feet subsoil water will be impounded and render alakline considerable land in the Kennewick and Two Rivers areas that is now well drained and arable.

658. Two diamond drill holes were put down at the Homly Rapids site, subsequent to geologic examination by Mr. Gilluly. Hole no. 1 near water's edge on west, or right, bank, at elevation 303.48, was drilled to a depth of 117 feet. The upper 3 feet were in sand and gravel; the next 35 feet in dense, hard jointed basalt; the next 43 feet in compact volcanic ash yielding a low percentage core, and the bottom 36 feet in cellular to dense, firm basalt. Hole no. 2, near water's edge on east, or left, bank, at elevation 308.7, was drilled to a depth of 143.3 feet; the upper 18 feet in sand, gravel, and boulders; the next 37 feet in firm basalt; the following 13 feet in blue clay; the next 38 feet in probably the same layer of ash penetrated in hole no. 1, yielding low core; and bottom 37 feet in hard gray basaltic lava.

659. *Plans for development.*—The dam as proposed in the report of the district engineer (par. 651) would have a height of 35 feet above low water, with pool at elevation 330. This would raise the low water level at mouth of Snake 17 feet and create a pool that would extend up the Columbia for a distance of 21 miles; to a point 11 miles above Pasco, and up the Snake River to foot of Five Mile Rapids.

660. *b. Wallula Power Site—Location.*—Below Homly Rapids, the Columbia flows between low sand and gravel banks and over a sand and gravel bottom for a distance of 5 miles to Wallula at mouth of Walla Walla River. Immediately below this point the Columbia enters a rockbound gorge known as Wallula Gap, or the Wallula Gateway. On both banks basaltic cliffs, one above another, rise to a height of nearly a thousand feet, and extend from mouth of Walla Walla River downstream a distance of about 8 miles, to Juniper Canyon, which drains into the Columbia from the south. The average width of the gorge from rim to rim is slightly over a mile. The Union Pacific Railroad on the east, or left, bank, and Spokane, Portland, and Seattle Railway on the west bank, have carried their tracks along the river through the gorge without excessive excavation. Surveys have been made and construction started to extend the Columbia Highway, on the left bank, between the Union Pacific tracks and the cliffs, from Umatilla through the gorge to Wallula.

661. Several points in the 8-mile Wallula gorge offer very favorable conditions for building high dams. Of these mention may be made of (1) the site at the entrance to the gorge, (2) that near Yellepit station on Spokane, Portland, and Seattle Railway 3 miles below entrance, and (3) the site just below Juniper station on Union Pacific Railroad 6 miles below entrance. At all of these sites bedrock extends out on both sides a considerable distance from the base of the cliffs. The site at entrance to the gorge was selected for special study in this investigation for the reason that bedrock out-croppings appear in channel when river is at low stages. The narrow width of the gorge at this site, however, is such that it would be necessary to locate the power house at an angle with spillway in order to secure room for the required number of units. For this reason it is possible that more extended exploratory drilling may show that a more economic development can be made at the Yellepit or Juniper station sites, where the width between bluffs is sufficient to admit of locating spillway and power house sections of dam on a tangent.

662. The selected site is 1 mile downstream from Wallula, Wash.; 313 miles from mouth of Columbia; 209 miles from Portland by line of Union Pacific Railroad on east, or left bank, and 216 miles from Portland by Spokane, Portland & Seattle Railway, on west bank. At low water the river stands at elevation 290 and at peak of record flood (1894) it stood at about elevation 325. A map of this site is shown on plate 52.[2]

663. *Geology and test borings.*—The basaltic bedrock exposed in the abutting cliffs at points along water's edge on both banks and in the channel seems excellently suited for supporting a high masonry dam. This opinion is borne out by the knowledge gained from a study of the records and an inspection of the core from one test hole drilled at the site. This hole, located near water's edge on left, or east, bank (see plate 51)[2] a short distance below mouth of Walla Walla River, was started in exposed bedrock at elevation 304.5, and drilled to a depth of 127.5 feet, all in excellent basaltic rock yielding a high-percentage of core. No open seams were struck, and below depth 17.5 feet, which is apparently a contact between two lava flows, the drill water was returned in full volume at all times.

664. *Plans for development.*—Two plans have been considered for developing power at the Wallula site. The first proposes a dam which would raise the water to elevation 400, give a static head at low water of 110 feet, and create a pool extending to foot of Priest Rapids, a distance of 84 miles. The second would raise the water to elevation 550, give a low water head of 260 feet, and create a pool extending to foot of Rock Island Rapids, a distance of 140 miles.

665. *a′. Wallula development to elevation 400.*—The general plan for the Wallula development to elevation 400 would be similar to that for development to elevation 550 as given in succeeding paragraphs. Several of the more important facts relative to development to elevation 400 follow:

| | |
|---|---|
| Drainage area ---------- square miles -- | 213, 200 |
| Area of pool ---------- acres -- | 107, 400 |
| Length of pool ---------- miles -- | 84 |
| Natural mean low water elevation ---------- | 290 |
| Maximum effective head ---------- feet -- | 110 |

[2] Not printed.

666. *General property damage.*—The reservoir above the proposed Wallula Dam with crest elevation 400, extending to Priest Rapids on the Columbia and to point near Ford's Landing on Snake River, 34 miles above its mouth, would have a surface area of 168 square miles. It would submerge the towns of Wallula, Pasco, Kennewick, and Richland, and practically all the irrigated lands contiguous thereto as embraced in the following incorporated districts: Attalia and Burbank Irrigation Districts, on east bank of Columbia below mouth of Snake; Franklin County Improvement District No. 1, between Columbia and Snake Rivers, adjoining Pasco; Columbia Irrigation District and Highland Water Users Association tract, which extends along west bank of Columbia from point several miles below Kennewick to a point several miles above Richland.

667. *b'. Wallula development to elevation 550—General.*—The Wallula power site, based on inspection of surface rock and information as to subsurface conditions gained from the one test hole put down, seems as adequate to support a dam with crest at elevation 550 as one to elevation 400 as just considered.

668. The crest elevation of 550, which corresponds to tailwater level of the power plant being constructed at Rock Island, is taken somewhat tentatively. The backwater curve has not been calculated; but the great width of lake and resulting large cross section indicate that the slope, for most of the distance, will be very flat.

669. *Dam.*—The dam would be of concrete, gravity type, and extend normally across the channel. For most of its length it would be a spillway section with roller crest gates to control the water level. The great fall and large volume of water passing the dam at time of flood would necessitate a liberal allowance in the estimate for the construction of a baffle weir, or weirs, to dissipate the enormous energy of the falling water. It would be necessary to construct a low concrete nonoverflow section to close the saddle through which the county road now passes at a point some 1,500 feet easterly from end of main dam.

670. *Power house and equipment.*—The power house would be located on the Washington shore and parallel with the stream. It would extend downstream from the westerly end of the spillway. The length of the power house would be about 3,200 feet. There would be installed 44 units, rated at 100,000 kilowatts at a head of 260 feet. This installation would carry a peak load of 3,400,000 kilowatts at 50 percent load factor.

671. A drawdown of 40 feet would give a total of 16,000,000 acre-feet of useful storage. Utilizing this storage, 1,700,000 kilowatts could be constantly produced at the Wallula site with present river elevations as tailwater levels. Considering dams below Wallula, with controlled water levels to elevation 330, the continuous output at the Wallula site would be 1,450,000 kilowatts.

672. *Navigation locks.*—The navigation locks would be located along the west shore and enter the pool at downstream end of power house.

673. *General property damage.*—The reservoir for Wallula development to elevation 550, extending to foot of Rock Island Rapids in Columbia and to a point about 12 miles above Riparia on Snake River, would have a surface area of 727 square miles. It would submerge, in addition to the towns and irrigated areas already mentioned

as being subject to submergence by a dam to elevation 400, the town of Hanford, the Hanford and White Bluffs irrigation district, and the Priest Rapids power site. Railroads to the extent of approximately 395 miles belonging to Union Pacific; Northern Pacific; Spokane, Portland & Seattle; and Chicago, Milwaukee & St. Paul systems would be submerged and require relocation estimated to cost in excess of $80,000,000.

674. The more important facts relative to Wallula power site, developed to elevation 550, follow:

| | | |
|---|---|---|
| Drainage area | square miles | 213, 200 |
| Area of pool | acres | 465, 000 |
| Length of pool | miles | 140 |
| Natural mean low-water elevation | | 290 |
| Maximum effective head | feet | 260 |

675. *c'. Wallula to Umatilla Rapids.*—From Wallula power site, as described in preceding paragraph, to the site of the proposed Umatilla Dam, is 21 miles. The Columbia, in the first 8 miles of this distance, or to mouth of Juniper Canyon, flows through a gorge having an average width of slightly over 1 mile and average depth of about 750 feet. Below mouth of Juniper Canyon for a distance of about 1 mile, the side slopes are steep, somewhat similar to those in the gorge above, though not so high. From this point down, rolling hills, steeper and higher on Washington than on Oregon side, take the place of the precipitous rock cliffs characteristic of the gorge above. The river flows with a generally even current over a sand and gravel bottom with only an occasional outcropping of rock until swift water is encountered at upper limit of Umatilla Rapids.

676. *d'. Umatilla Rapids site—Location.*—The Umatilla Rapids site is located about 3 miles above the town of Umatilla, Oreg., and 292 miles from mouth of Columbia. It is 186 miles from Portland by the line of the Union Pacific system on south and 195 miles from Portland by line of Spokane, Portland & Seattle Railway on north bank. The Columbia in a distance of about 3 miles has a fall of about 17 feet in what are designated on channel maps as upper, middle, and lower Umatilla Rapids. The greater portion of this fall occurs above the point generally accepted as the best for building a dam which is near foot of lower Rapids. At this point rock shows above water at many places during ordinary stages, and the site long has been considered one of the most favorable for the development of power in the Columbia below mouth of Snake. A map of Umatilla Rapids site is shown on plate 53 [2] and the plan of development on plate 55. The exploration drilling is given on plate 54.[2]

677. *Geology and test borings.*—The United States Bureau of Reclamation, which investigated this site in 1923, put down 24 exploration drill holes at Umatilla Dam site to depths varying from 15 to 195 feet. Twenty of these were located within what may be considered the high-water limits of the stream and four in adjacent flat on Oregon side. Of the 20 put down within the high-water limits of the stream, 5 were started in exposed bedrock and 15 in an overburden of sand, gravel, and boulders, that ranged in depth from 4 to 25 feet, the average being 7 feet. One hole was discontinued at a depth of about 6 feet in overburden without reaching bedrock. Bedrock was struck in 4 holes put down on Oregon shore after going through overburden

[2] Not printed.

to average depth of 20 feet. Basalt was struck in all of the 23 completed holes at depths of 1 to 50 feet below mean low-water surface, or at elevations varying from 252 to 203 feet above sea level. In four of these, volcanic tuff was penetrated after drilling 35 to 60 feet in basalt. In three of these, basalt was reached again after drill had passed through 30 to 60 feet of tuff. One hole was discontinued after drilling 80 feet in basalt and 12 feet in tuff, and in one hole an artesian flow amounting to 40 gallons per minute was tapped at depth of 170 feet at contact between tuff and the underlying basalt.

678. Mr. Kirk Bryan, geologist of United States Geological Survey, made an examination of the Umatilla site for the United States Bureau of Reclamation in December 1923. His report is quoted as follows:

> The area of the dam site is underlain by basalt and tuff in essentially horizontal beds. If these beds have a dip, it is so slight that it can be detected only by extensive drilling. The essential facts to be learned from drilling operations are, however, the thickness, quality, and type of contact between the several beds that occupy or underlie the dam site. In the banks of the river is exposed a basalt flow that may be called "No. 1 flow." On the Oregon shore the base of this bed is exposed at low water at elevations varying from 260 to 250 feet. The islands of the river are formed from a lower flow that may be called "No. 2 flow." The contact between the two flows on the Washington shore is concealed by soil and gravel at the end of the proposed dam but rises to the west and is exposed in the railroad cut at elevations of 300 to 310 feet.
>
> No. 2 flow is a thick massive body of lava. This fact is demonstrated by holes nos. 1 and 4, which penetrated 104 and 123 feet, respectively, of this flow. On a general argument we may reach the same conclusion, for had the flow not been peculiarly thick, massive, and resistant to erosion, Umatilla Rapids would not exist.
>
> It is believed that this flow will form an adequate foundation for a dam of the proposed height, provided that a reasonable thickness can be demonstrated under every part of the structure.
>
> No. 2 flow is underlain by a tuff bed, and this bed is in turn underlain by another flow, no. 3. The tuff bed has been penetrated by holes nos. 1, 4, and 7. The thickness in no. 1 hole is 48 feet and in no. 4 hole is 25 feet. (The thickness in no. 7 hole was later found to be 57 feet.) The tuff is a gray, black, blue, or green rock. It is compact and sufficiently cemented to ring when two pieces are struck together. The upper 3 feet of the tuff in hole no. 4 was decomposed to a blue clay. The upper surface of the tuff is not uniform. In hole no. 7 the upper surface is 25 feet above its level in hole no. 1 and this in turn is 22 feet above the level in hole no. 4. These holes are, however, 800 to 1,800 feet apart. The base of the tuff is exposed only in holes nos. 1 and 4, but here it shows a similar but smaller difference in elevation amounting to 9 feet. (The bottom of the tuff in hole no. 7 was later found to be 35 feet and 16 feet above that in holes nos. 4 and 1.)
>
> These irregularities in thickness and position of the tuff are to be expected. The top of flow no. 3, as shown by the drill cores, is either not vesicular or has only scattering vesicles. It was evidently subjected to erosion before the deposition of the tuff. The tuff was deposited in water, as shown by its lamination, but its base conforms to erosional irregularities in the underlying flow no. 3. The irregularities of the top of the tuff may also be due to erosion preceding the outflow of the overlying basalt. In its molten flow over unconsolidated fine-grained sediments, basalt will make irregularities and will catch up and engulf the underlying soft materials. Irregularities of 5 and 10 feet, produced in this manner, have been observed in the Columbia plateau. Some of this irregularity of the top of the tuff may be explained in this manner.

679. The exploratory drilling undertaken by the United States Bureau of Reclamation has been considered sufficient for the present investigation.

680. *a. Earlier investigations—United States Bureau of Reclamation plan.*—The Umatilla Rapids Association was organized at Umatilla and Pendleton, Oreg., in the early part of 1921 for the purpose of

promoting the building of a dam and power plant at Umatilla Rapids. Some money was raised and a preliminary survey of the site made in the spring of the same year by Lewis & Clark, engineers, of Portland, Oreg. The report (unpublished) prepared by this firm showing the site to be a favorable one, the Umatilla Rapids Association, with cooperation of other civic organizations, secured an appropriation of $10,000 by the Oregon Legislature and $50,000 by Congress for a comprehensive study of its possibilities. This study was made by the United States Bureau of Reclamation in 1923, E. R. Crocker, engineer, in charge. The field work, in addition to a survey and diamond-drill exploration of the dam site, covered extensive surveys or arable lands which were considered possible of irrigation by pumping with power from proposed development.

681. As a result of this investigation, a bill was introduced in the Seventieth Congress calling for an appropriation of $45,000,000 to build the dam and power plant, the Government to be reimbursed for both principal and interest through the sale of power. Similar bills have been introduced in subsequent sessions, but none of these has as yet come to a vote.

682. The plan for development as worked out by the United States Bureau of Reclamation proposed a dam near foot of Lower Umatilla Rapids, 3 miles upstream from the town of Umatilla. The elevation of water surface at low water at this point is about 253 and at record flood about 283. The plan of development proposed a dam with crest at elevation 310.5. This would give a static head at low water of 57.5 feet and at time of record flood about 27.5 feet. The dam was planned as a tangent, a concrete portion next to the Washington shore to constitute the power-house section, a concrete portion fitted with regulating gates across the main channel to constitute the spillway, and an earth section to extend across the low ground flanking the river on the Oregon side. It was proposed to install 34 propeller-type water wheels each of a capacity of 28,000 horsepower when operating under 56-foot effective head. Each wheel would be direct connected to a 25,000 kilovolt-ampere generator.

683. *b′. Present investigations—Plan for development.*—The present investigation of Umatilla Rapids site has resulted in working out plans for constructing at the point selected by the engineers of the United States Bureau of Reclamation a dam which will raise the water to elevation 330, or to a height 19.5 feet greater than that proposed in the Reclamation report. (See plate 55.)

684. *Dam.*—The river portion of dam would be built of concrete, gravity type. The spillway section would extend from Oregon shore normally across main channel and have a length of 2,180 feet. It would consist of a rollway with crest at elevation 300 on which would be seated 15 roller-type gates, each 130 feet long by 30 feet deep. The piers between gates would be 16 feet thick and extend up to and support a steel operating bridge at elevation 340.

685. From northern limit of spillway portion of dam, and deflecting about 60° downstream, the power-house section would extend a distance of 1,300 feet to a connection with the walls for navigation lock and fishway. Northerly from the locks a low-gravity type non-overflow section would extend to point where bedrock rises above pool level 1,900 feet to the north.

686. From the southern or Oregon end of the spillway an earth embankment section would extend southerly across the flat, a distance of about 1,800 feet. It would have a maximum height of 50 feet and would be constructed with concrete cut-off extending to bedrock.

687. *Power house and equipment.*—The power house, as shown on plate 55, forms part of the dam. It would be 1,300 feet long. There would be installed 14 units, rated at 65,000 kilowatts at a head of 68 feet. This installation would carry a peak load of 500,000 kilowatts at 50 percent load factor. The turbines would be of the adjustable blade propeller type. The installation is based on assumption of tail water being at elevation 260, which would result from constructing the next dam below to elevation 258, plus an allowance of 2 feet for slope in lower pool at time of low water. This raising of tail-water level results from desirability of deepening pool that river craft may gain access to the locks past the Umatilla Dam without encountering excessive current velocities.

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

689. *Navigation locks.*—The navigation canal would be constructed along the Washington shore and would consist of tandem locks which would extend from lower entrance directly to pool above power house. The depth and chamber dimensions of locks would be as specified in paragraph 618. The maximum lift with river at extreme low stage would be 76 feet, of which 28 feet would be made in lower and 48 feet in upper chamber. Provisions would be made for the construction of a parallel set of locks on the land side of those here described.

690. *Fishways.*—Two concrete fishways conforming to specifications in paragraph 610 would be provided, one at northerly end of spillway and the other between northerly end of power-house section and navigation locks, next to Washington shore.

691. *General property damage.*—The pool created by the dam would extend up the Columbia a distance of 47 miles, or to a point 15 miles above the mouth of Snake, and to foot of Five Mile Rapids in Snake River, 5 miles from the mouth. A total of about 3,000 acres of tillable land, or land occupied by homes, would lie below pool level. This, for the most part, is in an L-shaped area just above mouth of Walla Walla River. In this area is the town of Wallula. One plan for taking care of the damages would be to buy the property and move the town and railroad yards at Wallula to higher ground. An alternate plan would be to protect the low area by levee. The levee would have to extend along both the Columbia and the Walla Walla. In any event, the yard tracks would have to be raised to conform to the new main-line grades. For these reasons it is estimated that the cheaper plan, based on present values, would be to buy the property and move the town.

692. *Revision of railroads and highways.*—Constructing a dam at the Umatilla site with pool level at elevation 330 would make necessary the revising of 62 miles of railroad, assuming that profile grade of railroad be maintained at 10-foot elevation above water surface in pool. A portion of this revision may be accomplished by raising the track, but some will involve relocation. The revision of the main line of the Union Pacific Railroad would begin at a point about 1 mile west of dam site and terminate at a point about 2 miles east of Wallula, a distance of 27 miles. Two summits in this distance would reduce the