II. Discussion

A. GENERAL DESCRIPTION OF COLUMBIA RIVER AND ITS BASIN

34. Columbia River is about 1,210 miles long. Four hundred twenty-five miles of its course is in the United States between the international boundary and the mouth of Snake River, and 323½ miles between the latter point and the Pacific Ocean. (See pl. I, entitled "Columbia River Basin.") Its basin has an area of about 259,000 square miles, including about 39,000 square miles in Canada. About 64,000 square miles of the Columbia's basin above the Snake lies within the United States and embraces all of Washington east of the Cascade Range except the southeastern corner, northern Idaho, and Montana west of the Rockies. The basin of the Snake, the longest tributary of the Columbia (1,036 miles), covers about 109,000 square miles, embracing the extreme western part of Wyoming, southern Idaho, eastern Oregon, southeastern Washington, and small parts of Utah and Nevada. Below the mouth of the Snake the basin of the Columbia includes about 46,500 square miles in Washington and Oregon. About 27,000 square miles of this area lies between the Snake Basin and the Cascade Range, about 1,000 square miles through the Cascades and 18,500 square miles west of the Cascades. About 11,000 square miles of the last-mentioned area is in the basin of Willamette River.

35. Three principal systems form the headwaters of the Columbia River: First, the Columbia River proper, which, rising in Columbia Lake in British Columbia near the international boundary, flows northwesterly for nearly 200 miles then turns abruptly to the west and south, circling Selkirk Range, and enters the United States at the northeastern corner of Washington; second, Kootenai River (spelled Kootenay in Canada) which also rises in British Columbia near the source of the Columbia proper, but flows in an opposite direction (southeasterly), paralleling the Continental Divide, enters the United States at the Idaho-Montana-British Columbia corner for a short curved course of 167 miles, and empties into Columbia River proper about 30 miles north of the international boundary after flowing through Lake Kootenay in Canada; and third, Clark Fork, which, with its tributaries, drains the strip of Montana between the Continental Divide and Idaho. Clark Fork rises in western Montana, flows northwest between the Continental Divide and Bitterroot Mountains, crosses the panhandle of Idaho and the northeast corner of Washington, and, after a short course in British Columbia, empties into Columbia River very close to the international boundary and a short distance below the mouth of Kootenai River.

36. Columbia River thence flows southwest and south through northeast and central Washington, is joined by Snake River at Pasco, Wash., and a short distance below Pasco turns west, forming the Washington-Oregon boundary to the Pacific Ocean.

37. A description of the Columbia above the mouth of the Snake and of its headwaters and tributaries is given in part 2 of this report, and of the Columbia below the Snake and of its tributaries in that section is given in part 3, and printed in volume II of this document.

38. The outstanding characteristics of the Columbia and its basin are:

(*a*) The great fall in the river, amounting at low water to 975 feet between the international boundary and the mouth of the Snake, and 309 feet from the latter point to tidewater. This condition, with the existence of dam sites and usable low water flow is the basis of a large potential hydroelectric development, but the swift water resulting from the fall makes it adverse to navigation above tidewater.

(*b*) The large area of semiarid country in the basin, partly within economic reach of irrigation waters from the Columbia, a condition that, with the fertility of the soil, offers considerable possibilities of irrigation.

(*c*) The minor extent of area subject to flood damage.

These noteworthy characteristics are treated in detail in the district reports, wherein for the section of the river above the mouth of the Snake and that below, the four subjects of this report, viz: navigation, power development, flood control and irrigation, are discussed in turn and in combination.

Repetition here of the data relating to the basin and the river given in the district reports is unnecessary. Attention is invited to chapter II in each of the district reports (pts. 2 and 3 of the combined report (printed in vol. II of this document) of which this is pt. 1) for detailed physical data.

B. Navigation

39. *General.*—This section of this division report is intended to give a general picture of Columbia River from a navigation point of view. Such matter is included as is pertinent to the discussion of the benefits to navigation that might be conferred by power development of the stream. The subject of navigation is treated in detail in the district reports, parts 2 and 3 of this report, as to, respectively, the section of the Columbia above the mouth of the Snake and the section below. Attention is invited to the district reports.

40. Before any work was done on the Columbia to improve navigation conditions the entrance into the river from the sea was obstructed by a shoal across which there were one or more channels with unstable depths up to about 20 feet at mean lower low water. The channels were unstable also as to position; they shifted between Cape Disappointement on the north and Cape Adams on the south, a distance of about 6 miles.

41. The river channel from the entrance to Vancouver, Wash. (mile 105),[1] was, prior to improvement, obstructed by numerous sand bars, through which the channel or channels were comparatively narrow, with depths varying from 10 to 15 feet at low water. Vancouver was then, as now, the head of ocean navigation on the river proper, and Portland on the Willamette.

42. From Vancouver upstream to the foot of Cascade Gorge (mile 143), the head of tidewater, the controlling depth at low water was about 8 feet, adequate for river craft.

43. Through Cascade Gorge and at numerous points above to the international boundary (mile 749) the river in its natural condition was obstructed by falls and rapids. At many places the depth at low water was less than 5 feet. The principal obstructions below the mouth of the Snake (mile 323½) were the rapids, about 5 miles long, in Cascade Gorge (mile 143 to 148) and the falls and rapids between

[1] Distances given thus (mile —), are distances by river above the mouth of the Columbia.

The Dalles, Oreg., (mile 188) and Celilo, Oreg., (mile 200). Priest Rapids (mile 396) was the first of several serious rapids and falls in the Columbia between the mouth of the Snake and the international boundary.

44. Columbia River has been navigated since the early days of explorations in the Northwest. Below Vancouver, which includes the 99½ mile stretch from the sea to the mouth of Willamette River on which Portland, Oreg., is located, seagoing traffic has been continuous since 1792. The improvement of this stretch, below Vancouver and Portland, has been progressive, to keep pace with the growing needs of an important commerce. The works of improvement are described later in this and report in more detail in the district reports.

Above Vancouver (or rather above Camas, Wash., 14 miles above, over which 14 miles there has been and is special traffic in connection with pulp and paper manufacture at Camas) the Columbia has experienced several vicissitudes of navigation.

45. In the days of exploration and of fur trading the Columbia and Snake Rivers were the only highways through the Northwest. Early navigation was by canoes and batteaux, and usually, as to the upper rivers, was carried on during the higher river stages. This form of navigation disappeared many years ago. The next phase of navigation in the upper river was by flatboats, sailed or "lined" uptream and drifted down. With the introduction of steamboats on the rivers in the 1850's flatboat transportation was discontinued.

46. The advent of steamboats led to construction of portage roads past the obstacles to navigation formed by the rapids in Cascade Gorge and between The Dalles and Celilo. At first these two portages were pack roads, then vehicle roads and finally railroads. The one at the gorge was about 5 miles long; that between The Dalles and Celilo about 13 miles. Use of portages and of the river above Vancouver was discontinued temporarily on the completion of a railroad in 1882 along the river from Portland to Wallula, Wash. Later the portage railroads were reconstructed by the State of Oregon pending construction of the two canals, at the Cascade rapids and at the Dalles-Celilo rapids, and were again discontinued on the completion of those canals.

47. The section of the Columbia from tidewater to the town of The Dalles was used for boat service from the beginning of steamboat navigation (1850) to 1923, with one major interruption, 1882 to 1891. In 1923 the service was discontinued as a losing business and has not since been revived.

48. Navigation above the portage between The Dalles and Celilo began in 1858. It was never continuous for any considerable period. It was carried on mostly in combination with navigation of the Snake. Freight service above The Dalles was at its peak during the mining excitement on Clearwater River in Idaho in 1861–64. It was discontinued in 1882 upon the completion of the railroad from Portland along the river to Wallula.

49. Several attempts have been made to restore navigation on the Columbia River and on the Snake but none have been successful even though the Dalles-Celilo Canal, constructed by the United States and completed in 1915, eliminated the last portage. However, no attempts have been made by companies well equipped and financed.

50. The head of through navigation by steamer on the Columbia may be considered to be at Priest Rapids (mile 396). In only one reach above Priest Rapids and below the United States-Canada line, viz: between Wenatchee (mile 465) and Bridgeport, Wash. (mile 542), has navigation by steamer been more than an occasional trip or short series of trips. In this reach the river had been improved by the removal of obstructive rocks from the channel and was used for transportation for a number of years prior to the completion in 1913 of the railroad from Wenatchee to Brewster, at the mouth of Okanogan River, 10 miles below Bridgeport, where the railroad leaves the Columbia and goes up the Okanogan Valley. A boat line, operating launches, the only boats now in service on Columbia River above the Snake and below the international boundary, operates in the upper end of this Wenatchee-Bridgeport section, from Pateros on the railroad 7 miles below Brewster, to Bridgeport, about 20 miles by river above Pateros. These boats serve the farmers along a stretch of river which is not provided with rail facilities, and move by launch or barges towed by launch, small quantities of agricultural products and general merchandise.

51. The continuous navigation of the Columbia below Portland, Oreg., and Vancouver, Wash., and the intermittent navigation above Vancouver, led to various Federal projects for improvement of sections of the river.

52. At the mouth of the Columbia the original project, adopted in 1884, contemplated a channel 30 feet deep at mean lower low water, to be obtained by a south jetty 4½ miles long. Active construction work occurred during the period April 1885 to October 1895. Later, under the present project for a low-water depth of 40 feet and a width of not less than one half mile, the south jetty was lengthened to about 7 miles, and a north jetty, 2½ miles long, terminating 2 miles north of the end of the extended south jetty, was built. All the jetty work was completed in 1918. A depth in excess of the project depth and a width of at least one half mile were secured and have been continuously maintained by the jetties. Dredging was carried on prior to the completion of the jetties and will be done again as required to supplement the jetty action.

53. Some relief dredging was done as early as 1866 at various bars in the river above the mouth and below Portland and Vancouver for the aid of sea-going traffic. The original regular project for improvement below Portland, approved in 1877, has been followed by modifications from time to time. The first regular project contemplated a depth of 20 feet at low water to be obtained by means of dikes and revetments. Later, in 1892, the project was modified to provide for a depth of 25 feet. In 1912 the channel project depth was increased to 30 feet. The latest revision was in 1930 when the project dimensions of 35-foot depth and 500-foot width were adopted. Various acts of Congress related to the Columbia Channel between the Willamette River and Vancouver and have resulted in a present project for a channel 25 feet deep and 300 feet wide.

In the various projects in the lower Columbia and at its mouth the Port of Portland has made substantial contributions of funds and work. The Port of Vancouver has assisted in the section of the Columbia between the mouth of the Willamette and Vancouver (4½ miles).

There has never been a project for improvement of the Columbia between Vancouver (mile 104½) and the head of tidewater (mile 143).

54. From the head of tidewater to the head of the Cascade Gorge (about 5 miles) the river has a fall of 37 feet at low water. The main rapids at the head of the gorge presented a complete obstruction to navigation. A project was adopted in 1878 for the construction of a canal (the Cascades Canal) around the main rapids. This canal was completed in 1896 and is described below.

55. No project has been adopted for the section of the river from the head of Cascade Gorge to the foot of Three-Mile Rapids (mile 189½) about 1½ miles above the town of The Dalles, Oreg., owing to relatively deep water and moderate currents in this section.

56. Between the foot of Three-Mile Rapids and the head of Celilo Falls (mile 200) the river has a fall of 81 feet at low water. The lower 2½ miles of this section is covered by an existing project providing for a depth of 10 feet in a channel 250 feet wide to be secured by open river work. This project also covers the remainder of the section by the provision of a lateral canal. This canal, the Dalles-Celilo Canal described below, is 8.6 miles long, and was opened to navigation in 1915.

Between Celilo (mile 200) and the mouth of Snake River (mile 323½) there is a project for open river work consisting of the removal of obstructing boulders and ledges and raking of gravel bars.

57. There is at present no project for river improvement between the mouth of Snake River and Wenatchee, Wash. (mile 465). A small amount of work was done in this stretch under past projects. This work consisted of the removal of some of the more dangerous rocks from the channel and placing of ring bolts to aid boats in lining through the rapids.

The section of river from Wenatchee to Bridgeport, Wash. (mile 542) was improved by 1912 for a 5-foot depth. From Bridgeport to Kettle Falls (mile 707) a project was adopted with a view to a 7-foot channel depth. That depth was not secured in all places.

58. From the foot of Kettle Falls to the international boundary (mile 749) there has been no project for improvement. The foot of Grand Rapids (mile 700) has been considered the head of navigation, but navigation is possible above the head of Kettle Falls for about 40 miles in the United States, except at high stages when Little Dalles Falls forms an obstacle, and for several hundred miles in Canada.

59. All improvement of the Columbia River that has been carried on has been by open river improvement methods except at the two localities, Cascade Gorge and between The Dalles and Celilo. At these places lateral canals, with locks, have been constructed, as stated above, and are in serviceable condition.

60. The canal at the Cascades has a length of 3,000 feet, a clear bottom width of 90 feet throughout. There is one lock, located at the lower end of the canal. It has two chambers in flight, with usable lengths of 462 feet in the upper chamber and 469 feet in the lower chamber. The controlling depth of the canal system is that over the upper mitre sill, which at adopted low water stage is 8 feet. The river at times falls below that stage as much as 2½ feet. The total lift of the lock is 24 feet at low water and about 14 feet at high water.

61. The Dalles-Celilo Canal has a length of 8.6 miles and includes four locks, of which the lowest (downstream) lock has two chambers in flight. All the locks have a usable length of 265 feet and a width of 45 feet. The controlling depth of the canal system is 7 feet at low water, and occurs at lock sills. The canal trunk has a clear bottom width of 65 feet.

62. As a result of the improvements that have been made in the river and at its mouth, seagoing vessels drawing up to 29 feet navigate at low tide to Portland on the Willamette. The channel is now being deepened to 35 feet under a project adopted July 3, 1930. The channel above the mouth of the Willamette to Vancouver, 4½ miles, permits a draft of 23 feet at low tide. These sections of the Columbia are navigated by all types of seagoing and river craft.

63. Above Vancouver (mile 105) and to The Dalles (mile 188) navigation is wholly by river boats drawing less than 7 feet, for which there is adequate depth throughout the year. Above The Dalles, to the mouth of Snake River (mile 323½), the limiting draft for all year navigation is 4½ feet. The craft generally used (there is practically no navigation at the present time above tidewater except by launch) was the so-called Columbia River type of stern-wheel steamer. A typical vessel (the *Twin Cities*) had a length of 151 feet, a width of 32 feet, a depth of hold of 4.8 feet, and 600 horsepower; at full load (200 tons freight) the draft was about 4½ feet. The *Twin Cities* was one of the later vessels in service, built in 1908, and was engaged in the Columbia-Snake River trade.

64. During the calendar year 1930 seagoing traffic, inbound and outbound, of the Columbia River amounted to 6,767,165 tons, valued at $316,933,691, of which 5,041,243 tons valued at $276,909,527 passed over the river to and from Portland, and 95,604 tons valued at $3,040,479 to and from Vancouver. In general, the seagoing tonnage over this lower part of the Columbia has been steadily increasing, from about 3,000,000 tons in 1920.

65. In the calendar year 1930 inland river vessels handled, exclusive of rafted timber, 1,952,235 tons valued at $30,594,441 in the Columbia below Vancouver and Portland, and 4,076,937 tons of rafted logs for sawmills on the river, valued at $14,747,192. Tonnage moved by river vessels has likewise shown progressive increase for many years. Above Vancouver, as far as Camas, Wash., about 14 miles, there is considerable special freight movement in connection with paper and pulp mills at Camas.

66. On the river above Camas the tonnage always has been quite insignificant. During the 27 years from the date of the opening of the Cascades canal in 1896 and until 1923, when regular boat service was discontinued, the total tonnage through the canal was 794,896 tons, or an average of 29,500 tons annually. Since 1923 the average tonnage through the Cascade Canal, exclusive of rafted and floated logs and piling, was about 5,000 tons, with an average value of about $600,000. This tonnage moved partly between Portland and the city of Hood River and the remainder between Portland and The Dalles. The quantities have fluctuated widely during the period since 1923 owing to suspensions and brief resumptions of boat service. Relatively large movement of floated logs and piling began in 1926, and in the past 5 years has averaged 55,000 tons valued at $260,000. The logs and piling originated on the north side of the river within

these are general in character, though intermittent, as interference caused by ice. Swift currents are found over most of the tidewater to Snake River section at all or nearly all stages. Other obstacles like crooked and narrow channels and shoals are peculiar to particular localities or reaches.

72. From Bonneville, the head of tidewater, to the Cascades Canal, 4½ miles, the currents are so swift at all stages that only relatively high power boats can stem them going upstream and be controlled going downstream. The controlling depth at low water is not less than 7 feet.

73. Through the canal navigation is provided for with a minimum controlling depth of about 6 feet up to a stage of 42 feet (in the lower pool), above which stage the canal is closed to navigation. This closure occurs in the summer time during the regular freshets of the river caused by melting of snow in the headwaters. Drowning out of the canal occurs about 6 years out of 10 and lasts from a few days to a month at a time. At these high stages the current velocity below the canal is so great as to interrupt navigation; the canal design was based on that condition. During the periods the canal is drowned out, downstream navigation in the river proper is possible but extremely hazardous.

74. Between the Cascades Canal and the foot of Three Mile Rapid, just above The Dalles, a distance of 43 miles, the conditions for navigation are favorable at all stages with a controlling depth of about 12 feet at low water. The channel has ample width. The slope in this section is slight and no excessive velocities are present at any stage.

75. From the foot of Three Mile Rapid to the lower entrance of The Dalles-Celilo Canal, about 2½ miles, the conditions again become unfavorable for navigation. This is due to the fact that the river in this short section flows through a narrow rocky gorge with a sharp reverse curve at its lower end terminating in Three Mile Rapid. The navigation conditions are best during low stages due to absence of excessive velocities. The depths are ample. At high stages navigation is hazardous on account of the velocities and the sharp bends.

76. The Dalles-Celilo Canal offers 8½ miles of slack water with a controlled depth of 7 feet. The canal was designed for use by steamboats, the type of boats operating on the river. It was not designed for barge navigation. The canal is narrow and presents some difficulty to boats passing through it when subject to strong flank winds, a not unusual condition.

77. From the head of the canal to the mouth of Snake River, 124 miles, the controlling low water depth is not less than 6 feet, except at one point, Homly Rapids, 6 miles below the mouth of Snake River, where the depth is 4½ feet over a rocky bottom. The channel width is adequate. There are numerous rapids in this reach. The total fall is about 186 feet, largely concentrated at the rapids. These total about 18 miles in length. The rapids offer serious difficulties to open river navigation on account of strong currents, and, in the case of Homly Rapids, insufficient depth. Formerly the various rapids presented additional hazards in the form of pinnacles of ledge rock. Under the existing and former projects the most dangerous pinnacles have been removed from the navigation channel, but further removal of pinnacles and ledge is needed to rectify the channel to make navi-

gation easier and safer, and to permit night navigation over some stretches where it is not now possible.

78. Freshets are not, in general, obstacles to navigation on the Columbia, but they do cause excessive currents at places and at times drown out the canals. The latter, as stated above, is not important as the excessive velocities, not the drowning out, control the situation at those localities.

79. Ice is almost annually a complete obstruction to navigation in the section under consideration (tidewater to Snake River). The duration varies from a few days to about a month.

80. From the foregoing it may be noted that, except when interrupted by ice or by swift currents and canal closure due to freshets, boats drawing 6 feet can navigate from head of tidewater (and below) to Snake River, except at Homly Rapids and occasionally at the Cascades Canal at extreme low water. At Homly Rapids the controlling low-water depth of 4½-feet might be increased to 6 feet by rock excavation and closure of secondary channels. Even for 6-foot nagivation considerable removal of pinnacles and ledge would be needed at the various rapids to make navigation easier and safer. No open river improvement can reduce the excessive currents.

81. To provide for even slightly greater draft at low water would require modification of both canals and considerable rock excavation from the river channel. Depths throughout the tidewater-Snake River section adequate for 8-foot draft, the probable least draft for economical movement of large tonnages, could not be secured by open river methods.

82. *Benefits to navigation obtainable from power dams.*—Potential commerce on Columbia River is of importance in connection with this report, as the tonnage is the principal factor in determining the total acceptable probable savings to shippers through use of the river improved by power developments. These developments would be located in the section of the river above the head of tidewater and their effect on ease of navigation would not extend into the tidal section. That section of the river need not, therefore, be considered in connection with savings to shippers.

83. From Vancouver, Wash. (mile 105), to the city of Hood River, Oreg. (mile 167), the potential commerce will depend upon industrial development rather than directly upon the resources of the territory tributary to the river. This region is mountainous and its resources almost entirely timber. The timber is mostly included within the limits of the National forest reserves. Only small areas are actually tributary to the Columbia River. Some timber now being cut below Hood River is being rafted to the lower river.

84. The country tributary to the river between Hood River and the headwaters of the Columbia is generally open, and is in part suitable for dry farming or irrigation. There are no important mineral deposits near the river from which a large tonnage may be expected.

85. Wheat is the principal extensive agricultural product of the basin of the Columbia. Its production amounts to about 80 million bushels annually. Of this quantity, about 37 million bushels have been going to Portland and part, about 21 million bushels, to Puget Sound for shipment by water. The remainder is used locally for seed and milling. Barley and oats are raised, but only small quantities are shipped.

86. Rail rates are devised to give Portland a differential on the wheat raised in all that part of the Columbia Basin south of a line approximately described as running east and west through Lewiston and extending eastward to the Continental Divide; parity of rates to Portland and Puget Sound in an area north of the Portland differential area and east of Pasco and Spokane; and a differential in favor of Puget Sound points in the area in Washington west of the Pasco-Spokane line and north of the Portland differential area.

87. There is no commerce on the Columbia above the mouth of the Snake at the present time except a little local traffic by launch over 20 miles of the river just above the mouth of the Okanogan River. Commerce in earlier years was over a greater stretch—from Wenatchee to Bridgeport—but this was discontinued over the Wenatchee-Pateros section with the advent of the railroad. The past tonnages were small, averaging for the years 1904 to 1912, the only years of record, about 35,000 tons.

88. Little commerce can be expected to develop on the Columbia above Pasco at the mouth of the Snake with the river in its present condition, or even with additional open river work in reaches where such method of improvement is feasible. Such commerce as would develop could be only local except that for a few miles above the mouth of the Snake it could form part of through commerce below Pasco. Only by canalization can through navigation over the upper river be made possible. And even in such event potential river commerce remains a matter of conjecture. The topography of the river and adjacent land does not favor movement of freight between the farms and the river. The favorable Puget Sound rail differential of much of this territory is not conducive to use of the river and shipment in export via Portland. The country is well supplied with main and branch-line railroads, and with highways. Nor does possible increase of agricultural products, through increased irrigation, offer much, if anything, in the way of potential river tonnage.

89. The district engineer, Seattle, estimates in chapter III of his report, part 2 of this report, that the shipments on the river in and out of the territory above the mouth of the Snake River would not exceed 250,000 tons annually with a completely canalized river, and that with such tonnage the cost of transportation by water would represent no saving to producers, shippers or consumers over rail haul from points above the Snake to Portland. He is of the opinion that no river commerce will develop above Wenatchee even with a canalized river. He does not believe that expenditures, except for locks when needed through power dams, to canalize the river to permit through traffic on the Columbia above the Snake are justified by any reasonable expectation of water shipments in and out of the territory. This view of the district engineer is concurred in by the division engineer.

The ton-mile rate for rail haul used by the Seattle district for comparison with estimated cost of water haul is believed to be too low, as it is the average for the State and does not represent the local rates. There is no railroad along the Columbia River from Wenatchee to Kennewick or Pasco, and to get to Portland, shipments by rail must go via Everett and Seattle, a distance of 341 miles, passing nearly all of the Puget Sound shipping ports enroute or via Adrian and Pasco, a distance by rail of 392 miles. The distances by river from Wenatchee to the mouth of the Willamette River is 365 miles, and to Portland on the Willamette is 376 miles. The rail haul from Wenatchee by Great Northern Railway to tidewater at Everett is only 131 miles and to Seattle 159 miles. It is, therefore, not probable that shipments originating in the vicinity of Wenatchee would go by water to Portland for transhipment to seagoing vessels nor is it likely that such shipments would go to Portland for local consumption there. It is doubtful if Portland could compete with Puget Sound in the Wenatchee territory on account of more favorable freight rates from Puget Sound points to Wenatchee, so that there would be but little if any up or downstream water-borne commerce.

Shipments originating from points below the foot of Priest Rapids to the mouth of the Snake are more likely to go downstream by water than from points above the foot of Priest Rapids, as the railroad freight rates are generally more favorable to Portland. The freight rates from Pasco to Portland are the same as those to Seattle. The territory tributary to the river between Snake River and Priest Rapids is mostly included in the report on the Columbia below the Snake River, part 3 of this report, so that no appreciable amount of tonnage in addition to that given in part 3 would be added by the section of river between Snake River and Wenatchee.

90. Satisfactory determination of potential tonnage on the Columbia below the mouth of the Snake to head of tidewater is almost as difficult as of that above the mouth of the Snake. Here, as above Pasco, there is no river traffic at the present time. The history of navigation on this lower part of the Columbia is not helpful in making forecasts for the future. Such improvements as have been made for the benefit of river commerce have not produced commensurate returns—except through reduction of rail-freight rates. The costly Cascades and The Dalles-Celilo Canals are unused.

91. The section of the Columbia below the Snake, combined with the Snake itself up to about Lewiston, Idaho, is held by some to offer an important future avenue of commerce of the Northwest. This claim is based mainly on the large wheat production in the territory tributary to Portland, a product suffering at present from low market value. The belief is held by some that navigation of the Snake and Columbia will be the salvation of the wheat grower, whose product is generally not suited to domestic distribution, except as used locally, but is dependent on foreign markets and cannot meet rail rates to the coast.

92. In chapter II, part 3 of this report, the district engineer, Portland, states that the total tonnage reported moved by rail for the fiscal year 1928–29 in and out of counties contiguous to the Columbia below the mouth of the Snake amounted to 1,956,292 tons. Of this total 392,707 tons was eastbound and 1,563,585 tons was westbound. About 60 percent of the westbound freight was wheat. Improvement of the river would not develop any new tonnage in the territory served. Any tonnage shipped by river from this territory would have to be diverted from the railroads or from truck lines. The latter carriers move some freight into and out of the territory, but the quantities are not of available record; this freight, paying relatively high rates and being usually of the kind requiring dispatch, is not important to the matter now being discussed.

93. Various estimates have been made of the tonnage that might move on the Columbia below the Snake.

The Columbia Valley Association, with headquarters in Portland, solicited promises of freight for movement on the river. Promises were forthcoming to a total of 400,000 tons, upstream and downstream combined, between Portland and Lewiston on the Snake. About 100,000 tons of this promised tonnage is tributary to Lewiston, but its movement over the Columbia would be contingent on improvement of the Snake. The promised tonnage tributary to the Columbia, 300,000 tons, is conditional on establishment of a reliable river freight service, on improvement of the river channel to 7-foot depth (5 feet at Homly Rapids), and on freight charges by river being at least 20 percent less than rail charges.

The district engineer (pt. 3, vol. II of this document) believes, from studies made by him, that this estimate of 300,000 tons is too liberal under the condition of river improvement desired and that 100,000 tons annually is more reasonable. He believes that with greater improvement of the Columbia to the mouth of the Snake (through increased lateral canal provisions at the gorge and at the Dalles-Celilo rapids) the potential tonnage may increase to 200,000 tons annually; and to 600,000 tons annually in the event of creation of through slack-water conditions from tidewater to the Snake, as by power dams. The last estimate in particular is germane to this report, as it is related to potential power development.

94. The district engineer estimates that if 600,000 tons of freight moves annually on the river, improved by power dams, up and downstream, between the mouth of Snake River and Portland, the total gross savings to shippers over existing freight charges would amount to about $1,100,000 annually. The cost of freight movement on which this estimated saving is based includes the cost of providing and operating the vessels, the terminal charges and the expense of moving freight between the river bank and the inland points of origin and destination. The cost of freight movement, however, does not cover the first cost of the navigation features through the dams, nor their maintenance and operation. The costs of this annual operation and maintenance, and the interest on the first cost of the navigation features through the dams, required for handling the 600,000 tons, total about $900,000. The net saving would, therefore, be about $200,000 per year, but with no provision for amortization.

95. The costs and savings of an open river improvement would depend on the useful life of such improvement. This life depends, not on ordinary depreciation of works which would be minor in amount, but on the length of time elapsing before the power dams would be built and the open river navigation works be rendered obsolete by the slack-water improvement.

The district engineer finds that with the open river improvement desired by the Columbia Valley Association (par. 93 above) the net savings on the district engineer's estimate of 100,000 tons would amount to $15,000 annually, with no consideration being given to amortization of the first cost of the open river works. In this computation the first cost of the two canals, Cascades and Dalles-Celilo, and also of the past works of open river improvement have been considered as written off; the operation and maintenance of these two canals is taken into consideration. The $15,000 is comparable with the $200,000 given above as savings from slack-water improvement.

96. The difference between the annual saving, $200,000, estimated for the slack-water improvement, and $15,000, the savings through further open river improvement, or $185,000, amounts, capitalized at 4 percent, to $4,625,000. This sum may be considered the maximum (see par. 16 above) that the United States might contribute toward power development on the Columbia below the mouth of the Snake in return for expected benefits to navigation.

In view of the uncertainty of the figures used in this study as to potential tonnage below the mouth of the Snake, and of the possible development of additional lower Columbia River tonnage originating at or be destined to points above the mouth of the Snake (omitted from consideration in calculating the savings referred to in this paragraph because of their conjectural nature), it is believed reasonable that the United States may contribute not to exceed the amount of $5,000,000 (in addition to providing the navigation features through the dams) toward the cost of the two power dams between tidewater and the mouth of the Snake contemplated in the comprehensive plan stated at the conclusion of this report.

C. POWER DEVELOPMENT [2]

97. Construction of dams on Columbia River will be controlled primarily by considerations of power development. Navigation, irrigation, and flood control will receive benefits from the reservoirs formed by the dams and from the developed power, but in general the benefits may be regarded as collateral or incidental. One exception exists in the case of the so-called "Columbia Basin" irrigation project in the State of Washington which has induced special consideration of a combination power-irrigation development at the head of Grand Coulee as a means of supplying water to the area from the main Columbia for comparison with gravity supply of irrigation water from Clark Fork, a tributary of Columbia River.

98. Power development, in turn, will be controlled by the demand for electrical power. Accepting the existence of large hydro-power development potentialities on Columbia River and feasibility of transmission of energy to appropriate points for use, the primary element of power study is the amount of hydroelectric power that can at present and within a reasonable future be utilized in the Northwest. This section of this report (power development) is treated under three major headings: Power market, power transmission, and power generation.

POWER MARKET

99. *General.*—Consideration of physical conditions in the Northwest leads to the conclusion that the principal market for hydro-electric power from the Columbia River will be found in the States of Oregon and Washington, together with that part of Idaho lying north of Salmon River and the northwestern corner of Montana, now served by the Thompson Falls plant of the Montana Power Co. Present practice and limitations usually confine direct transmission of large quantities of power to distances under 300 miles. By interconnection

[2] Prepared in collaboration with Barry Dibble, consulting engineer.

and substitution the effects of distance can be lessened and the marketing range extended.

100. The international boundary between Canada and the United States has for the purpose of this study been considered the northern limit of the power market. Interconnection and interchange with Canadian power systems is now of minor amount and will probably so continue as political reasons are likely to prevent the development of large blocks of power on one side of the line for use on the other. British Columbia contains many excellent power sites capable of meeting all probable needs of the province for many decades.

101. Existing interconnections between the system of Washington Water Power Co. in Washington and Idaho and the Thompson Falls (Montana) generating station of the Montana Power Co. result in important interchanges between the two most important properties in those regions. Thompson Falls station, which supplies much of the Montana territory west of the Rockies, is interconnected with other stations of the Montana Power Co. only through the transmission lines of the Chicago, Milwaukee, St. Paul & Pacific Railway, and it has therefore been possible to secure separate records of consumption in the market supplied by that plant. Practically all the electrical energy used in northern Idaho is generated by either the Washington Water Power Co. or the Thompson Falls plant. All this area is within transmission distance of Grand Coulee and other power sites on the upper Columbia River in Washington. Therefore, it is desirable and convenient to include these parts of Idaho and Montana in the market study. The remaining parts of both States are omitted from the Columbia River power market as their load centers are located relatively far from the Columbia and they have their own large sources of power supply.

102. Present power requirements are small in the part of Oregon that lies east of the Blue Mountains. Part of the energy now used is supplied directly by The Idaho Power Co. and part is sold by the Idaho company to the Eastern Oregon Light & Power Co. There is no immediate prospect of a market condition that will warrant the construction of a transmission line to connect this system with that in the Columbia River country. However, it has been convenient in this study to use statistics prepared by the Bureau of the Census, United States Geological Survey, and others; these follow State lines. The figures for this part of eastern Oregon are so small that they have no appreciable effect upon the total and therefore the statistical information has been allowed to stand without attempting a minor change.

103. The system of the California-Oregon Power Co. is partly in California and partly in Oregon. It is interconnected with the Mountain States Power Co. which operates in Oregon and through it to the Portland General Electric Co. Examination of the records shows that about the same amount of power crosses the California-Oregon boundary line in each direction. This condition makes the State boundary a convenient dividing line for the market study and it has so been used. The influence of Columbia River power might be extended into California either by direct transmission or by using it to replace power which now moves northerly in Oregon. Replaced power would be available to transmit southerly in California. The possibilities under either method are somewhat limited and have not

been used in preparing estimates. On the west the definite line of the Pacific coast has been taken as the boundary of the market area.

104. Power sites on the Columbia, with one possible exception, are located east of the Cascade Mountains in an arid country largely agricultural through dry farming and irrigation. In this basin an important power load has been created by pumping water for irrigation where a gravity supply cannot be obtained. Mining and lumbering in the mountains north and east of the basin are also large power users. Spokane is the principal business center of the region.

105. The Cascade Mountains separate the arid inland basin from the well watered country on their west in which are located a number of tidewater cities including Seattle, Tacoma, and Portland. Those mentioned seem destined to be the principal commercial centers of the Northwest. Within and surrounding them are many industrial plants. The timber resources of the country are the basis for a large percentage of the manufacturing. However, a number of secondary industries have been established and are of growing importance.

106. The population of the States of Washington and Oregon increased from 2,140,010 in 1920 to 2,517,182 in 1930, a gain of 17.6 percent. Of this total population that portion east of the Cascade Mountains increased from 601,300 to 645,567 or 7.4 percent in the decade, while in the counties west of the Cascades the growth was from 1,538,710 to 1,871,615 or 21.6 percent.

107. The falls of Willamette River at Oregon City and West Linn, about 14 miles above Portland, were used for power development as early as 1842. In that year Dr. John McLoughlin, chief factor of Hudson's Bay Co., at Fort Vancouver, utilized the falls to furnish motive power for a sawmill and other industries which were established to supply the needs of the growing population in the "Oregon Country." This location, where the river drops 42 feet at low water, offered conditions similar to those at New England and other eastern water powers about which mills clustered before the electric era. Here on the Oregon City side of the river there was built in 1889 by Willamette Falls Electric Co., a predecessor of the present Portland General Electric Co., one of the earliest commercial hydroelectric power plants in the United States. It had a capacity of over 1,000 kilowatts divided among 19 machines. The power was transmitted to Portland at 4,000 volts. This plant was operated until 1897. The Oregon City Woolen Mills, and two large paper mills which are now located at these falls use in part the original water rights granted by Congress by act of September 27, 1850. At West Linn in 1894 the present "station B" of the Portland General Electric Co. was put into service.

108. In 1882, the same year that Edison built his first central station—Pearl Street in New York City—Charles Hanson installed a small steam engine and electric generator at Tacoma to furnish light in his flour mill and elsewhere. Tacoma's present municipal system is an outgrowth of the flour mill lighting plant.

109. Lumbering, the dominating industry of the Northwest, originally developed its own power with steam engines driving long lines of shafting. Sawdust and waste wood were used as fuel. It is only in recent years that the convenience and flexibility of electric motors have led to the electrification of sawmill machinery and the construction of steam turboelectric power plants by the principal sawmills.

110. Wood pulp and paper manufacture have grown to importance in the past decade. Large blocks of electric power are utilized. Much of it is developed by steam turbines using waste wood as fuel. The remainder is developed by water powers owned by the companies or is purchased from public utility companies.

111. The utilities of the Northwest in general have depended upon water power for their production of energy with steam as a stand-by for peaks and periods of low water. As the market has expanded it has become economical to develop sites with increasingly larger capacities and of reservoirs for the regulation of stream flow.

112. In the United States the first commercial applications of electricity were solely to lighting. Later, small motors were introduced in order to use power-generating equipment that otherwise was idle in the daylight hours. Electro-chemical industries grew up around Niagara Falls before the days of long-distance transmission. Each year has brought new and larger applications and a rapid expansion of earlier uses, extending into industries, the farm, and the home. It was 1902 before the generation and consumption of electricity had gained sufficient importance to be reported upon as a separate industry by the Bureau of the Census. Since that time it has made a steady and rapid growth, reaching out into all departments of human activities until it is now one of the most important industries of the United States, with an annual revenue from the sale of electric service estimated to have been $2,155,000,000 in 1930. In the State of Washington the 1930 revenue was about $31,000,000; in Oregon, $17,000,000.

113. No segregation of revenue to different classes of load is available for northwestern utilities. In general, trends in the Northwest are similar to those in the Nation. Table A shows for the United States the total revenue for each year from 1920 to 1930 and its percentage distribution among the several classes of service. The figures emphasize the increasing importance of small consumers who are classified in the columns headed "Residential" and "Retail light and power—commercial." Together these paid 46.6 percent of the utility revenue in 1920 and increased their portion to 61.7 percent in 1930. On the other hand, the revenue from "Wholesale power and light", which includes the large industries, was 38.3 percent of the total 1920 revenue but only 23.7 percent of the 1930 total.

TABLE A.—*Revenue of electric light and power industry of United States by sources, 1920–30* [1]

Year	Total revenue for electric service (millions of dollars)	Percentage of total					
		Residential	Retail light and power—commercial	Wholesale power and light	Municipal	Railway	Other electric service
1920	882.7	25.4	21.0	38.3	4.4	4.7	6.2
1921	911.5	27.0	22.4	32.3	4.8	4.9	8.6
1922 [2]	1,020.4	27.0	22.8	32.8	4.8	5.0	7.6
1923	1,180.8	27.4	23.4	33.3	4.6	4.4	6.9
1924	1,322.0	28.8	25.0	30.5	4.6	4.1	7.0
1925	1,425.2	29.6	26.1	29.7	4.1	3.7	6.8
1926	1,621.5	30.0	26.9	28.2	4.2	3.6	7.1
1927 [2]	1,802.7	30.4	27.7	26.5	4.3	3.6	7.5
1928	1,941.9	30.9	27.6	26.4	4.3	3.3	7.3
1929	2,105.9	31.0	28.1	26.2	4.4	3.1	7.2
1930	2,155.0	32.7	29.0	23.7	4.5	3.0	7.1

[1] Compiled from statistics in Electrical World, Jan. 3, 1931, p. 28. [2] United States census.

114. Table B gives corresponding information on the distribution of energy delivered to the several classes of ultimate consumers by public utilities operating in the United States during the period 1920–30. Small consumers, residential and commercial, used 21.8 percent of the energy sold to ultimate consumers in 1920. In 1930 their use increased to 36.6 percent of the greater total. The large industries classified under wholesale power and light consumed 61.3 percent of the total in 1920. Their portion was reduced to 51.6 percent in 1930.

TABLE B.—*Distribution of central-station energy to ultimate consumers in the United States, 1920–30* [1]

Year	Total (millions of kilowatt-hours)	Percentage of total				
		Residential	Retail light and power—commercial	Wholesale power and light	Municipal	Railway transportation
1920	32, 530	9. 1	12. 7	61. 3	2. 2	14. 7
1921	30, 700	10. 7	15. 4	56. 3	2. 6	15. 0
1922	35, 822	10. 3	14. 5	57. 0	2. 5	15. 7
1923	42, 220	10. 5	15. 1	58. 4	2. 5	13. 5
1924	45, 000	11. 5	16. 8	56. 5	2. 6	12. 6
1925	50, 221	11. 8	17. 7	56. 5	2. 7	11. 6
1926	56, 964	12. 2	18. 5	56. 0	2. 7	10. 6
1927	63, 612	12. 7	19. 6	54. 4	2. 7	10. 6
1928	68, 695	12. 9	19. 4	55. 5	2. 6	9. 6
1929	77, 062	13. 4	20. 0	54. 9	2. 6	9. 1
1930	76, 120	15. 3	21. 3	51. 6	2. 8	9. 0

[1] Compiled from statistics in Electrical World, Jan. 3, 1931, p. 28.

115. Figures for 1929 in table C show the distribution of the energy delivered to the different classes of consumers by seven of the large utilities operating in Washington and Oregon compared with corresponding percentages in the United States.

TABLE C.—*Energy delivered to ultimate consumers in 1929*

Class	In Washington and Oregon		In United States, percent of total
	Kilowatt-hours, millions	Percent of total	
Residential	469	19. 7	13. 4
Retail light and power—commercial	396	16. 7	20. 0
Wholesale power and light	1, 325	55. 8	54. 9
Municipalities	82	3. 4	2. 6
Railway transportation	103	4. 4	9. 1
Total	2, 375	100. 0	100. 0

116. The residential consumer appears to be relatively more important in the Northwest than in the country as a whole. Here he utilized 19.7 percent of the total energy sold during 1929 compared with 13.4 percent in the country as a whole. This is counterbalanced by a smaller percentage used by retail light and power consumers. Electric railway transportation in 1929 used only 4.4 percent of the

total energy in Washington and Oregon as compared with 9.1 percent in the entire Nation.

117. Lack of information as to the segregation of revenue of northwestern utilities does not permit calculation of the average rates per kilowatt-hour paid by consumers of different classes, but such average rates for the United States as a whole are given below (table D) for the years 1920 and 1930. The average rate per kilowatt-hour appears to have slightly increased during the decade. This is due to the greater importance in 1930 of the small customer, who pays a relatively high rate for his service.

TABLE D.—*Rates per kilowatt-hour (in cents)*[1]

Class	Cents per kilowatt-hour		Change in decade, (+) increase, (−) decrease
	1920	1930	
			Percent
Residential	7.50	6.05	−19
Retail light and power	4.46	3.85	−16
Wholesale power and light	1.69	1.30	−23
Municipal	5.40	4.55	−16
Railway	.87	.95	+9
Weighted average	2.70	2.83	+5

[1] Computed from data contained in Electrical World, Jan. 3, 1931, p. 28.

118. The increasing importance of the small consumer has had a stabilizing effect upon both output and revenue of electrical utilities. While the large industrial loads are adversely affected by periods of depression, residential and retail commercial loads have uniformly progressed steadily upward. In the year 1930, when in the United States the industrial load dropped 7.7 percent, domestic consumption increased 12.8 percent and that of small commercial light and power customers increased 5.9 percent. The result was that the gross revenue of the utilities increased in spite of the industrial depression.

119. Increase in load comes both from new customers and from additional requirements by old customers. The latter source is the more important. It is estimated that, in 1930, 70.5 percent of the population of the United States lived in electrically lighted homes. Perhaps one third of the remainder were within reach of transmission lines. The other two thirds, about 20 percent of the total population, were mostly in rural districts as yet remote from such facilities. It is probable that these percentages are also fairly representative of conditions in the Northwest at the present time. The number of small consumers has increased faster than the growth of population and will probably continue to do so, though at a declining rate. The greatest rate of growth comes from increased consumption by the small consumer. These conditions are illustrated by statistics concerning residential consumers reported by seven leading utilities of Oregon and Washington, as given below in tables E and F.

Table E.—*Number of residential consumers of electric power*

Utility	1925	1926	1927	1928	1929
Puget Sound Power & Light Co.			105,335	108,354	120,919
Portland General Electric Co.	72,252	79,915	84,085	88,181	89,762
City of Seattle			75,083	80,540	82,824
Pacific Power & Light Co.	32,206	35,190	37,350	48,645	49,063
Washington Water Power Co.					43,399
City of Tacoma			31,122		32,002
Northwestern Electric Co.	16,079	18,857	20,423	21,880	23,786
Total					441,755

Table F.—*Average sales for residential use in kilowatt-hours per year per consumer*

Utility	1925	1926	1927	1928	1929
Puget Sound Power & Light Co.			726	529	1,011
Portland General Electric Co.	546	596	697	771	870
City of Seattle			853	925	1,018
Pacific Power & Light Co.	454	533	620	778	890
Washington Water Power Co.					1,799
City of Tacoma			1,050		1,161
Northwestern Electric Co.	669	814	936	1,019	1,058
Weighted average					1,037

120. It is the general opinion among utilities that the residential market can be greatly expanded. The increase from 1920–30 was 295 percent. A recent statistical study concludes that there is possible an annual "economic domestic use of 40,000 kilowatt-hours per home for a large percentage of the customers." Results similar to those for residential service are being secured in the growth of the load of small commercial light and power consumers. It increased 293 percent from 1920–30. Municipal uses have been increasing at a pace somewhat faster than the average advance in the use of electricity. From 1920–30 the consumption for municipal purposes increased 194 percent. In all of these fields population is a factor, though at the present time its influence in the trend is minor. The trends are well defined and will probably continue in the immediate future much as they have in the past.

121. The amount of power used by electric railways has been practically stationary for the past 4 years. There is no reason to expect much change in the requirements of street railways in the near future. Electrification of additional steam railways will probably occur from time to time. The general growth of the use of electricity has been so great that possible steam railway electrification is not now relatively such an important factor as it would have been a few years ago.

122. The future of electricity in the major industries is less easily predicted. In the United States, during the decade 1920–30, consumption in the usual classification "Wholesale power and light" increased 96 percent. The requirement of the average consumer of this class is not very large. He uses only 75,000 kilowatt-hours per annum, equivalent to about 35 motor horsepower for 8 hours a day, 300 days per year. Included are many small consumers whose businesses probably partake of the character of those included in the class designated "Retail light and power—commercial" in which little fluctuation of power consumption is caused by periods of depression.

On the other hand, the "Wholesale" classification does not record the many large industries which have their own generating stations. The output of such stations is not reported to the usual statistics-collecting agencies except as to the part that is sold and enters into "public use." Census reports for 1929 show 20,100,000 horsepower for motive power developed in factories and mills having their own power plants, while the motors driven by purchased energy had a rated capacity of 22,700,000 horsepower. In other words, the industries themselves generate almost as much power as they buy.

123. Timber is the raw material for the largest manufacturing industry of the Northwest. In 1927 the lumber business accounted for $189,000,000 or 42.5 percent of the value added by manufacture [3] to the products of Washington and Oregon. Another 4 percent is added by the pulp and paper business. Both of these industries use large amounts of electric power. Much of it is generated in the steam plants operated by the companies with wood waste as fuel. Several of the pulp and paper mills secure energy from water power plants owned and operated by the manufacturing company. The aggregate installed power capacity of the lumber and paper companies is very large. Two concerns alone have major installations totaling 84,000 kilowatts (113,000 horsepower) of which 59,000 kilowatts is steam-electric and 25,000 kilowatts is hydro-electric. They have some smaller power plants, of which statistics are not available. Large quantities of energy are also purchased by them from utility companies.

124. In addition to the wood used for fuel by the manufacturing companies, other large quantities of waste material are sold to be used as fuel in power plants of the electrical utility companies and for heating office buildings and residences. The United States Geological Survey reports that in 1930 wood fuel was used to produce 362,900,000 kilowatt-hours for public use in Oregon and Washington. It is estimated that the wood refuse now available annually is sufficient to produce 750,000,000 to 1,000,000,000 kilowatt-hours.

125. At the present time a number of processes are being developed to convert waste wood into byproducts which will give it a higher value than it has for fuel. These include the use of chips for paper, the manufacture of fiber board, and other articles. On the Atlantic coast the rayon industry is using wood fiber. Resins and various products can be obtained by distillation. As the waste is graudally absorbed for such treatment, hydroelectric power or other fuel must take the place of the wood that is now burned.

126. A study of the timber industry [4] indicated that the lumber business in the Northwest has passed its peak, but that the reproductive power of the timber lands of Washington and Oregon is such that lumber will always be an important product. The industry will probably find a profitable field in the further manufacture of lumber into many articles of commerce instead of shipping rough lumber to be manufactured elsewhere. Paper manufacturing will probably continue to increase in importance for many years. It should remain one of the basic industries of the region.

[3] "Value added by manufacture," as used by the Bureau of the Census, is the value of the product less the cost of raw materials, containers for products, fuel, and purchased electrical energy. Its use in these statistics eliminates the duplication that otherwise enters the figures because of the use of the product of one process as the raw material of another.

[4] See appendix 4, by R. R. Montell, of pt. 2 of this report. (P. 1211, vol. II of this document).

127. Around the lumber, paper, and other basic industries are grouped many secondary industries designed to supply material and service of various kinds. Other important industries serve the population. As industry and population gradually grow they in time create an actual or potential demand which makes it economically possible to establish factories to supply articles which were formerly imported. This cumulative effect is of extreme importance in the growth of communities having varied natural advantages, such as those of the Pacific Northwest. Such expansion serves to diversify the market for electric power and adds to its stability. Development of any industry along any line leads both directly and indirectly to increased demands for power. However, the absorption of large blocks of power comparable with the sizes of the enterprises adapted to the major sites on the Columbia, will be facilitated if advance contracts can be made with industries which themselves will use energy in large quantities. Most prominent among these are industries involving electro-chemical and metallurgical processes.

128. For the purposes of this report B. Nienburg, economic consultant, Washington, D.C., has made a special study of these industries to learn their history, methods, requirements for raw material, consumption of electric power, costs, and amount of production and location and size of their markets insofar as such information has been found available. Statements for the separate industries accompany this report as appendix I. A résumé of these individual reports is also included in that appendix. The local availability of minerals useful as raw material for manufacturing processes have been investigated for this report by Dean Henry Landes, consulting geologist, Seattle, Wash., and Mr. Ira Williams, consulting geologist, Portland, Oreg., and their discussion appears in papers which are included as appendices to the reports of the Seattle and Portland districts (pts. 2 and 3 of this combined report, printed in vol. II of this document). With the Seattle report there is also included a study of the timber industry of Washington and Oregon by Mr. R. R. Montell, consulting engineer, Seattle, Wash., in which is contained a discussion of the waste material available for byproducts.

129. Outgoing shipments from Puget Sound and Columbia River ports consist largely of lumber, other wood products, wheat, and flour. These are distributed to all the world. Return cargoes are relatively small. In 1930 foreign imports received at Columbia River ports amounted to only 8 percent of the export tonnage. California fuel oil, gasoline, and distillate constitute the bulk of the receipts from coastwise commerce. They are shipped in barges and tankers, which are generally not suited to carry cargoes of lumber on the return voyage to California ports. Coastwise receipts other than petroleum products entering Columbia River are only 33.5 percent of outgoing coastwise tonnage. Commerce of Puget Sound ports includes imports from and exports to nearby Canadian ports. Many of the coastwise receipts and shipments move between ports within the Sound. If such cargoes are eliminated, the lack of balance between outgoing and incoming shipments is found to be much the same as for the Columbia River. Such a condition favors the possibility of obtaining low freight rates on bulky ores or other raw materials which can be brought to these ports as ballast by incoming vessels. This has an important bearing on the feasibility of obtaining needed raw

material for electro-chemical and metallurgical processes where these are not conveniently and cheaply available from local sources.

130. Constantly changing conditions in those manufacturing industries which use large quantities of electricity make it futile to attempt to predict what new enterprises may ultimately be influenced to locate in the Pacific Northwest by the availability of hydroelectric resources and by other advantages. Pertinent data adapted from appendix I is given in table G to show the relative importance of the principal electro-chemical processes in the United States in 1929, the latest year for which figures are available. It therefore gives an idea of the outlet which they might afford as a market for Columbia River power. In excess of 7,000,000,000 kilowatt-hours were consumed in the United States during 1929 in the production of some 50 chemical substances. Many of the processes used such small amounts that they are not separately reported. Appendix I contains much detailed information concerning the world production and power requirements of these and other industries.

TABLE G.—*Electrical requirements of electro-chemical processes in the United States during 1929*

Product	Process	Kilowatt-hours required per short ton	Kilowatt-hours consumed in United States during 1929 in 1,000's	Principal competing processes in United States or other countries
Aluminum	Electrolytic reduction of alumina to aluminum.	19,000–25,200	2,519,375	None.
	Electrothermal reduction of bauxite to alumina.	4,082	None.	Alkali reduction of bauxite to alumina.
Ferro-alloys:				
Ferro-silicon, 50 percent.	Electrothermal smelting	5,000	994,011	By product of fused alumina production. Blast furnace reduction for less than 12 percent silicon.
Ferro-molybdenum, 70 percent.	do	8,000– 9,000	228,258 (Ferro-molybdenum, Ferro-uranium, Ferro-chromium)	None.
Ferro-uranium	do	6,000–10,000		
Ferro-chromium, 60 percent.	do	6,000		
Ferro-tungsten	Electrothermal smelting and refining.	7,600	26,395	Do.
Ferro-vanadium, 30 to 35 percent.	Electrothermal smelting	6,800	13,035	Thermit reduction.
Ferro-manganese, 80 percent.	Electrothermal reduction	4,400	None.	Blast furnace reduction.
Calcium carbide	do	2,600– 3,200	720,000	None.
Caustic soda and chlorine	Electrolytic reduction of brine.	[1] 2,328– 2,984	660,000	Lime-soda ash process.
Copper	Precipitation from oxide and mixed ores.	1,700– 2,625	62,849	Flotation and reverberatory smelting.
	Electrolytic refining	141– 233	309,351	None.
	Electric furnace smelting for alloying.	200– 300	[2] 220,000	Fuel fired pit furnaces.
	Annealing	50– 100		Fuel fired furnaces.
Zinc	Electrolytic precipitation	2,206– 3,200	[3] 507,115	Retort distillation.
Steel:				
Castings	Electric melting solid charge.	500– 760	281,594	Open hearth furnace. Bessemer furnace. Crucible furnace.
Ingots	Electric melting or refining or super-refining of molten charge.	210	125,219	Open hearth furnace. Bessemer furnace. Crucible furnace.
Treatment	Electric annealing or hardening.	182– 286		Fuel fired furnaces.
	Electric galvanizing or electro-zincing.	101– 230		Fuel, hot process.

[1] Per ton of caustic soda.
[2] 1927 figures.
[3] Includes power required in operations immediately essential to electrolytic precipitation of zinc.

TABLE G.—*Electrical requirements of electro-chemical processes in the United States during 1929*—Continued

Product	Process	Kilowatt-hours required per short ton	Kilowatt-hours consumed in United States during 1929 in 1,000's	Principal competing processes in United States or other countries
Crystalline graphite	Electrothermal reduction	7, 600	91, 200	None.
Phosphoric acid	do	5, 400	81, 000	Sulphuric acid process. Blast furnace reduction.
Oxygen (compressed)	Electrolytic reduction of water.	[4] 250	50, 575	Liquefaction process.
Hydrogen	do	[4] 140		Water, gas and iron contact processes.
Fused alumina	Electrothermal fusion	2, 000– 2, 540	[5] 43, 318	None.
Carbon bi-sulphide	do	850	30, 179	Do.
Silicon carbide	Electrothermal reduction	6, 666– 8, 333	[6] 23, 655	
Potassium hydroxide	Electrolysis of potassium chloride.	2, 100– 2, 300	15, 831	Chemical process.
Synthetic ammonia	Electrolytic hydrogen; pressure synthesis.	12, 055	13, 140	Water gas hydrogen; coke oven gas hydrogen; by-product hydrogen.
Metallic magnesium	Electrolysis of magnesium chloride in brine.	16, 000	10, 640	Electrolysis of magnesium chloride from mineral magnesite plus chlorine requiring 17,000 kilowatt-hours.
Lead	Electrolytic refining	95– 111	6, 180	
Cadmium	Electrolytic precipitation of zinc residue.	2, 000– 2, 500	2, 730	None.
Silver	Electrolytic refining	316– 714	1, 283	Sulphuric acid process.
Phosphorus	Electrothermal reduction	9, 000	1, 250	None.
Gold	Electrolytic refining	266	45	Sulphuric acid process.
Metallic sodium	Electrolysis of fused caustic soda.	13, 000	(7)	Electrolysis of fused sodium chloride.
Fused quartz	Electrothermal fusion	10, 000–16, 000	(8)	None.
Silicon	Electrothermal reduction	12, 000	(8)	Do.
Potassium chlorate	Electrolysis of potassium chloride.	1, 350	(8)	Chemical process.
Iron	Magnetite ore reduction in arc furnace.	2, 000– 2, 500	None.	Blast furnace. Electro-deposition.
	Electro-deposition from ore.	900	None.	Blast furnace. Electric furnace reduction.
Sponge iron	Electrothermal low temperature ore reduction.	400	(8)	Oil or gas low temperature reduction.
Iron castings	Electric melting Duplex systems, continuous.	115– 550	(8)	Fuel fired cupola melting.
Nitric acid	Arc	61, 000	None.	Oxidation of ammonia.
Calcium cyanamide	Electrothermal reduction	2, 830	[9] None.	None.

[4] Kilowatt-hour per 1,000 cubic feet.
[5] Canadian and United States consumption in 1929 was 152,489,000 kilowatt-hours for production of fused alumina.
[6] Canadian and United States consumption in 1929 was 227,000,000 kilowatt-hours for production of silicon carbide.
[7] United States production not officially recorded. Estimated world consumption in 1927 was 375,000,000 kilowatt-hours for manufacture of metallic sodium.
[8] Not reported.
[9] The amount of calcium cyanamide shipped into the United States required 84,900,000 kilowatt-hours to produce.

131. *Conclusions as to future power market.*—Estimates of the future always involve many uncertainties. In the electrical industry 5 years ahead is as far as plans can usually be prepared with any definiteness. A 10-year estimate is hazarded only with reservations. However, in connection with the preparation of a comprehensive plan for the development of the Columbia River it is necessary to make comparisons between many possible alternatives, and the amount of power that is involved is so great that the comparisons require a forecast of the probable rate at which the power market can absorb electrical

energy over a long period of years. Therefore, the conclusions of this study have been carried beyond the usual limits.

132. Study of available data leads to the conclusion that there is not likely to be a sudden change in the general trend of growth in the market for electrical energy in the Northwest. Conditions prevailing during the business depression of 1930–31 tend to support this conclusion. Production of energy has been growing at the average rate of approximately 9.5 percent per year compounded. At this rate the business doubles in 7.6 years. In 15.2 years it quadruples. Yet in spite of past trends it is difficult to conceive that consumption of electrical energy will continue indefinitely to increase at the rate of 9.5 percent per year. Electric power has greatly changed modern methods. It is within the bounds of possibility that the progress of science and invention may bring forth other sources of energy for the service of mankind and that these will in time supersede the generation of electricity as we know it.

133. The estimates for the future consumption of electricity proposed in the district reports are concurred in. These assume that the rate of increase of production will gradually decrease following a smooth curve until at the end of 30 years (1960) the rate will be 4.75 percent per year instead of 9.5 percent. After 30 years it is assumed that the rate of increase will continue to decline along the same smooth curve until at 60 years (1990) growth ceases. Table H gives the estimated figures at 5-year intervals from 1930 to 1960.

TABLE H.—*Estimated future electrical production within marketing distance of Columbia River power sites* [1]

Year	Kilowatt-hours	Average	Installed capacity	Year	Kilowatt-hours	Average	Installed capacity
	Millions	*Kilowatts*	*Kilowatts*		*Millions*	*Kilowatts*	*Kilowatts*
1930	4, 041	461, 333	922, 877	1950	22, 930	2, 617, 000	5, 234, 000
1935	6, 480	740, 000	1, 480, 000	1955	31, 830	3, 633, 000	7, 267, 000
1940	10, 230	1, 168, 000	2, 336, 000	1960	41, 630	4, 752, 000	9, 504, 000
1945	15, 650	1, 787, 000	3, 574, 000				

[1] Includes Washington, Oregon, that part of Idaho which is north of the Salmon River and that part of Montana now served by the Thompson Falls plant of the Montana Power Co.

134. Plate II shows separately the growth from 1907 to 1930 in the generation of electricity by public utilities as compiled by the Bureau of the Census and the United States Geological Survey for the United States, the Pacific States, Washington and Oregon. It also shows the growth of generation during the same period in the area south of the international boundary where electric energy produced by the Columbia will probably be marketed. This area includes the States of Washington and Oregon, that part of Idaho which lies north of Salmon River, and the northeastern corner of Montana which is now served by the Thompson Falls plant of the Montana Power Co. There has been indicated graphically and numerically on plate II the normal trend of growth during the past decade or more. The graph of generation in the market area for Columbia River power has been extended from 1930 to 1960 in conformity with the estimates of table H. In the district reports (see vol. II of tnis document) there will be found comparable data for

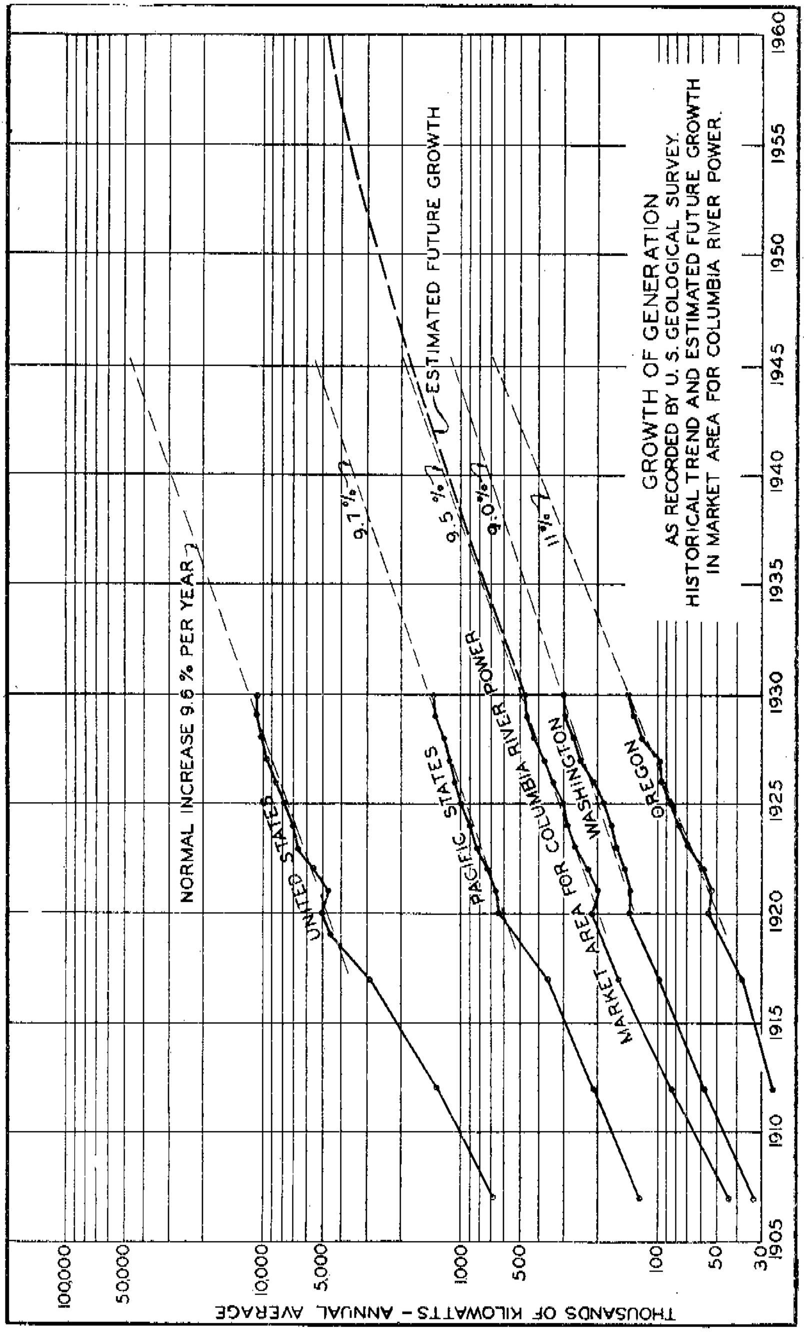
GROWTH OF GENERATION
AS RECORDED BY U. S. GEOLOGICAL SURVEY.
HISTORICAL TREND AND ESTIMATED FUTURE GROWTH
IN MARKET AREA FOR COLUMBIA RIVER POWER.
NORMAL INCREASE 9.6 % PER YEAR
UNITED STATES
PACIFIC STATES
MARKET AREA FOR COLUMBIA RIVER POWER
WASHINGTON
OREGON
ESTIMATED FUTURE GROWTH
9.1 %
9.5 %
9.0 %
11 %
THOUSANDS OF KILOWATTS - ANNUAL AVERAGE
100,000
50,000
10,000
5,000
1000
500
100
50
30
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960

PLATE II.

the individual utilities and other information which has been used in arriving at the conclusion represented by table II.

135. These estimates appear to give reasonable and consistent results satisfactory for the purpose of this report. Should growth continue as it has in the past the estimates will be exceeded. Should the industry fail to continue its progress or should it be detrimentally affected by some new discovery, it may fall considerably short of the estimate.

136. *Economics of power production.*—Economic justification for the construction of large dams for the development of power on Columbia River depends upon successfully marketing the power at a price and in the large quantities necessary to pay all fixed charges, including interest and operating expenses, and to insure the return within a reasonable time of the original investment either directly or by setting up ample reserves for depreciation and obsolescence. The range of the selling price will lie between the minimum that will meet these requisites and a maximum controlled by competitive prices and also by the amount industries can afford to pay for power.

137. It is assumed that in general any water-power sites in the Northwest that could produce power more cheaply than the sites on the Columbia River would be put to use before development of the Columbia is undertaken. In steam power also will be found a potential competitor worthy of consideration when any project is debated.

138. The basis for determining the cost of energy produced in a large steam turbine electric station, constructed at the load center by a utility company, is discussed in some detail in the district reports. With fuel oil costing $0.50 and $1 per barrel it is estimated that the cost per kilowatt-hour for different load factors will be as given in the ollowing table:

TABLE I.—*Cost of steam power per kilowatt-hour*

Annual load factor	Fuel oil $0.50 per barrel	Fuel oil $1 per barrel
Percent	*Mills per kw.-hr.*	*Mills per kw.-hr.*
40	4.38	5.46
50	3.70	4.77
55	3.46	4.51
65	3.08	4.13
75	2.80	3.84
85	2.59	3.62
100	2.35	3.38

139. Quotations for fuel oil during 1930 and early 1931 with barge deliveries in the Northwest have ranged from $1.10 down to $0.75 per barrel. One dollar per barrel is a reasonable and convenient figure to take for determining competitive prices. Annual load factor varies greatly for different classes of service. For a large system with usual commercial diversity it is approximately 55 percent. Under such a condition the estimated cost of steam power is 4.51 mills per kilowatt-hour when fuel oil costs $1 per barrel delivered at the steam plant. Should the service be to a large industrial plant which uses power quite uniformly throughout the 24 hours of the day and 365 days of the year it is not improbable than an annual load factor of 85 percent might be attained. This would reduce the cost of steam generation to 3.62 mills per kilowatt-hour. Future variations in the cost of fuel

will, of course, affect the price at which steam power can be produced with corresponding effect upon the maximum limit at which large blocks of hydroelectric power can be sold when delivered at the load centers.

POWER TRANSMISSION

140. Hydroelectric power can be generated only where a natural fall or a suitable site for a dam exists. This is usually at some distance from the place where the electric power is to be used. Columbia River sites are no exception. Some industries may find it economical to locate close to the generating stations, but the bulk of the energy will require long-distance high-tension transmission for delivery to the points at which it can be used most conveniently.

141. Present transmission lines are shown on plate 101,[1] electric power systems of Pacific Northwest—1930, in the report of the district engineer, Portland, Oreg., which is part 3 of this report. These lines have been designed and constructed to serve the present needs of the utilities to which they belong. They have insufficient capacity to transmit or distribute the power which the Columbia River is capable of producing. The distances involved and the amount of energy to be transmitted will require the construction of a new system of high-voltage circuits which will be superimposed upon the present or then existing systems. Appendix II of this report is a study by E. A. Loew, professor of electrical engineering, University of Washington, of the type and cost of such circuits. The probable voltage is determined to be 220,000. Double-circuit steel towers would be used. The estimates of cost include rights of way, towers, conductors, and telephone lines. Substation building and synchronous condensers are included at the delivery end of the circuits; and transformers, circuit breakers, and switches at both ends. Allowances have been made for contingencies, overhead charges, and interest during construction. A comparison is made between the cost when financed with money borrowed by a utility company at 6 percent and the cost with 4 percent public money. The cost of one double circuit, 220,000-volt line, with its terminal equipment, is estimated for several circuit lengths as shown in table J below.

TABLE J.—*Construction cost of double circuit 220,000-volt transmission line with terminal equipment*

[Line designed for maximum economy of transmission] [1]

Length of line	Peak capacity (receiver end)	Investment when financed by [2]	
		4 percent money	6 percent money
Miles	*Kilowatts*		
100	325,000	$8,078,200	$8,183,100
150	271,000	8,495,700	8,605,700
200	216,000	9,144,400	9,263,200
250	162,000	9,933,600	10,062,600

[1] For the sake of brevity and simplicity certain refinements are omitted which enter the economic study for the final design of the line. The present study is sufficiently accurate for purposes of comparison. Line conductors have been estimated on the basis of copper cable at 17 cents per pound. This is higher than current prices. The cost of conductors is 17.4 percent of the total cost of the 100 mile line; 17.8 percent of the 150 mile line; 19.7 percent of the 200 mile line and 22.7 percent of the 250 mile line.

[2] Assumed construction period is 16 months. Interest during construction is computed at 4 and 6 percent on the entire cost for one half this period.

142. Annual fixed charges for the two assumed methods of financing are made up as shown in table K which follows:

[1] Not printed in this document.

TABLE K

4 percent money	Percent	6 percent money	Percent
Interest	4.00	Interest	6.00
Depreciation reserve	1.78	Depreciation reserve	1.27
Amortization	1.05	Taxes	1.50
Total	6.83	Total	8.77

143. Annual expense of operation and maintenance is estimated at $150 per circuit mile. For the lines estimated in table J the total annual charges are given in table L below.

TABLE L.—*Annual charges for double circuit, 220,000 volt, transmission line with terminal equipment*

[Line designed for maximum economy of transmission]

Length of line (miles)	Annual expense of operation and maintenance	Annual fixed charges		Total annual charges	
		4 percent money	6 percent money	4 percent money	6 percent money
100	$30,000	$551,700	$717,700	$581,700	$747,700
150	45,000	580,300	745,700	625,300	799,700
200	60,000	624,600	812,400	684,600	872,400
250	75,000	678,500	882,500	753,500	957,500

144. Assuming that the transmission lines are properly proportioned for the peak loads which they will carry (in which case the load factor is equal to the capacity factor) the cost of transmission per kilowatt-hour for various load factors will conform approximately to the figures in tables M and N below. These transmission costs must be considered in determining the cost of energy delivered at the load center or in estimating the value of the energy if it is sold at the switchboard of the hydroelectric generating station.

TABLE M.—*Cost of transmission per kilowatt-hour for 220,000-volt lines of different length*

[4 percent money]

Load factor	Length of line in miles				Load factor	Length of line in miles			
	100	150	200	250		100	150	200	250
	Mills	*Mills*	*Mills*	*Mills*		*Mills*	*Mills*	*Mills*	*Mills*
50	0.409	0.527	0.724	1.060	75	0.272	0.351	0.483	0.707
55	.372	.479	.657	.965	85	.241	.310	.426	.625
65	.314	.405	.556	.817	100	.204	.264	.362	.530

TABLE N.—*Cost of transmission per kilowatt-hour for 220,000-volt lines of different length*

[6 percent money]

Load factor	Length of line in miles				Load factor	Length of line in miles			
	100	150	200	250		100	150	200	250
	Mills	*Mills*	*Mills*	*Mills*		*Mills*	*Mills*	*Mills*	*Mills*
50	0.525	0.675	0.921	1.350	75	0.350	0.449	0.615	0.898
55	.477	.615	.838	1.225	85	.309	.396	.542	.797
65	.403	.518	.709	1.037	100	.262	.337	.461	.675

POWER GENERATION

145. *General.*—In the early days of the electrical industry, both steam and water power plants were limited to capacities that now seem very small. This was necessary in order that initial investment might be in keeping with the market for power. It is usually true that water power sites of large capacity, when they are fully utilized, show a lower unit cost of production than do sites of smaller capacity. When, however, large dams and expensive hydraulic construction have been prematurely undertaken, carrying charges have sometimes placed heavy burdens on the financial structure of utilities before the market has been developed sufficiently to permit the accruing costs to be distributed to the consumers. As the power business has grown from year to year, the average annual increase in load has become greater. Therefore, the productive capacity of the larger power sites is now more quickly absorbed than it would have been in an earlier period. The growth of the power market, as estimated in this report, assumes the continuance of this trend. In the future it will undoubtedly become economically feasible to develop power sites which are larger than would be warranted at the present time.

146. It is a desirable condition precedent to the construction of a large power plant that it serve the needs of as large a market as possible. The principal Columbia River sites are within reasonable transmission distance of all the more important load centers of Oregon, Washington, northern Idaho, and western Montana. It is logical to consider the utilities occupying this region as forming a single market to be supplied by radiating transmission lines. Such an arrangement makes it possible to draw on a single source for all or a large part of the growth of the power sales until the capacity of that particular power site has been fully utilized. A long step in this direction has already been made by interconnection of the systems of independent and related power companies.

147. The following table O gives the total and average output of generating stations for 1930 and the installed capacity of generating equipment of the principal utilities within the area in which Columbia River power would be marketed. It also shows the totals of the United States Geological Survey as reported for Oregon and Washington. Provision for carrying peak loads, for irregularities in stream flow, for stand-by service and for caring for the normal growth of business causes the total rated capacity of generating equipment to be maintained at more than double the average output. In order to make the figures of the table comparable the installed generating capacity has been given as of December 31, 1930. This will account for some differences which will be found between these figures and those contained in the district reports as in the latter power plant capacities include installations made during 1931 insofar as information has been available.

TABLE O.—*Capacity and output of generating stations in public service within marketing area for Columbia River power*

Reported by	Output, 1930	Average output, 1930	Installed generating capacity Dec. 31, 1930	System capacity factor
LARGER UTILITIES	*Kilowatt-hours, thousands*	*Kilowatts*	*Kilowatts*	*Percent*
Puget Sound Power & Light Co.	891,812	101,800	262,735	38.7
Washington Water Power Co.	843,376	96,200	202,535	47.5
Portland General Electric Co.	600,861	68,600	181,480	37.8
City of Seattle	380,749	43,500	128,300	33.9
City of Tacoma	219,655	25,000	91,000	27.5
Northwestern Electric Co.	257,036	29,400	59,000	49.8
Montana Power Co. (Thompson Falls plant)	201,646	23,019	35,000	65.8
Pacific Power & Light Co.	138,760	15,900	34,735	45.8
Mountain States Power Co.	12,767	1,460	24,889	------
Washington Gas & Electric Co.	92,848	10,600	24,000	44.2
Grays Harbor Railway & Light Co. and associated companies	37,913	4,650	12,900	36.0
City of Eugene	32,007	3,660	8,950	40.9
City of Centralia (from October only)	1,760	201	4,000	------
Eastern Oregon Power Co.	9,698	1,110	3,580	31.0
Total of separate reports	3,720,888	428,980	1,082,276	39.6
MARKET AREA				
Washington total, reported by United States Geological Survey	2,555,233	293,177	784,435	37.4
Oregon total, reported by United States Geological Survey	1,219,250	139,137	315,075	44.2
Thompson Falls	201,646	23,019	35,000	65.8
Lewiston and Grangeville	52,560	[1] 6,000	10,625	56.5
Total for market area	4,028,689	461,333	1,145,135	40.3

[1] Estimated.

148. The business of all these utilities is growing rapidly. Frequent increase in generating capacity and other facilities for securing electric power is required to meet the needs of the consumers. Construction programs are constantly under way.

149. Puget Sound Power & Light Co. is now constructing under Federal license a dam and power plant at Rock Island near Wenatchee, Wash. This is the first dam to be built on the Columbia River. Two 15,000 kilowatt units are to be in service by January 1, 1932. The entire capacity of 150,000 kilowatts to 200,000 kilowatts is expected to be needed by 1937.

150. Washington Water Power Co. has applied for a Federal license to develop Kettle Falls on the Columbia 41 miles south of the international boundary. Plans propose an ultimate capacity of 230,000 kilowatts. The original program contemplated completion prior to 1940. The application has been held pending the completion of this report.

151. Portland General Electric Co. is beginning the development of storage on Clackamas River, a tributary of Willamette River, which will increase the firm output of its power plants on that stream. This company has tentative plans for the construction of power plants at other sites on the Clackamas as they are needed to meet its requirements.

152. Seattle has a program for developing the Skagit River with reservoirs and power plants to provide 783,000 kilowatts which it is estimated will meet the growth of the city load for about 15 years.

153. Tacoma, since December 31, 1930, has completed a steam plant with a capacity of 25,000 kilowatts. It is also installing a

second unit with 27,000 kilowatts capacity in the Cushman no. 2 power plant.

154. Inland Power & Light Co. is constructing under Federal license a storage dam and power plant at Ariel on Lewis River, about 36 miles from Portland, Oreg. One 45,000 kilowatt unit will be ready for service in the autumn of 1931. This power site is planned for the installation of three additional units of the same size. The power will be supplied to Northwestern Electric Co. and Pacific Power & Light Co. at Portland, Vancouver, Condit, and elsewhere. Preliminary plans of the company contemplate the progressive development of a number of power and storage sites on Lewis River with a possible ultimate capacity of 1,200,000 kilowatts.

155. Montana Power Co. is constructing under Federal license a 100,000 kilowatt power plant on Flathead River 4 miles below the outlet of Flathead Lake in Montana. This plant is to be completed in 1933 or 1934.

156. Rivers other than the Columbia in the States of Washington and Oregon have undeveloped potential water-power capacities somewhat as indicated in the following table P. The figures in this table have been collected from a number of different sources, official and unofficial. They do not purport to be final and are given merely to show the general extent of available hydropower in the Northwest. The possible sites vary greatly in commercial desirability. On many streams, little is known of the probable cost of developing the potential power. It is to be expected that at many sites the costs will be so great as to make them uneconomical of development in competition with other means of securing power under present conditions or those likely to exist in the future. Insofar as the information is available the figures in table P are given on the basis used by the United States Geological Survey, which assumes 70 percent efficiency and uniform output of 90 or 50 percent of the time. The proper installed capacity would be quite different and would be determined by considerations which are too complicated for inclusion at this time.

TABLE P.—*Undeveloped potential water powers of rivers other than the main Columbia in Washington and Oregon*

River	Estimated potential powers at 70 percent efficiency		River	Estimated potential powers at 70 percent efficiency	
	90 percent of time	50 percent of time		90 percent of time	50 percent of time
	Kilowatts	*Kilowatts*		*Kilowatts*	*Kilowatts*
Tributaries to Columbia:			Other streams:		
Kootenai	154,000	266,000	Skagit	490,000	644,000
Clark Fork	1,140,000	1,950,000	Stilaguamish	79,000	99,000
Spokane	57,000	75,000	Snohomish	168,000	284,000
Wenatchee	195,000	195,000	Puyallup	16,000	24,000
Yakima	97,000	197,000	Siuslaw	39,000	39,000
Snake (below Huntington)	964,000	1,455,000	Umpqua	260,000	410,000
White Salmon	64,000	96,000	Coquille	27,000	27,000
John Day	34,000	48,000	Rogue	292,000	370,000
Deschutes	500,000	540,000	Klamath (Klamath Lake to		
Klickitat	114,000	161,000	Oregon boundary only)	76,000	112,000
Willamette Basin	403,000	783,000	Other streams	194,000	680,000
Kalama		22,000			
Lewis	217,000	232,000	Total other streams	1,641,000	2,689,000
Cowlitz	300,000	353,000			
Minor tributaries	536,000	919,000	Combined total	6,416,000	9,961,000
Total tributaries	4,775,000	7,252,000			

NOTE.—On the same basis Columbia River power within the United States has been estimated to be 3,577,000 kilowatts 90 percent of the time and 5,951,000 kilowatts 50 percent of the time.

POSSIBILITIES ON COLUMBIA RIVER

157. The district engineers submit plans for an ultimate development of Columbia River between tidewater and the international boundary which include power dams at the sites named in table Q and creating maximum heads as there shown.

TABLE Q

Site	Miles from international boundary	Miles from Pacific Ocean	Normal Forebay elevation m.s.l.	Minimum tailwater elevation m.s.l.	Head at natural low water
Above the mouth of Snake River:					*Feet*
Grand Coulee	151	597	1,287.6	933.0	354.6
Foster Creek	202	546	928.6	764.6	164.0
Chelan	244	504	762.0	667.0	95.0
Rocky Reach	274	474	665.0	604.0	61.0
Rock Island	295	453	599.0	548.0	51.0
Priest Rapids	351	397	540.0	405.0	135.0
Below the mouth of Snake River:					
The Dalles (or Big Eddy)	556	192	330.0	54.0	276.0
Warrendale	608	140	54.0	1.0	53.0
Total					1,189.6

158. Plans for the river above the mouth of Snake River have been prepared by the district engineer of the Seattle district (see pt. 2, vol. II of this document). Plans below the mouth of the Snake have been prepared by the district engineer of the Portland district (see pt. 3, vol. II of this document). With one exception each dam as planned will back water practically up to the dam next above, thus making available for power production almost all the head that can be obtained at each site without interference with the next. The exception occurs in the stretch of river between Priest Rapids and Pasco, Wash. It is proposed by the Portland district that The Dalles Dam will back water up to elevation 330. The next dam above, as proposed by the Seattle district is at Priest Rapids where the natural low water is at elevation 405. This leaves a gap of 75 feet between the two elevations. There are no favorable power sites between Priest Rapids and the mouth of Snake River, a short distance below Pasco. Raising the water to an elevation greater than 330 at any site below Pasco will flood part or all of the towns of Pasco and Kennewick, besides causing extensive damages to other property. This has been an important factor in the decision to omit from present consideration the development of the fall existing in this section of the river.

159. Where the Columbia crosses the international boundary the water surface elevation is 1,288.4 at the minimum stage of record (14,000 second-feet). The maximum head proposed to be utilized occurs at natural low water with the ponds full at each dam as shown in table Q. This is the time when high efficiency is particularly important with the unregulated stream, since low water then determines the minimum potential power which is available. The total head utilized at low water is 1,189.6 feet or 92.3 percent of the 1,288.4 feet which the river falls between the Canadian boundary and the Pacific Ocean.

160. It is planned that at each site pondage will be available for use in supplying daily variations of the load. At Grand Coulee and at

The Dalles seasonal storage is provided for increasing the flow of the river during low water stages. The drawing down of the ponds will decrease the head that is utilized. This might be offset in part by making some of the dams slightly higher. At higher stages the total fall from the international boundary to tailwater at Warrendale remains about the same, but the gradient of the river between the dam sites is steepened. This causes the tailwater surface at each site to rise, resulting in a decrease of the head available. Except at locations such as Rocky Reach and Rock Island where at high water the fall will be insufficient for the effective production of power and at sites with seasonal storage, the minimum potential output occurs at time of low water and high head. When higher stages cause the head to be less, it is possible to maintain the output and carry the same peak loads as under low water conditions provided sufficient turbine capacity is installed.

161. With the information now available a combination of the plans of the two districts seems well suited to conserve and develop the potential power of the waters of the Columbia and to form a comprehensive plan for the river as a whole.

162. The flow of the Columbia is contributed by watersheds differing widely in character. The low flow is tripled and the flood flow nearly doubled by tributaries which enter between the Canadian boundary and tidewater. Proportionately its variation between extreme maximum and minimum is less than for other rivers of the western portion of the United States. The principal run-off comes from melting snow fields in high mountainous areas. Flood stages normally occur during May and June in the upper river and in June and July in the lower river. The flow is well maintained throughout the summer. Low water occurs during the winter months. Occasional brief periods of severely cold winter weather in the interior valley are the usual cause of extremely low stages of the river.

163. During recent years the West has received an annual precipitation markedly lower than the recorded average. This is directly reflected in the run-off of the Columbia on which records have been kept at The Dalles since 1878. Such changes in precipitation appear to be more or less cyclic in character. Present scientific knowledge is not sufficient to make it possible to determine the length of time during which drouths will continue nor when they may recur. For the purpose of this report estimates of the amount of electrical energy which may be secured from the Columbia have been based on the records of the 17-year period from April 1, 1913, to March 30, 1930, excluding the years prior to 1913 with their larger run-off. Spillways for dams have been designed to carry floods 25 per cent or more in excess of the maximum known flood which was recorded in June 1894.

164. Irrigation is important in the arid valleys east of the Cascades. The irrigation season is more or less coincident with the period when natural stream flow is above its average. Much of the water diverted for irrigation returns slowly to the river by percolation. This has an equalizing effect upon the flow. Diversions decrease the floods. Percolating waters increase the low water flows.

165. On the headwaters of the Columbia and its northern tributaries are a number of large lakes which act as natural detention reservoirs to equalize the flow. Their possibilities are described at some

length in the report of the Seattle district. Principal among them are the following:

Lake	River	Location	Lake	River	Location
Upper Arrow	Columbia	British Columbia.	Priest	Priest	Idaho.
Lower Arrow	do	Do.	Coeur d' Alene	Spokane	Do.
Kootenay	Kootenay	Do.	Okanogan	Okanogan	British Columbia.
Flathead	Flathead	Montana.	Chelan	Chelan	Washington.
Pend Oreille	Clark Fork	Idaho.	Wenatchee	Wenatchee	Do.

166. Coeur d' Alene and Chelan Lakes are now regulated in the interests of power development. Construction has been begun which will regulate Flathead Lake. Each of the lakes has further possibilities as a controlled reservoir to maintain the flow of the Columbia River for power production beyond the effect of natural regulation. It is possible to create a large reservoir by a dam on the south fork of Flathead River, a tributary to Clark Fork, at the Hungry Horse site in Montana. A smaller reservoir can be constructed on the Chiwawa River in Washington. Some pondage, enough for daily regulation, will be available at each of the power dams proposed for the Columbia. In addition, important quantities of water to aid in maintaining the power supply during the winter months can be stored in the reservoirs created by the proposed dams at the Grand Coulee and The Dalles sites.

167. The plans for Columbia River proposed in the district reports contemplate that ultimately storage will be available for use as needed for irrigation and power to the following extent:

Reservoirs	Useful storage	Reservoirs	Useful storage
	Acre-feet		*Acre-feet*
Hungry Horse	1, 100, 000	Chelan	665, 000
Flathead	1, 540, 000	Wenatchee	1, 000, 000
Priest	569, 000	Chiwawa	482, 000
Pend Oreille	1, 610, 000	The Dalles	4, 625, 000
Kootenay (British Columbia)	715, 000		
Couer d'Alene	430, 000	Total	17, 764, 000
Grand Coulee	5, 028, 000		

168. A number of possible power sites have been investigated and considered, but have not been included because they do not fit into the most desirable plan. The sites thus eliminated are listed below. Some of them have characteristics which make them physically good as independent dam and power sites. Others lack essential or important qualifications.

Site	Miles from international boundary	Miles from Pacific Ocean	Site	Miles from international boundary	Miles from Pacific Ocean
Little Dalles	15	733	Blalock Rapids	514	234
Kettle Falls	41	707	Four o'Clock Rapids	516	232
Gaviota	188	560	Squally Hook Rapids	525. 5	222. 5
Wells	231	517	John Day Rapids	532	216
Vantage	325	423	Biggs Rapids	541	207
Homly Rapids	430	318	Five Mile Rapids	554. 5	193. 5
Wallula	435	313	Three Mile Rapids	558	190
Umatilla Rapids	456	292	Wind Mountain	593	155
Canoe Encampment Rapids	484	264	Cascade Rapids	601	147
Arlington	506	242	Bonneville	605	143

169. The following paragraphs contain a brief description of the physical conditions at the power sites which are incorporated in the plans proposed by the districts.

170. *Grand Coulee.*—This site is of particular importance in connection with the comprehensive plan because of its location at the head of an ancient water course known as the Grand Coulee, a prominent topographic feature of the vicinity. It is proposed to use this old channel as a storage reservoir and canal in connection with the pumping plan for irrigation of the lands of the Columbia Basin irrigation project. The floor of the Coulee is at elevation 1,500 or about 600 feet above the present channel of the Columbia. A dam at this site not only serves to provide power for pumping, but by raising the natural water surface of the river it decreases the pumping lift. The drainage area of the Columbia River above this site is 74,000 square miles. The canyon is 700 feet deep, 2,000 feet wide at the bottom, 1 mile wide at top. Granite outcrops on the canyon walls with basalt on rim of left bank. Average elevation of natural river bed is 910 feet. Natural low water elevation 933. Subsurface conditions have been investigated with 16 drill holes. Bedrock (granite) extends across the river at about elevation 870 for 2,500 feet and rises with 2:1 slopes on the canyon sides. The granite is dense with few seams. Overburden is 40 feet thick in center of stream and 200 feet thick at toes of slopes. It consists of 40 feet of blue clay next to the bedrock covered by boulders, gravel, and sand. Proposed dam will raise water surface to elevation 1,287.6 feet. At this elevation length of pool will be 151 miles and the area of water surface 74,900 acres. Land overflowed is mostly barren canyon and damages to property will be comparatively small (estimated at $6,661,200).

171. *Foster Creek.*—Drainage area is 75,500 square miles. At low water the river is 500 to 600 feet wide. Natural low water surface elevation is 765 feet. The south (left) bank is fairly flat and irregular and is composed of solid granite bedrock with little overburden. The north (right) bank rises about 250 feet above the water on a steep slope to a comparatively level bench. Six drill holes were put down at or near the site to explore subsurface conditions. Granite with some overburden apparently is continuous across the channel. On the north bank the granite bedrock extends horizontally beneath the bank at an average elevation of 755 feet. It outcrops three quarters of a mile north of the river at an elevation of 1,100 feet. The overburden above the granite is a glacial till composed of heterogeneous mixture of boulders, gravel, and sand, and contains enough clay to insure the closing of the voids and prevention of water percolation. The proposed dam will raise the water surface to elevation 928.6 feet. At this elevation the length of the pool will be 51 miles and the area 7,400 acres. Land overflowed is mostly in the canyon and valueless. The total damages are estimated at only $50,000.

172. *Chelan.*—Drainage area is 85,500 square miles. The main valley is about 2,200 feet wide, the low water channel from 500 to 600 feet wide and is close to the east (left) bank. Natural low water elevation is 667 feet. Test borings indicate that bedrock is probably continuous across the valley at elevation between 500 and 600 feet. It consists mainly of gneiss with minor quantities of mica schist and granite. Overburden is principally sand and gravel intermixed

with cobblestones and small boulders. Further investigation is necessary to determine definitely the porosity of the material and the suitability of foundation conditions for the construction of a dam. The proposed dam will raise the water surface to elevation 762 feet. At this elevation the pool will be 42 miles long and have an area of 9,200 acres. The land overflowed is mostly barren sagebrush desert, and with the exception of about 16 miles of railroad to be relocated the damages are small. The damages are estimated at $1,200,000.

173. *Rocky Reach.*—Drainage area is 87,200 square miles. The natural channel is 1,200 to 1,500 feet wide. Natural low water elevation is 604 feet. An isolated butte of gneiss and granite rising to an elevation of about 1,150 feet, east of the present channel, separates it from a dry channel which is about 75 feet above the present low water. A test hole drilled on the right bank opposite the upstream end of this butte shows the overburden to be 100 feet deep. Further investigation is necessary to determine the feasibility of this site. The proposed dam will raise the water surface elevation to 665 feet. At this elevation the pool would be 30 miles long and have an area of 5,400 acres. Construction of this dam would require the revision of about 5 miles of railroad and highway. Damages are estimated at about $400,000.

174. *Rock Island.*—Drainage area is 88,700 square miles. The local formation is a basalt resulting from lava flows of unusual thickness. Rock Island divides the river into two channels each approximately 200 feet wide at low water. The site is now being developed by Puget Sound Power & Light Co. under license 943 of the Federal Power Commission. The proposed dam will raise the water surface elevation to 599. At this elevation the pool will be 20 miles long and have an area of 2,250 acres.

175. *Priest Rapids.*—Drainage area is 95,400 square miles. Except at extreme high water, the river is divided into two channels at this site by Panhandle Island. The low water channel just below the site is about 2,000 feet wide. Natural low water elevation is 405 feet. The country rock in the vicinity is basalt. Test borings by a private company several thousand feet upstream from the present site have been made available, but no subsurface data are available at this site. The proposed dam will raise the water surface elevation to 540 feet. At this elevation the pool will be 57 miles long and have an area of 34,200 acres. Damages are estimated at $3,063,000.

176. *The Dalles.*—Drainage area is 237,000 square miles. Columbia River basalt, with no overburden, occurs along the margin of the river on both sides and in the channel. At the dam site the channel has a depth of 150 feet at low water. Natural low water elevation is 46 feet. Test holes put down at this site penetrated successive flows of basalt for over 260 feet. At this depth they were 90 feet below the bottom of the channel and 190 feet below sea level. The proposed dam will raise the water surface to elevation 330 feet. At this elevation the pool will be 147 miles long and have an area of 140,000 acres. The area inundated at this elevation contains several small towns, about 7,000 acres of irrigated farm land, and would require the revision of 323 miles of railroad and 103 miles of main highway. Damages are estimated at $71,300,000.

177. *Warrendale.*—Drainage area is 240,000 square miles. The river is divided into a main and a secondary channel by low sand islands or bars. The main channel next to the Oregon shore is 800 to 1,400 feet wide, and the secondary channel is about 500 feet wide at low water. The greatest depth at low water in the main channel is 40 feet and the average depth 25 feet. The secondary channel carries very little water at low stages. Extreme low water elevation is 1 foot above mean sea level. Beacon Rock, an andesite upthrust, is a prominent landmark which stands practically at the water's edge on the Washington shore. There is no surface indication that rock of any kind is to be found at reasonable depth anywhere in the river bed. One test hole drilled on the north side of the main channel went to elevation −144 in sand and sand and gravel. This material is unconsolidated river-carried sediments filled into the buried former channel of the Columbia River. The proposed dam would raise the water-surface elevation to 54 feet. At this elevation the pool would be 50 miles long and have an area of 22,000 acres. Property damage would be comparatively small, including the moving of the Oregon State fish hatchery, the purchase of a private cannery, and the revision of 17 miles of railroad and 2 miles of main highway. Total damages are estimated at $3,600,000.

178. Selection of an ultimate plan for their respective sections of the Columbia River development was one of the last steps in the studies made by the district engineers. From a consolidation of these a comprehensive plan for the entire river has been prepared. Time has not permitted a revision and recomputation of all district estimates to put them on the basis of the comprehensive plan. However, it is believed that the data given in parts 2 and 3 of this combined report and summarized in the following pages give a fair picture of the results which may be expected from the plan.

179. Extremes of flow and the mean flow, as used in the preparation of the district engineer's studies of each of the sites, are shown in table R, together with the corresponding natural water surface.

TABLE R.—*Records of flow on Columbia River and corresponding natural water surface elevations*

Location	Period April 1913 to March 1930					June 1894, maximum record for all time	
	Minimum record		Mean	Maximum record			
	Flow	Elevation	Flow	Flow	Elevation	Flow	Elevation
	Sec.-ft.	*M.S.L.*	*Sec.-ft.*	*Sec.-ft.*	*M.S.L.*	*Sec.-ft.*	*M.S.L.*
International boundary	14,000	1,288.4	99,000	450,000	1,333.3	700,000	1,347.5
Grand Coulee	17,000	933.0	109,000	462,000	948.0	725,000	1,003.0
Foster Creek	17,000	764.6	109,000	492,000	798.6	725,000	814.0
Chelan	17,600	667.0	113,000	500,000	713.0	735,000	724.0
Rocky Reach	20,300	604.0	117,000	510,000	641.5	735,000	665.7
Rock Island	21,000	548.0	121,000	528,000	589.5	740,000	600.0
Priest Rapids	21,000	405.0	121,000	528,000	431.0	740,000	445.0
The Dalles	40,000	43.0	185,000	800,000	[1] 94.0	1,170,000	[1] 110.0
Warrendale	43,000	1.0	190,000	800,000	37.5	1,170,000	47.6

[1] Natural water surface at The Dalles site for 800,000 second-feet is 102.5; for 1,170,000 second-feet it is 114.5. The proposed design diverts flood water from the present channel. Due to this change there would be less back water at the power house, and it is estimated that the results shown in the table will be obtained.

180. Preliminary designs of dams have been made for each of the sites included in the proposed plan and also for a number of other sites that were considered. While the available data are insufficient to permit final conclusions on the best designs and methods of construction, it is believed that the present studies give a reasonable basis for estimating the cost of the structures and the time which will be needed for their construction. This statement should be qualified as to the sites known as Chelan, Rocky Reach, and Warrendale, for which the studies and subsurface explorations have been insufficient to establish with finality their suitability as dam sites. A dam at Rock Island is now being constructed by the Puget Sound Power & Light Co. under Federal license. It is therefore omitted from the estimates which follow, although other data concerning it are included where appropriate. Table S, which follows, summarizes some statistical data contained in the reports of the district engineers.

TABLE S.—*Design of dams*

Site	Type of section	Length	Maximum height to walkway		Minimum free board[1]	Spillway		Depth on crest designed capacity
			Above foundations	Above low water		Designed capacity	Clear length	
		Feet	*Feet*	*Feet*	*Feet*	*Sec.-ft.*	*Feet*	*Feet*
Grand Coulee	Gravity overflow	2,800	490	370	13	910,000	700	16
	Bulkhead	1,490			13		1,680	23
Total		4,290					2,380	
Foster Creek	Gravity overflow	1,390	220	179	15	910,000	1,064	35
	Canal Gate section	320			15			
	Earth fill	290			15			
Total		2,000					1,064	
Chelan	Combination	4,540	150	95	13	940,000	1,770	28
Rocky Reach	Curved gravity overflow	2,500	100	81	3	960,000	1,950	43
Priest Rapids	Gravity overflow	3,270	202	145	10	1,000,000	2,460	22
	Bulkhead	700			10			
	Earth fill	6,580			10			
	Power-house intake	1,150			10			
Total		11,700						
The Dalles	Bulkhead	4,900	440	294	10			
	Power-house intake	2,700			10			
	Multiple arch	5,200			10			
	Gravity overflow	2,500			10	1,400,000	2,210	30
	Earth fill	4,700			15			
Total		20,000						
Warrendale	Spillway section	2,200				1,400,000	2,200	30
	Power-house section	1,800	101	84	3			
	Abutment section	2,000			3			
Total		6,000						

[1] Figures given for minimum free board show clearance above water surface when spillway is discharging at designed capacity.

181. The comprehensive plan contemplates that ultimately 5,764,000 acre-feet of storage capacity will be provided on tributaries of the Columbia above Grand Coulee. With these reservoirs it is estimated that the minimum flow of the river at Grand Coulee can be increased from 17,000 second-feet to 32,900 second-feet. The Seattle district has drawn comparisons of the power sites above the mouth of Snake River based on this regulation. (See table T.)

182. Without assuming any benefit from upstream regulation of the flow of the river, the Portland district has determined that the minimum daily flow at The Dalles can be increased from 40,400 second-feet to 70,000 second-feet by the use of 4,625,000 acre-feet of storage contained in the upper 40 feet of the reservoir which would be created by The Dalles dam. This regulation may be used to produce 1,450,000 prime kilowatts. The same minimum flow at Warrendale would produce 240,000 prime kilowatts. The Portland district has prepared estimates based on this regulation.

183. The figures presented by the districts to illustrate the power possibilities of the several sites under the above conditions are given in table T.

TABLE T.—*Limiting conditions controlling power output of 17-year period from April 1913 to Mar. 31, 1930, as assumed by district engineers. (See pts. 2 and 3, Vol. II of this document)*

Power site	Average natural flow for maximum month	Head corresponding to flow of (2)	Hydraulic capacity of plant with head in (3)	Full gate capacity of installation at head in (3) limiting peak load	Average regulated flow in minimum month [1]	Head corresponding to flow in (6)	Average output in month of minimum flow, prime power	Minimum load factor for prime power	Installed capacity used in layout and estimates
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Sec.-ft.	*Feet*	*Sec.-ft.*	*Kilowatts*	*Sec.-ft.*	*Feet*	*Kilowatts*	*Percent*	*Kilowatts*
Above Snake:									
Grand Coulee	436,000	307.5	65,000	1,359,000	32,900	351.4	785,000	58.0	1,575,000
Foster Creek	436,000	132.4	76,000	684,000	32,900	163.8	366,000	53.5	691,200
Chelan	455,000	52.0	100,000	354,000	34,500	92.1	216,000	61.0	450,000
Rocky Reach	466,000	26.2	100,000	178,000	36,600	58.5	146,000	82.0	336,000
Rock Island	480,000	25.0	85,000	145,000	39,400	50.0	134,000	82.5	180,000
Priest Rapids	480,000	110.7	83,000	625,000	39,900	131.3	356,000	57.0	648,000
Below Snake:									
The Dalles	[2] 800,000	234.5	140,700	2,900,000	70,000	272.5	1,450,000	50.0	3,800,000
Warrendale	[2] 800,000	31.5	254,500	480,000	70,000	50.0	240,000	50.0	836,000

[1] For sites above the mouth of the Snake this flow is taken as conforming to the Seattle district plan for regulation with reservoirs on tributary streams but no use of Columbia River storage (designated in part 2 as plan 4, case 6). For sites below the mouth of the Snake this flow assumed use of storage created by the Dalles dam but no benefit from other storage.

[2] Flow for maximum day of 17-year period.

184. Details of the estimates of cost of the dams and power plants for which data has been given in tables S and T will be found in the district reports. For each site estimates include cost of flowage rights and damages in connection with the acquisition of rights of way for the reservoirs; preliminary and construction costs of dam, power house, and all accessories; an allowance of 10 percent for contingencies and a further allowance of 12.5 percent for engineering and overhead expenses. The length of time required for construction is estimated, and interest during construction is computed for both 4 and 6 percent money.

185. In comparing sites of such widely different productive capacities, it is necessary to take into account the length of time that the market may require for absorption of the possible output. This is done by capitalizing the "carrying charges" or interest that will accumulate on part of the investment between the time that operation is begun and the time when the growth of the market is sufficient to absorb all the prime power. For this purpose it has been assumed that beginning with 1940 one half of the estimated growth of the power

market in the Pacific Northwest would be available to load any one plant.

186. A brief summary of the estimated investment required for power sites which are part of the comprehensive plan is given in table U. No investment in reservoirs on tributary streams is included.

TABLE U.—*Estimated investment at power sites*

[Installed generating capacity as given in table T]

Site and item	Investment	
	4 percent money	6 percent money
Grand Coulee:		
Dam and reservoir	$138, 736, 160	$147, 180, 969
Power house and machinery	32, 450, 617	34, 425, 872
Total construction	171, 186, 777	181, 606, 841
Carrying charges	33, 296, 676	52, 985, 149
Total investment	204, 483, 453	234, 591, 990
Foster Creek:		
Dam and reservoir	24, 524, 372	25, 639, 116
Power house and machinery	21, 696, 684	22, 682, 897
Total construction	46, 221, 056	48, 322, 013
Carrying charges	2, 942, 924	4, 615, 041
Total investment	49, 163, 980	52, 937, 054
Chelan:		
Dam and reservoir	22, 676, 864	23, 516, 747
Power house and machinery	14, 968, 465	15, 522, 853
Total construction	37, 645, 329	39, 039, 600
Carrying charges	1, 814, 149	2, 822, 010
Total investment	39, 459, 478	41, 861, 610
Rocky Reach:		
Dam and reservoir	23, 682, 057	24, 559, 171
Power house and machinery	12, 931, 840	13, 410, 797
Total construction	36, 613, 897	37, 969, 968
Carrying charges	1, 420, 923	2, 210, 325
Total investment	38, 034, 820	40, 180, 293
Priest Rapids:		
Dam and reservoir	41, 301, 632	43, 178, 978
Power house and machinery	16, 590, 710	17, 344, 833
Total construction	57, 892, 342	60, 523, 811
Carrying charges	4, 956, 196	7, 772, 216
Total investment	62, 848, 538	68, 296, 027
The Dalles:		
Dam and reservoir	190, 297, 000	198, 950, 000
Power house and machinery	83, 743, 000	87, 600, 000
Total construction	274, 040, 000	286, 550, 000
Carrying charges	70, 460, 000	110, 450, 000
Total investment	344, 500, 000	397, 000, 000
Warrendale:		
Dam and reservoir	23, 020, 000	23, 660, 000
Power house and machinery	40, 970, 000	42, 140, 000
Total construction	63, 990, 000	65, 800, 000
Carrying charges	3, 010, 000	4, 560, 000
Total investment	67, 000, 000	70, 360, 000
Grand total investment	805, 490, 269	905, 226, 974

187. The estimates of the annual charges for the several sites are contained in table V. Allowances for interest, amortization, and tax items for the sites above Snake River as contained in the estimates of the Seattle district (pt. 2) have been increased to cover the extra investment represented by "carrying charges." The annual charges are given for both 4 percent money, corresponding to public construction, and 6 percent money, corresponding to construction by a large corporation. The estimated available prime output in kilowatt-hours per year is also given. From the annual cost and output the cost per kilowatt-hour is directly computed and shown in the final column of table V. In presenting these figures certain differences in the basis of estimate should be noted. The installed capacity of the power plants on which the estimates have been based does not bear a uniform relationship to the amount of prime power that can be produced by the sites. (See table T.) This is illustrated by the load factors necessary to be maintained to produce the prime power with the installed equipment. Estimates of output at sites above the mouth of Snake River reflect benefits assumed to be received from regulatory storage on tributary streams, but the cost of this storage is not included. At the Grand Coulee site a large storage reservoir is created on Columbia River. The figures include the cost of this reservoir but do not reflect any use of it except as the high dam increases the head on the power plant. At The Dalles also the proposed dam creates a large reservoir. In this case both the cost of the reservoir and its use to regulate the flow and increase the prime power are reflected in the estimates. At Warrendale it is assumed that regulated flow from The Dalles will be available.

TABLE V.—*Estimated annual charges, available prime output, and cost per kilowatt-hour installed generating capacity as given in table T*

Site	Load factor	Operation and maintenance	Depreciation	Interest	Amortization	Taxes	Total cost	Annual prime output	Cost
	4 percent money								
	Percent							*1,000 kw.-hr.*	*Mills/ kw.-hr.*
Above Snake River:									
Grand Coulee	79.5	$151,758	$665,239	$8,179,338	$2,147,076	----------	$11,143,411	7,945,000	1.40
Foster Creek	53.5	148,616	402,934	1,966,559	516,222	----------	3,034,331	3,206,160	.94
Chelan	61.0	148,616	279,753	1,578,379	414,325	----------	2,421,073	1,892,160	1.28
Rocky Reach	82.0	148,616	247,072	1,521,393	399,366	----------	2,316,447	1,278,960	1.81
Priest Rapids	57.0	148,616	325,905	2,513,942	659,910	----------	3,648,373	3,118,560	1.17
Below Snake River:									
The Dalles	50.0	760,000	1,566,000	13,780,000	3,618,000	----------	19,724,000	12,702,000	1.55
Warrendale	50.0	380,000	744,000	2,680,000	703,500	----------	4,507,500	2,102,400	2.14
	6 percent money								
Above Snake River:									
Grand Coulee	79.5	$151,758	$454,680	$14,075,519	----------	$3,518,880	$18,200,837	7,945,000	2.29
Foster Creek	53.5	148,616	289,740	3,176,223	----------	794,056	4,408,635	3,206,160	1.37
Chelan	61.0	148,616	198,695	2,511,697	----------	627,924	3,486,932	1,892,160	1.84
Rocky Reach	82.0	148,616	172,915	2,410,817	----------	602,704	3,335,052	1,278,960	2.62
Priest Rapids	57.0	148,616	225,740	4,097,762	----------	1,024,440	5,496,558	3,118,560	1.76
Below Snake River:									
The Dalles	50.0	760,000	1,130,000	23,820,000	----------	5,955,000	31,665,000	12,702,000	2.49
Warrendale	50.0	380,000	538,400	4,222,000	----------	1,055,000	6,195,400	2,102,400	2.95

188. In view of the differences cited it is apparent that the figures of tables U and V, and particularly the unit costs per kilowatt-hour, are not directly comparable. They do not represent the results to be secured at an individual site if it were developed independently. However, they do indicate that any of the sites, but particularly Foster Creek and Priest Rapids, can produce power very cheaply as part of a general plan in which the flow of the river is regulated by large reservoirs. When the decision was reached to include, as part of the comprehensive plan, a high dam at Grand Coulee which would back the water of the Columbia River to the international boundary, it became apparent that the 5,028,000 acre-feet of useful storage which would be made available in the upper 80 feet of the reservoir thus created would make regulation of the river possible without depending upon the construction of upstream reservoirs. The Seattle district engineer estimates that with this 5,028,000 acre-feet the minimum flow at Grand Coulee can be increased to an average of 40,400 second-feet during the 182-day period from October 1, 1929, to March 31, 1930, which is the controlling low-water period of the 18 years from April 1913 to March 31, 1931. This minimum is obtained after allowing 1,000 second-feet for winter diversion to the Columbia Basin irrigation project. This gives a basis for considering the economics of the Columbia River Dam and power plant at Grand Coulee as a source of electric power independently of other construction included in the comprehensive plan. It also makes it possible to compare the economics of this site and of the site at The Dalles.

189. This comparison is of particular value because among the seven undeveloped power sites included in the comprehensive plan, Grand Coulee and The Dalles are of outstanding importance, not only on account of their size and the regulatory storage which they provide, but because of their strategic location. The Columbia River Dam at Grand Coulee is essential to the Columbia Basin irrigation project for reducing the pumping lift and supplying power for pumping. The Dalles Dam would reduce the pumping lift to irrigation projects below the mouth of the Snake and could supply power for pumping to these and other projects. It would improve the navigability of the Columbia and Snake Rivers by submerging all obstructions between The Dalles and the mouth of Snake River by raising the low-water surface at the latter point about 17 feet. Regulatory storage at Grand Coulee would benefit all the other power sites on the river. Storage at The Dalles would be beneficial at the Warrendale site. The relative distances of the two sites from the principal prospective power markets are not greatly different.

190. To secure a direct comparison of Grand Coulee and The Dalles developments with each other, each as an independent entity, though, in fact, elements of the comprehensive plan, the estimates that immediately follow do not take into account any benefit which may ultimately be secured from upstream regulation nor any abstraction of power for irrigation use.

191. At Grand Coulee the regulation is assumed to be for an average flow of 40,400 second-feet during the 182 days above mentioned and for the equivalent of prime power of 907,000 kilowatts, or an annual prime output of 7,945,000,000 kilowatt-hours. The average flow for the maximum month of the 17-year period from April 1, 1913, to March 31, 1930, was 436,000 second-feet. The corresponding head

is 307.5 feet. At this head the full gate capacity of the turbines and generators included in the estimate is computed to be 1,359,000 kilowatts. However, the assumptions made involve an 80-foot draw-down of the reservoir. With the reservoir empty the head will be reduced to 270 feet.[5] At a head of 270 feet the 15 generating units would have a full gate capacity of 1,140,000 kilowatts. This, then, determines the limiting peak load of the installation, and makes 79.5 percent of the minimum load factor for prime power under the stipulated conditions. The estimated investment for this installation is given in table U. The estimated annual charges are given in table V.

192. At The Dalles the regulation is assumed to be for an average flow of 70,000 second-feet during the minimum month and for prime power of 1,450,000 kilowatts, or an annual prime output of 12,702,000,000 kilowatt-hours. The maximum flood for the 17-year period from April 1, 1913, to March 31, 1930, was nearly 800,000 second-feet. The corresponding head is 234.5 feet. At this head the capacity of the 38 turbines and generators included in the Portland estimate is 2,900,000 kilowatts. At this site the assumptions involve a 40-foot draw-down of the reservoir. Under this condition the head will also be 234.5 feet.[6] In order to modify the figures for The Dalles and put them on a basis comparable with those for Grand Coulee, advantage has been taken of the flexibility of the Portland methods to reduce the size of the Dalles power plant to 24 units, with a peak output of 1,987,000 kilowatts at 234.5-foot head, such as would be appropriate for producing the prime power of 1,450,000 kilowatts at a minimum load factor of 79.5 percent. The Portland district has prepared estimates of investment and annual charges to apply to this condition at The Dalles. These figures are shown in table W with the corresponding figures for Grand Coulee in parallel columns.

TABLE W.—*Comparison of investment and operating results for power sites at Grand Coulee and at The Dalles estimated to operate at 79.5 percent load factor*

Item	4 percent money		6 percent money	
	Grand Coulee	The Dalles	Grand Coulee	The Dalles
Investment:				
Dam and reservoir	$138,736,160	$193,520,000	$147,180,969	$202,370,000
Power house and machinery	32,450,617	54,040,000	34,425,872	56,490,000
Total construction	171,186,777	247,610,000	181,606,847	258,860,000
Carrying charges	33,296,676	69,600,000	52,985,149	109,100,000
Total investment	204,483,453	317,210,000	234,591,990	367,960,000
Annual charges:				
Operation and maintenance	151,758	480,000	151,758	480,000
Depreciation	665,239	1,040,000	454,680	734,000
Interest	8,099,338	12,688,000	14,075,519	22,078,000
Amortization	2,147,076	3,331,000		
Taxes			3,518,880	5,519,000
Total	11,063,411	17,539,000	18,200,837	28,811,000
Prime output per year...1,000 kilowatt-hours	7,945,000	12,702,000	7,945,000	12,702,000
Cost per kilowatt-hour...mills	1.40	1.38	2.29	2.27

[5] At the estimated maximum flood stage of 910,000 second-feet for which the spillway is designed the head available at the power house would be 267.6 feet.

[6] At the estimated maximum flood stage of 1,400,000 second-feet the head would be reduced to 222 feet. At this head the capacity of the 38 units would be 2,850,000 kilowatts. Such a flood has not occurred since records were begun in 1878. During the June 1894 flood, which reached a peak of 1,170,000 second-feet, the minimum head would have been 225 feet and the peak capacity of the 38 units 2,919,000 kilowatts. The average occurrence of floods greater than 800,000 second-feet is less than 2 days per year. The studies made in both districts have disregarded such extremes in the computation of prime power output.

193. The above figures should be used only for the purpose for which they are intended—namely, for a comparison of the probable cost of power generated at the two sites under the specified conditions. A load factor of 79.5 percent is too high to be commercially attainable under ordinary conditions. It is here used for comparison because of the limited number and size of units included in the estimate for Grand Coulee.

194. The annual load factor on large utility systems with the usual commercial diversification in types of service is ordinarily not in excess of 55 percent. Detailed estimates have not been made to determine the amount of the expenditure that might be necessary to increase the power-house installation at Grand Coulee to a size appropriate for producing, at 55 percent of other load factors, the prime power which would be available if the controlling low flow of the Columbia were regulated to 40,400 second-feet. However, the uncertainty due to lack of these estimates involves a relatively small part of the total cost of the Grand Coulee development. Under the existing conditions a reasonable approximation of the effect which such a change in the power-house installation might have upon the cost per kilowatt-hour can be obtained by adjusting the cost to compare with the analysis which has been made in Portland for The Dalles. These costs per kilowatt-hour for various load factors at Grand Coulee and The Dalles are given in table X. Here again it is assumed that one half the estimated growth of the power market will be taken by the plant. Beginning on this basis in 1940, it would take 12 years to absorb the prime output at Grand Coulee and 17 years at The Dalles.

TABLE X.—*Cost per kilowatt-hour with capacity of power plants adjusted to generate the given prime power but at different load factors*

Load factor	Grand Coulee (prime output, 7,945,000,000 kilowatt-hours)		The Dalles (prime output, 12,702,000,000 kilowatt-hours)	
	4 percent money	6 percent money	4 percent money	6 percent money
	Mills	*Mills*	*Mills*	*Mills*
100	1.34	2.21	1.33	2.20
85	1.38	2.26	1.36	2.26
79.5	1.40	2.29	1.38	2.28
75	1.42	2.31	1.40	2.30
65	1.46	2.35	1.45	2.36
55	1.52	2.43	1.51	2.44
50	1.55	2.47	1.55	2.48

195. The figures in table X show the cost of energy delivered at the switchboard of the generating station. Table Y has been prepared for a wide range of load factors to show the cost of energy from Grand Coulee and The Dalles when delivery is made at load centers. (For transmission costs see tables M and N.) Comparison is made for areas centering at Seattle, Portland, and Spokane.

TABLE Y.—*Estimated cost per kilowatt-hour of energy generated at Grand Coulee and The Dalles power sites and delivered at the load centers*

Load center	Load factor	Grand Coulee			The Dalles		
		Cost of generation	Cost of transmission	Total cost at load center	Cost of generation	Cost of transmission	Total cost at load center
	4 percent money						
	Percent	*Mills*	*Mills*	*Mills*	*Mills*	*Mills*	*Mills*
Seattle	100	1.34	0.36	1.70	1.33	0.53	1.86
	85	1.38	.43	1.81	1.36	.62	1.98
	79.5	1.40	.45	1.85	1.38	.66	2.04
	75	1.42	.48	1.90	1.40	.70	2.10
	65	1.46	.55	2.01	1.45	.81	2.26
	55	1.52	.66	2.18	1.51	.96	2.47
	50	1.55	.72	2.27	1.55	1.02	2.57
Portland	100	1.34	.53	1.87	1.33	.18	1.51
	85	1.38	.62	2.00	1.36	.22	1.58
	79.5	1.40	.66	2.06	1.38	.23	1.61
	75	1.42	.70	2.12	1.40	.25	1.65
	65	1.46	.81	2.27	1.45	.29	1.74
	55	1.52	.96	2.48	1.51	.33	1.84
	50	1.55	1.02	2.57	1.55	.35	1.90
Spokane	100	1.34	.18	1.52	1.33	.47	1.80
	85	1.38	.22	1.60	1.36	.56	1.92
	79.5	1.40	.23	1.63	1.38	.59	1.97
	75	1.42	.25	1.67	1.40	.63	2.03
	65	1.46	.29	1.75	1.45	.72	2.17
	55	1.52	.33	1.85	1.51	.86	2.37
	50	1.55	.36	1.91	1.55	.95	2.50
	6 percent money						
Seattle	100	2.21	.47	2.68	2.20	.67	2.87
	85	2.26	.55	2.81	2.26	.79	3.05
	79.5	2.29	.58	2.89	2.28	.84	3.12
	75	2.31	.62	2.93	2.30	.90	3.20
	65	2.35	.70	3.05	2.36	1.00	3.36
	55	2.43	.85	3.28	2.44	1.22	3.66
	50	2.47	.94	3.31	2.48	1.30	3.78
Portland	100	2.21	.67	2.88	2.20	.24	2.24
	85	2.26	.79	3.05	2.26	.28	2.54
	79.5	2.29	.84	3.13	2.28	.30	2.58
	75	2.31	.90	3.21	2.30	.32	2.62
	65	2.35	1.00	3.35	2.36	.37	2.73
	55	2.43	1.22	3.65	2.44	.44	2.88
	50	2.47	1.35	3.82	2.48	.48	2.96
Spokane	100	2.21	.24	2.45	2.20	.58	2.78
	85	2.26	.28	2.54	2.26	.71	2.97
	79.5	2.29	.30	2.59	2.28	.76	3.04
	75	2.31	.32	2.63	2.30	.80	3.10
	65	2.35	.37	2.72	2.36	.90	3.26
	55	2.43	.44	2.87	2.44	1.09	3.53
	50	2.47	.48	2.95	2.48	1.16	3.64

196. At present about twice as much electrical energy is consumed in the Puget Sound (Seattle) area as is used in the area of which Portland is center. Assuming the power output of either Grand Coulee or The Dalles to be divided in this proportion between these load centers, the weighted average cost per kilowatt-hour for the two sites is given in table Z. For comparison there are also given in table Z corresponding average costs assuming the energy is divided equally between the Seattle and Portland centers.

TABLE Z.—*Estimated cost per kilowatt-hour of energy generated by steam power with fuel oil at $1 per barrel, compared with weighted average of estimated cost per kilowatt-hour generated at Grand Coulee and The Dalles power sites and delivered to load centers in the proportion indicated*

Load factor	Energy generated by steam power	Energy delivered			
		⅔ at Seattle, ⅓ at Portland		½ at Seattle, ½ at Portland	
		From Grand Coulee	From The Dalles	From Grand Coulee	From The Dalles
	6 percent money	4 percent money			
	Mills/kw.-hr.	*Mills/kw.-hr.*	*Mills/kw.-hr.*	*Mills/kw.-hr.*	*Mills/kw.-hr.*
100	3.38	1.76	1.74	1.78	1.69
85	3.62	1.87	1.85	1.90	1.78
79.5	3.72	1.92	1.90	1.95	1.83
75	3.82	1.97	1.95	2.01	1.88
65	4.15	2.09	2.09	2.14	2.00
55	4.53	2.25	2.26	2.33	2.15
50	4.75	2.37	2.35	2.42	2.24
		6 percent money			
100	3.38	2.75	2.73	2.78	2.65
85	3.62	2.89	2.88	2.93	2.79
79.5	3.72	2.97	2.94	3.01	2.85
75	3.82	3.02	3.01	3.07	2.91
65	4.15	3.15	3.15	3.20	3.09
55	4.53	3.40	3.40	3.46	3.27
50	4.75	3.48	3.51	3.57	3.44

197. It is of interest to note in the foregoing tables that the unit costs for power delivered from either Grand Coulee or The Dalles are nearly the same. Should the market for electrical energy absorb the possible output less rapidly than estimated, the carrying charges will become more of a burden, and consequently the cost per kilowatt-hour will be increased. Such a change would affect the unit costs at The Dalles with its greater initial investment proportionately more than it would those at Grand Coulee. Should construction be undertaken by one of the present utilities of the Pacific Northwest to secure power for distribution in its own relatively limited market area, it is probable a site of smaller capacity than either The Dalles or Grand Coulee would be more practical from an economic standpoint, even though the initial construction cost per kilowatt of capacity might be considerably greater.

198. The margin of economic feasibility of the development of one of these large sites is increased if there be concentrated upon it a large part of the growth of the power market of the Northwest until its total potential output is absorbed. Several years will be required for preliminary work and construction at any of these sites. It has been assumed that 1940 is about as early as first-power production would begin. By that time most of the present construction programs of the several utilities will be completed and their power plants loaded. It should not be impossible to find a plan under which these public-service organizations could pool their interests to the extent of draw-

ing upon a single large development for the supply of a major part of the prospective growth of their business over a term of years, especially if such a plan would result in lower cost to them and would help the expansion of business in the whole region. There is enough of an analogy between the separation of the electrical business into generation, transmission, and distribution and the customary division of merchandising into manufacturing, transportation, and retailing to establish the possibility of mass production of power and its disposal in wholesale quantities to large distributing organizations.

199. The above discussion has concerned the cost of power. There is a considerable margin between the estimated cost of production at Grand Coulee or The Dalles and the competitive cost of steam power in favor of hydroelectric power. This margin represents the limit of possible profit. It is illustrated in table Z, which shows in parallel columns the cost of energy delivered at the principal load centers. It is neither necessary nor desirable that the initial selling price of the hydroelectric energy be kept down to absolute cost provided it is kept within reasonable limits. Should the selling price be fixed somewhat above the estimated cost, one or all of several things can be accomplished. Among them are: First, the undertaking can be made a financial success even though sales are less than estimated; second, reserves can be built up to be used in advancing additional development; third, applying particularly where public credit has been used, the investment can be retired or amortized in less than the 40 years estimated.

200. Tables X, Y, and Z show costs at annual load factors ranging from 50 to 100 percent. The tables illustrate the variations that may be expected between these limits. Service to a utility having a well-diversified commercial load and a load factor of 55 percent would cost the power-producing organization about 1.52 mills per kilowatt-hour if construction has been financed with 4 percent money and 2.44 mills per kilowatt-hour if financed with 6 percent money. In both cases delivery of energy is assumed to be made at the power house. Similarly, if energy is delivered to a large electrochemical industry which maintains an 85 percent load factor, the cost per kilowatt-hour would be 1.38 mills per kilowatt-hour with financing at 4 percent and 2.26 mills per kilowatt-hour at 6 percent. Should power be sold at a flat rate under which the customer may take energy continuously, the rate for 100 percent load factor may be applied. This is equivalent to an annual rate of $11.74 per kilowatt (or $8.76 per horsepower) of peak demand with 4 percent financing and $19.26 per kilowatt ($14.44 per horsepower) with 6 percent financing. In a similar manner the additional cost of transmission for different load factors and different distances may be estimated to determine the cost of energy delivered at the load center.

201. The comprehensive plan contemplates pumping water from the Columbia River at Grand Coulee and Priest Rapids for the irrigation of the Columbia Basin irrigation project, as distinguished from an alternative irrigation scheme under which diversion would be made by gravity from Clark Fork and Spokane River. Studies made by the Seattle district develop the fact that withdrawal of water by gravity for the Columbia Basin irrigation project results in a reduction of the prime hydroelectric power that can be generated with the falling water. Floods in the Columbia come at such a time of the year that irrigation pumping can be done with seasonal or secondary

power and thus will not encroach on the primary power. Including the power possibilities at Z Canyon and Clark Fork, at the sites on the Spokane River, and at those on the main Columbia from Grand Coulee to Warrendale, there can be produced for sale under the comprehensive plan about 400,000 kilowatts more prime power than if the gravity plan for irrigating the Columbia Basin irrigation project were adopted.

202. Completion of the comprehensive plan would undoubtedly be accomplished step by step over a long period of years. If properly coordinated, each step would increase not only the yield of power but also the economy and flexibility of operation. This would be particularly true if the entire river were controlled and managed as one system. In order to produce the entire quantity of available prime power at commercial load factors, the installed generating capacity at each site would need to be increased materially above that included in the foregoing estimates. Some provision for additional capacity should properly be made at the time of original construction, although the length of time which must elapse before completion of the proposed system of reservoirs is so great that the extent of such expenditure should be carefully controlled and limited. The enormous potentialities of the plan are well illustrated by the totals in table AA. The total prime output of 41 billion kilowatt-hours per year or 4.7 million average kilowatts is sufficient to meet the estimated growth of the power demands in the Pacific Northwest (see par. 133) over a period of 30 years. In the entire United States the 1930 production of public utilities was 90 billion kilowatt-hours. Total production in 1930, including that of plants operated by manufacturers, was estimated at 125 billion kilowatt-hours. The Columbia can produce prime power equal to one third of this quantity and in addition can supply secondary power to meet all the probable requirements for irrigation pumping.

TABLE AA.—*Ultimate prime power possibilities of the comprehensive plan*

Site	Kilowatt-hours per year	Mean output	Probable requirements for peak capacity of generating
Grand Coulee			
Foster Creek		*Kilowatts*	*Kilowatts*
Rocky Reach	24,440,000	2,790,000	5,580,000
Rock Island			
Priest Rapids			
The Dalles	14,279,000	1,630,000	3,260,000
Warrendale	2,365,000	270,000	540,000
Total	41,084,000	4,690,000	9,380,000

D. FLOOD CONTROL

203. *General.*—The Columbia above tidewater flows through a well-defined and deep channel with only occasional places where there are low lands subject to overflow. The areas of these low lands are small. The problem of flood protection of these areas is wholly local and by reason of the absolute and relative unimportance of the lands is not considered in this report.

204. The tidal section of the river includes the lower 140 miles between Warrendale and the sea. In this section the immediate valley floor of the Columbia differs from that above tidewater, being wider. Between the mouth of Sandy River, a minor tributary which empties into the Columbia 19 miles below Warrendale, and the sea the valley floor includes numerous areas of low lands subject to overflow. This section of the river is further considered below.

205. There are records of floods on the tributaries of the Columbia; but except for the Snake, mentioned below, these floods do not affect the flood problem of the Columbia. Some of these tributary floods are locally quite serious, as those sometimes following so-called "cloudbursts." Local flood conditions at Flathead Lake, Pend Oreille Lake, and Coeur d'Alene Lake and on the lower Kootenai are discussed in the Seattle district report (pt. 2, printed in vol. II of this document).

206. By far the greater part of the drainage basin of the Columbia lies in the basins of the upper Columbia and Snake. These contribute the flows that produce the annual freshets of the Columbia below the mouth of the Snake. These freshets occur during the period May to July and are due to the melting of snow in the headwaters, combined with spring precipitation. The flood of 1894, the greatest of record, both above and below the mouth of the Snake, was produced by unusual combination of melting snow and heavy spring precipitation. This flood was exceptionally large below the mouth of the Snake, due to the approximate coincidence at the mouth of the Snake of the flood peaks of the upper Columbia and Snake.

207. In addition to these periodic freshets of various stages from upstream sources, the Columbia, in its lower reaches where precipitation is relatively heavy, shows the effects of winter and spring snows and rains in those lower areas in the form of minor increases in river stage. These rises occur during the winter and spring. The Willamette is the principal contributor, but there are others, like the Cowlitz and Lewis. While the flood discharges of these streams are considerable, they reach the Columbia at its lower stages and are not important as to flood heights or flood effects on marginal lands.

208. The peak flow of the annual freshets of record in the lower river, measured at The Dalles, varied from about 332,000 second-feet in June 1930 to 1,170,000 second-feet in June 1894. These discharges corresponded to stages, respectively, of 11 feet and 33 feet on the gage at Portland and 6.3 feet and 26 feet on the gage at Longview.

209. Actual flooding of unleveed lowlands along the tidal section of the Columbia begins when the discharge reaches about 600,000 second-feet, corresponding to about 11.2 feet on the gage at Longview. As the flood height rises, a greater area of land is inundated, increasing the potential damage. Little actual damage on such lands occurs before the discharge reaches 700,000 second-feet. Such a flood may be expected to occur once in about 3 years. Floods of 700,000 or more second-feet have durations from 4 to 42 days.

210. *Lands along the tidal section subject to overflow.*—As stated above, only lands along the Columbia below the head of tidewater are considered in this report. These lands are included, not because they can be economically protected through a comprehensive development of the river for the various purposes of navigation, power

development and irrigation, but because of the importance of the lowlands to the States of Oregon and Washington as present and prospective agricultural lands of high value. It is deemed proper that this report should set forth the conditions that exist and the steps that may be taken by interested parties for protection against floods.

211. Detailed consideration of the flood control problem in the tidal section of Columbia River is contained in the Portland district section of this report. (Pt. 3, printed in vol. II of this document.) The principal features of this section follow.

212. There is about 266 square miles of arable lands below the crest elevation of the 1894 flood, distributed in small parcels along the Columbia between the mouth of Sandy River and the Pacific Ocean. About 226 square miles of these areas are below the crest elevation of floods occurring as often as once in 3 years. About 119 square miles of this latter area are now more or less protected by dikes of various heights. About 8 square miles of the diked area includes the cities of Longview and Kelso. About 2 square miles of Portland's industrial area along the Willamette which is affected by backwater from Columbia River floods is partially protected by a seawall with crest elevation 4 feet below the plane of the 1894 flood. Map showing the lowlands and the existing levee system along the tidal section of the Columbia is contained in the district report (pt. 3, printed in vol. II of this document).

213. About one third of the levees protecting land along the tidal section of the river have been built to a height about 2 feet above the crest elevation of the 1894 flood. The remaining levees have elevations, in many cases, little higher than ordinary flood crests. In general, the levees on the river front are constructed of material dredged from the river side of the levees and the levees are close to the river bank. Portions of the levee lines, aggregating about 17 miles of levee, are exposed to eroding or caving banks.

214. There have been no floods of height sufficient to overtop the higher levees, all of which have been built since 1894. However, the lower levees have been frequently overtopped. The district engineer estimates that the probable annual damages from overflow, including damage to levees, throughout the leveed and unleveed areas will not exceed about $150,000 with the levee system left in its present condition. This damage would occur principally in the areas now partially protected by levees of inadequate height. The damage would be much higher were it not that the inhabitants have advance notice of impending floods and probable flood heights and can take appropriate measures to safeguard livestock and other property. Further, the duration of many floods is so slight that excessive loss to crops is not entailed.

215. The district engineer estimates that the cost of raising the existing low levees and reconstructing levees exposed to attack of caving and eroding banks to an elevation 2 feet above the 1894 flood plane, would be about $1,665,000. This sum includes only the cost of substantial levees. Pumping and other auxiliaries are in the main already provided.

216. Of the 266 square miles of arable land below the 1894 flood plane, 147 square miles are unprotected by levees of any height. This land is mostly in small isolated parcels, the protection of which by

levees would not, in general, be justified at present. However, some 23 square miles could be leveed as parts of existing leveed areas, or as independent areas. The cost of leveeing this 23 square miles, exclusive of bank revetment, but including pumping facilities and tide-gates, would be about $1,200,000.

217. Raising or reconstruction of levees to a height of 2 feet above the 1894 flood plane would provide ample protection against all but exceptional floods occurring probably not oftener than about once in 50 years.

218. The district engineer considers in his report various possible methods of control of floods other than levees, or dikes as locally termed, and concludes that leveeing is the most suitable method for protection of the lands in the tidal area. This view of the district engineer is concurred in. Raising of existing low levees and moving back those now too near caving banks appears to be economically justified at this time by the additional protection they would afford, and some extension of the levee system to include additional areas may likewise be justified. These conclusions, however, are based on estimates of damages due to inadequacy of the present levee system and of costs of current repairs to levees. Both of these basic figures are indefinite because of meager records.

219. Flood control on the Columbia is not susceptible to inclusion in an economically feasible combined project for utilization of the waters of the river for navigation, power development, and irrigation. It cannot be combined with a navigation project to the benefit of navigation, but dredging for navigation improvement could aid levee construction by furnishing levee material, usually, however, at cost greater, often considerably greater, than for the navigation work alone. A project of power development or irrigation or the combination of the two as may be adopted for the river above would automatically give some benefits to the lowlands of the tidal section through regulation of discharge and resultant lessening of flood heights, but the cost of storage or regulation for flood control alone would be far greater than the benefits to the lowlands would justify.

220. While flood protection of the lowlands along the tidal section of Columbia River is a matter of concern to the owners and cultivators of the land and of importance to the States of Oregon and Washington through affording means of augmenting the assets of those States, national interest justifying expenditure of funds of the general public in works for flood control or protection of these lands is not present. This case is unlike that of the lower Mississippi Valley, where the area of land subject to overflow is enormous, occurring in many States, and where works of flood protection in one State have adversely effected the conditions in another. In the lower Columbia case both Oregon and Washington and their citizens can proceed with flood-control plans without fear of adverse effects produced by or in the other State. Nor does the fact that the waters of the lower Columbia come from several States constitute a reason why the general Government should participate in the cost of flood control in the tidal section of the river. No upstream State or agency will, in connection with river flow or works, take action adversely affecting the right of the lowlands in the lower river. On the other hand, some benefits, as stated, may flow from power development and irrigation in the upper river.

E. IRRIGATION

221. *General.*—Over most of the area of the Columbia Basin east of the Cascades, except in general in the higher altitudes at the headwaters where topographic conditions are unfavorable to agriculture, rainfall is insufficient for crops other than wheat and grass, and for wheat only under dry-farming methods in selected areas. Precipitation in the mountains traverses the arid regions, as rain and melted snow run-off, through the well-defined channels of the Columbia and its tributaries. This fact has from early days challenged the settler to apply the water to the arid land. But existence of land and a nearby source of water do not alone warrant irrigation. Cost of works, with its related matters of capital and credit, is an important feature, as is reasonable assurance of adequate water supply, of fertility and other fitness of the land for irrigation, of the existence of a favorable climate and growing season, and of a market for the products; and finally, of great importance, is settlement of the land. These are essentials to the success of irrigation of an area, and deficiencies in one or more of these respects have led to failure or partial failure in some cases where irrigation has been undertaken in the Columbia Valley and elsewhere.

222. In the district reports, herewith, parts 2 and 3 of this combined report,[1] the various potential irrigation projects of the basin are treated in considerable detail. The potentialities of these areas are considered from the point of view of the areas themselves in order to determine the promise of success of irrigation by a study of costs and returns.

223. It appears evident that as time goes on the area of cultivable land in the United States will need to be extended unless increased production through improved fertilization, intensified crops, raising of products for domestic consumption instead of for export, further motorization of agriculture and consequent decrease in demand for feed, possible changes in the American dietary, or stabilization of population cause the present cultivable areas to be adequate. Recommendations as to the broad questions of increasing the area of cultivable land in the United States, of the time for such increase and of the propriety of the expenditure of national funds on development of further irrigation projects are matters of policy beyond the scope of this report, and are not made. These are matters for the attention of Congress. This report attempts to point out irrigation possibilities along the Columbia River, and to show the economic features of the possible developments.

224. It may be expected from the history of irrigation in the basin that national participation, already a fact in certain areas, will be urged more and more. Briefly stated, the history is as follows:

225. Lands suitable for development from an irrigation point of view are found in one or another of three situations. The problems involved in their conversion to farms have depended on such circumstance.

First, there are the small tracts onto which water could be diverted by individuals from nearby streams. Such local irrigation was begun by the earliest settlers, and almost all suitable lands of this class in the Northwest were taken up between 1850 and 1890.

[1] Printed in vol. II of this document.

Second are low bench lands that could be watered from nearby streams by small canals within the capacity of local organized effort of corporate enterprise. Almost all of the less expensive of the larger developments have been of this type. Although from necessity, prior to 1900, such lands were the principal additions to the areas farmed, they were not all so developed, and a large aggregate of work by small organizations is being carried on to this time.

By far the greatest areas are of the third type. These are vast plains—remains of old lake beds or the gently sloping ridges into which they have been eroded; high benches, wide alluvial cones at the debouchment of streams from the mountains, and finally, various lands for which works are required of a magnitude and cost not warranted by return expected under the other conditions. An essential feature to be noted in the case of land of this third type is that its settlement is impracticable until after the irrigation works are well on their way toward completion. After 1903, when the United States through the United States Bureau of Reclamation began to construct projects, these enormous undertakings became possible. Even today, however, the problems of colonization and repayment are more complex than those of construction.

226. Notes on western system of water appropriation and on formation of irrigation districts are given in part 3 of this report, chapter II E.

227. In this report the following irrigable tracts have been considered. The acreages given do not include areas, which, while irrigable, have poor soils.

IRRIGABLE TRACTS ABOVE THE MOUTH OF THE SNAKE

(For details see report of district engineer, Seattle—pt. 2, vol. II of this document.)

Rathdrum prairie tract.—This tract is located in north Idaho and consists of 40,000 acres. It can be irrigated by a pumping diversion from Pend Oreille Lake or by a gravity diversion from Priest River. These two possible methods are discussed in a general way in the Seattle report, as the water used would affect the supply available for tracts along the main stream, the primary subject of the report, and because of the importance to Idaho of the Rathdrum prairie tract.

Marginal areas.—There are various small areas marginal to the section of Columbia River between the international boundary and the mouth of the Snake. These areas aggregate about 52,000 acres. Irrigation by pumping diversion from the Columbia River, the only source of water supply, is considered.

Little Spokane valley tract.—This tract consists of about 30,000 acres which can be reclaimed only as a part of the gravity plan of the Columbia Basin irrigation project. (See Combination of Areas, below.)

Methow-Okanogan tract.—This tract consists of 18,000 acres in Methow and Okanogan Valleys. A gravity diversion from Methow River is discussed.

Greater Wenatchee or Quincy tract.—This has a total area of about 340,000 acres of which 20,000 is located in Wenatchee Valley and the remainder on the Quincy Flats, a high tableland east of the Columbia River and south of Quincy and Ephrata. Reclamation by a gravity diversion from the Wenatchee River is discussed. The Qunicy division of this tract may be irrigated in connection with and as part of the Columbia Basin irrigation project. (See Combination of Areas, below.)

Priest Rapids tract.—This area consisting of about 140,000 acres, located between Saddle Mountains and Columbia River, is irrigable by a pumping diversion from the Columbia River near Bend, Wash. This tract also enters into the combination of areas forming the Columbia Basin irrigation project.

Pasco tract.—This area, north and east of Pasco, Wash., consisting of about 102,000 acres, is irrigable by a pumping diversion from Snake River as an individual unit and also as a member of the combination of areas forming the Columbia Basin irrigation project.

Palouse tract.—This area lying between the Snake and the upper Columbia consists of about 100,000 acres. It is irrigable independently by a gravity system making a diversion from the Palouse River. It also forms part of the combination constituting the Columbia Basin irrigation project.

Lind tract.—This tract, consisting of 784,260 acres, is the largest tract included in the Columbia Basin irrigation project (see next item below) under the scheme of gravity diversion from Clark Fork. It is located east of the Quincy Flat and Palouse tracts listed above.

Columbia Basin irrigation project.—See next item.

Combination of areas.—The Columbia Basin irrigation project includes Lind, Palouse, Pasco, Priest Rapids, and Quincy tracts. Various combinations of these and two plans of water application (by gravity and by pumping) are considered in detail in the Seattle district report.

Hanford tract.—An area in the northern portion of Benton County consisting of about 40,000 acres that can be reclaimed only as an individual unit, by pumping from the Columbia.

IRRIGABLE TRACTS BELOW THE MOUTH OF THE SNAKE

(For details see report of district engineer, Portland, pt. 3, vol. II of this document.)

Cold Springs tract.—This is an area of about 67,000 acres in Umatilla County, Oreg., of which 50,000 acres is considered irrigable. It lies east of the United States Bureau of Reclamation Umatilla project. The upper and easterly boundary of the area lies at about 1,000 feet elevation above sea level. The area extends about 15 miles southerly from Columbia River.

Horse Heaven tract.—This is an area of about 200,000 acres in Benton and Klickitat Counties, Wash., of which about 142,000 acres is considered irrigable. It is bounded on the north by elevation 1,000 feet above sea level, and on the south by elevation 350 feet, near Columbia River. It extends from Spaw Canyon (mile 303, Columbia River) on the east, to Alder Creek (mile 257) on the west. The extreme width east and west is about 40 miles and the greatest north and south is about 18 miles.

Irrigation of Horse Heaven area is considered in three divisions: Division A between elevations 350 and 575; division B between elevations 575 and 800; and division C between elevations 800 and 1,000.

Horse Heaven area has also been considered for irrigation from Klickitat and Cispus Rivers, by gravity. This plan of irrigation is not considered feasible.

Willow Creek tract.—This is an area of about 207,000 acres in Umatilla, Morrow, and Gilliam Counties, Oreg., of which 173,060 acres is considered irrigable. The area extends from elevation 350 feet above sea level near Columbia River on the north, to elevation 1,000 feet on the south. It is bounded on the east by Butter Creek, Umatilla River and the Westland irrigation district, and on the west by Willow Creek and Eightmile Canyon. The greatest width of the area from north to south is about 17 miles.

Willow Creek area is considered for irrigation in three parts: Division A between elevations 350 and 616; division B between elevations 616 and 800; and division C between elevations 800 and 1,000.

Irrigation of this area and Arlington area, described below, by gravity from John Day River has been considered in a separate report. A comparison of cost estimates shows that the pumping plan is less expensive than the gravity.

Arlington tract.—This is an area of about 18,000 acres in Gilliam County, Oreg., of which about 11,500 acres is considered irrigable. It is located on a high bench near Arlington, Oreg., and extends south from Columbia River about 7 miles. It is bounded on the east by Willow Creek and Eightmile Canyon, and on the west by Alkali Canyon.

Roosevelt tract.—This is an area adjacent to Columbia River in Benton County, Wash., near Roosevelt, Wash. The total area of this tract is about 2,000 acres, of which 1,500 acres is considered irrigable.

228. *Economic features.*—Eliminating duplications of acreage in the tracts described above, the area of irrigable land in the Columbia Basin above Snake River and irrigable from the Columbia includes approximately 1,560,000 acres, and the area in the Columbia Basin below the mouth of the Snake, also irrigable from the Columbia, includes approximately 378,000 acres, making a total of 1,938,000 acres. With the exception of a portion of the Lind tract, which lies at a higher elevation above sea level than the remainder of that and other tracts, the various areas are essentially the same so far as climate, soils, and water supply are concerned. All tracts, with the exception of the Lind area, have similar ranges of crop adaptability, will produce three cuttings of alfalfa on the average in a season, and will return approximately the same yields per acre, since areas of poor soil are not considered in the report. The cost of land, land leveling, farm buildings, and other permanent improvements have been estimated to be approximately $100 per acre on the average in all of the areas considered.

229. Markets are essentially the same for agricultural products of the entire Columbia Basin. Studies of markets for the products of irrigated areas have been made by the Seattle and Portland districts and appear in chapter II E of parts 2 and 3[1] of the combined report. The study of the Seattle district is based on the Columbia Basin irrigation project possibilities. That of the Portland district is more general. From these studies the general conclusion may be drawn that, assuming increase in the area of cultivable land in the United

[1] Printed in vol. II of this document.

States is desired (see par. 223 above) the desirable rate of accretion to areas of irrigated lands of the United States depends on the prospective market growth and on the feasible rate of efficient settlement of the irrigated lands. In the case of the areas considered in this report the latter controls.

230. A rate of settlement of 50,000 acres of irrigated land a year has been used as reasonable for the portion of the Columbia Basin lying within the States of Washington and Oregon. In determining the costs of irrigation the rate of interest on construction costs is uniformly figured at 4 percent, while the farmer's return is in all cases taken as 6 percent on his investment (other than construction costs). Table I below gives a summary of costs and annual charges for the various tracts considered in this report. For purposes of comparison a uniform period of 40 years after construction is complete is assumed for repayment of construction costs, with repayments figured on an amortized basis.

TABLE I.—*Summary of costs and annual charges,[1] irrigation from Columbia River*

Name	Irrigation plan	Irrigable area, acres	Construction cost [2]		Annual costs per acre			
			Total	Per acre	Interest and repayment [3]	Electrical energy	Operation, maintenance and depreciation	Total
Greater Wenatchee-Quincy tract.	Gravity	320,310	$94,896,200	$296.26	$14.97	--------	$3.00	$17.97
Priest Rapids tract	Pumping	140,520	15,092,800	107.40	5.43	[4] $1.59	3.00	10.02
Pasco tract	do	102,000	15,355,030	150.54	7.61	[4] 2.04	3.00	12.65
Lind tract	Gravity	784,260	257,491,560	328.32	16.59	--------	3.00	19.59
Hanford tract	Pumping	40,000	5,176,200	129.40	6.54	[4] 1.44	3.00	10.98
Columbia Basin irrigation project.	Gravity	1,519,890	598,285,020	393.63	19.89	--------	3.13	23.02
Do	Pumping	1,174,630	207,397,120	176.56	8.92	[4] 1.28	3.00	13.20
Cold Springs tract	do	50,000	7,975,000	159.60	8.06	[5] 4.13	3.00	15.19
Horse Heaven tract, division A.	do	28,500	3,933,000	138.00	6.97	[5] 1.52	3.00	11.49
Horse Heaven tract, division B.	do	47,500	6,574,000	138.40	6.99	[5] 2.20	3.00	12.19
Horse Heaven tract, division C.	do	66,000	10,091,000	152.90	7.73	[5] 3.79	3.00	14.52
Willow Creek tract, division A.	do	37,940	5,209,000	137.30	6.94	[5] 2.64	3.00	12.58
Willow Creek tract, division B.	do	103,770	13,270,000	127.95	6.46	[5] 3.06	3.00	12.52
Willow Creek tract, division C.	do	31,350	4,751,000	151.54	7.66	[5] 3.63	3.00	14.29
Arlington tract	do	11,500	1,427,000	124.07	6.27	[5] 2.73	3.00	12.00
Roosevelt tract	do	1,500	170,000	113.37	5.73	[5] .92	3.00	9.65

[1] Does not include any part of cost of power dams, electrical energy being purchased at the rates given.
[2] Includes interest during construction and period during settlement.
[3] Interest at 4 percent with amortized payments covering a period of 40 years. Annual payments equal 5.0524 percent of principal.
[4] Assumed price of power $0.00075 per kilowatt-hour.
[5] Assumed price of power $0.001 per kilowatt-hour.

231. Comparing various tracts, differences are found in the cost of construction, the pumping lift, operation and maintenance charges, and the rate for power. All of these except pumping lift appear in the table. The effect of the rate of settlement varies with the size of the project. Small projects bear a comparatively small carrying charge for interest during the construction period because the period is relatively short. Small projects, for the same reason, have a

decided advantage over large projects in that they allow an elasticity in stage development which is not permitted in projects requiring large investments of capital to cover the essential construction program.

232. Independent studies have been made in the Seattle and Portland districts of the economic feasibility of irrigation developments. While the Seattle district has referred particularly to areas above the mouth of the Snake and the Portland district to areas below, it is in the method of analysis rather than in the basic characteristics of the areas that the two studies differ.

233. The study made in the Seattle district (pt. 2 of this combined report)[1] indicates that the following yields and prices represent a reasonable expectation over a period of 30 years, or a period required for the construction of the larger projects involved:

Crop	Yield	Price	Returns per acre
Alfalfa (representing all forage crops and alfalfa) ____ tons__	3.75	[1] $14.00	$52.50
Small grain and corn ____ bushels.	40	[2] 1.00	40.00
Potatoes ____ tons__	5.75	20.00	115.00
Beans and peas ____ pounds__	1,200	.04	48.00
Fruit ____ tons__	10	25.00	250.00

[1] Fed to cows. [2] Fed to hogs.

In this Seattle district study an analysis of the probable market conditions indicates that livestock products, including dairy and poultry products, will form an important part of the demand. Fruit, which offers the highest returns per acre, cannot be indefinitely planted on account of the restricted market. Although the exact demand cannot be anticipated, a study of the present per capita consumption of products raised in the Columbia Basin applied to the estimated increase in population indicates that the following distribution of crop acreage will approximately meet the increased demand during the next 30 years, assuming 1,000,000 acres as a possible combined total of newly irrigated land: Forage and hay crops and pasture 60 percent, small grains and corn 24 percent, beans and peas 8 per cent, truck crops 6 percent, fruit 2 percent.

234. Assuming the above distribution and applying these percentages to the crop yields and prices given above, the per acre income will be approximately $54 per year. This figure is based on the definite elimination of all areas where soil conditions and topography are not sufficiently favorable to produce satisfactory yields. This matter is emphasized because of the prime importance of yields in projects having high construction costs. If any large areas of second-class land are included, the returns will be appreciably less than the assumed figure.

235. The permissible charge for water, based on the returns given in the table in paragraph 233 above, has been estimated in the Seattle report to be $6 per acre. This is considerably higher than the average charge made by the Bureau of Reclamation, but the figure is approximately equal to the average charge in irrigation districts in the West. If returns per acre are lower than the estimated production indicates, the permissible charge for water will also be lower. In the interest of rapid and successful settlement, it is entirely possi-

[1] Printed in vol. II of this document.

ble that the charge should be reduced. The "permissible charge for water", as used in the Seattle report, is the amount the farmer can pay for water from his returns from sale of crops after meeting all other production costs, including interest on his investment (other than costs of irrigation works) and $75 per month for his own time.

236. The Seattle district concludes that, comparing this permissible charge for water with the per acre cost of construction, operation and maintenance and cost of power, no project in the Columbia basin above the mouth of the Snake is economically feasible if the cost of construction of irrigation works must be paid wholly from the returns from the sale of water for irrigation.

237. The study made in the Portland district shows that in addition to the total construction costs shown in table I following paragraph 230 above, which the farmer would have to invest in pumping plant and canals to get water to his land, he would have to meet the costs of farm buildings, expense of leveling, ditching, and other permanent improvements, cost of farm implements, and have a capital investment in livestock and an operating fund. These additional items are estimated at $161 per acre by the Portland district.

238. On such basis the total investment per acre in the areas below the mouth of the Snake would vary from $274 per acre to $320 per acre. Allowing 6 percent return on the $161 item of the total investment, and adding this to the annual charges as estimated in the above table for the irrigation system for each of the areas below the mouth of the Snake would give a fixed charge varying from $19.31 per acre to $24.85 per acre, which would have to earned each year over and above other production costs, if the costs of irrigation are to be paid from the returns from the sale of farm products.

239. The Portland district holds that if the gross returns do not exceed the costs of production other than the fixed charges by an amount sufficient to cover the fixed charges, the project is not economically sound, and, like the Seattle district, arrives at the conclusion that under present agricultural conditions the fixed charges on none of these tracts could be met from the direct returns from sale of agricultural products. Considering the similarity of tracts above and below the mouth of the Snake as to matters affecting economic justification of irrigation, the views reached independently by the two district engineers are corroborative.

240. The Portland district is of the opinion that under favorable conditions returns from irrigated areas in the future may justify the expenditures for irrigation indicated for the tracts below the Snake. Such conditions include fair prices, reasonable production costs, careful selection and rotation of crops. Under present conditions of overproduction and general agricultural depression, it is felt that it would be unwise to develop any of the areas until prices for farm products and costs of production are such that net returns of $19.31 to $24.85 as described above can be secured.

241. There are benefits flowing from irrigation that are not used above in the test for economic justification. Such benefits have been made the subject of a study in the Seattle report. They can be grouped into two distinct classes:

The first result from increased production and are reflected in reduced prices to the consumer. This class of benefits may be considered as indirect and may form a proper basis for public subsidy if there is a general need for increased production.

The second class of benefits results from the activities created because of the buying power of the farmer and are reflected in increased land values, increased profits and, in the case of public utilities, in increased franchise values. This class of benefits may be considered the basis for a determination of economic feasibility, because these benefits are direct, are more or less specific and are assessable insofar as they affect local and regional interests. The benefits to interests outside of the State or States involved are direct and specific but too widely scattered to be assessable.

The method used in the Seattle study above referred to, while made specifically for tracts above the mouth of thr Snake, is applicable equally to tracts below the mouth of that river. The Seattle report concludes that some irrigation projects, otherwise not feasible, may be classed as economically justified through recognition of the collateral benefits.

242. Another classification of benefits divides them into three: first, the return to the farmer from the sale of his product; second, the benefit to the general public through the expected lowering of price of foodstuffs; and, third, the incidental benefits to the inhabitants of the region through increase in value of lands and in commercial activity. The first one, should, it is thought, be the test of economic feasibility of and measure of general interest in a project and control the choice of the project to be adopted when several are under consideration, due regard being paid to the question of size of tract desired to be irrigated; the second relates to general interest, but is too indeterminate to appraise; the third should be held a measure of the local interest which may properly be recognized by local support and local funds.

243. It has been proposed by various interests that, in the case of the Columbia Basin irrigation project, the profits from the sale of power developed by the Grand Coulee Dam be used to subsidize the irrigation project. This could be done, by charging enough for the power to cover the costs of the irrigation project. Such subsidy of irrigation projects by the use of revenue from power is equally applicable to The Dalles power project in the section of the river below the mouth of the Snake.

244. The Columbia Basin irrigation project has an area in excess of 1,000,000 acres within easy reach of Grand Coulee dam site. Part 2 of this report estimates the cost of irrigation construction for this area at $176.56 per acre, with annual charges of $13.20 per acre for irrigation, including interest and repayment, and operation and maintenance. In the section below the mouth of the Snake nine irrigable areas are considered conveniently located with respect to The Dalles dam site, totaling about 375,000 acres. Separate costs for the nine areas are estimated in part 3[1] of this report; the average cost per acre for the entire area being $141. The estimated average annual charge for irrigation of these nine areas is $13.22 per acre.

245. The estimates of annual costs of irrigation of the various tracts considered in this report have been based on availability of large quantities of low-cost (about 1 mill per kilowatt-hour) secondary power. Large quantities of cheap power could be made available by construction of one or more of the dams described in this report. There is a limited supply of cheap power from existing plants. It

[1] Printed in vol. II of this document.

would be adequate for only the Hanford tract, of the three to which water could be pumped from unregulated river levels. This tract is favorably situated for irrigation from a construction point of view, but not favorably from others. Neither of the other two tracts irrigable by pumping from present river levels, the Pasco and the Priest Rapids, are considered feasible for irrigation with power from existing plants.

Even with such cheap power none of the projects is economically justified under present conditions.

246. Table I, in paragraph 230 above, includes all tracts along the Columbia believed worthy of consideration for irrigation with water from the main river. These are discussed in detail in the district reports. There are other tracts, on the tributaries of the Columbia, that present opportunity for irrigation. Consideration should be given to these before decision is reached to irrigate any of the tracts listed. Except as to the Rathdrum Prairie tract they are not discussed in detail, as not falling within the scope of this report. Attention is invited to reports under House Document 308, Sixty-ninth Congress, first session, on Snake, John Day, Willamette, Cowlitz, and Lewis Rivers, and to various reports listed in the district sections of this report.

III. Conclusions

247. Below are given the conclusions of the division engineer based on the matter presented in brief above and in detail in the reports of the Seattle and Portland district engineers, herewith as parts 2 and 3 of this combined report on Columbia River. (Printed in vol. II of this document.)

AS TO THE TIDAL SECTION OF THE RIVER

(*a*) Columbia River below Vancouver, Wash., and Portland, Oreg., is primarily of value as an avenue of commerce and in that respect ranks high among the waterways of the United States; it will continue to merit favorable consideration by the Federal Government in the matter of maintenance and improvement of the navigation channel.

(*b*) No power development is feasible in the tidal section of the river.

(*c*) There are areas of fertile low lands along the tidal section of the Columbia that are worthy of protection against the flood effects of the river. These areas have in part been protected to some degree; in some cases they have been fully protected. The most suitable method of securing protection is the one already adopted—by levees (or dikes as locally called). The present levee system is inadequate in places through deficient levee heights and improper levee location, and in extent. Raising of low levees, reconstruction of levees when too close to the river bank, and some extension of levee lines, while desirable, cannot be absolutely declared justified at this time. Works on the upper river specifically for flood protection of these areas or works for flood control in combination with navigation, power, or irrigation are not feasible, but some decrease of flood effects will be produced by any power or irrigation development that may be installed in the upper river. Finally, flood protection of the low lands in the tidal section of the Columbia is of local and State concern and not a matter for Federal control or the expenditure of Federal funds.

(*d*) No irrigation use of the water of the tidal section of the river is needed.