available. Storage is effected in large piles convenient to the point of use.

982. The United States Geological Survey reports [23] that in 1930 there were produced in Oregon utility plants with wood fuel 315,800,000 kilowatt-hours. This is 79 percent of the energy produced from wood fuel in the entire United States. In the State of Washington the production in this class was an additional 47,100,000 kilowatt-hours, or 12 percent of the total. A large part of this Washington production is accounted for by the Washington Gas & Electric Co. plant at Longview. It is probable that within a few miles of Portland the consumption of wood fuel by utility power plants accounts for 85 percent of the wood so used in the United States.

983. The importance of wood for fuel in Oregon utility power plants is also indicated by figures showing that in 1930 67 percent of the fuel power and 26 percent of the total generation was produced with wood.

TABLE 38.—*Fuel power for public use produced in Oregon* [1]

| Year | Kilowatt-hours produced by fuel (in millions) | Fuel power in percent of total production | Year | Kilowatt-hours produced by fuel (in millions) | Fuel power in percent of total production |
|---|---|---|---|---|---|
| 1920 | 104, 676 | 22. 0 | 1926 | 246, 580 | 29. 6 |
| 1921 | 94, 469 | 20. 2 | 1927 | 245, 425 | 29. 1 |
| 1922 | 147, 531 | 28. 8 | 1928 | 286, 522 | 27. 4 |
| 1923 | 172, 734 | 29. 0 | 1929 | 392, 510 | 33. 8 |
| 1924 | 196, 682 | 29. 0 | 1930 | 446, 999 | 36. 7 |
| 1925 | 166, 640 | 22. 9 | | | |

[1] From reports of the U.S. Geological Survey.

984. No definite figures are available to give the extent of the use of wood fuel in other than utility power plants. Lumber, manufacturing, pulp, and paper mills are large consumers. Sawdust-burning furnaces are in common use for residential heating. It is estimated that the wood refuse now available may be sufficient to generate approximately 750,000,000 kilowatt-hours per annum. This amount might be slightly increased by conditions, such as higher lumber prices, which would warrant bringing to the mill the poorer logs that are now left in the woods. Such material yields a large percentage of waste. However, no great increase in the lumber business is likely to occur in Oregon or Washington.

985. At the present time it appears probable that there will be an increasing use of refuse wood in the manufacture of byproducts for which it will bring a higher price than can be obtained when it is sold as fuel. Hemlock chips are being used for paper. Fir refuse is being made into fiber board in a factory completed in 1930. On the Atlantic coast the rayon industry is using wood fiber. Resins may be obtained by distillation. The development of these and other products will absorb waste wood that is now available as fuel for the production of electricity. As this occurs the utilities will make up the shortage by the use of other fuel or by the substitution of water power.

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[23] Monthly and annual production of electricity for public use in the United States in 1930, dated Apr. 30, 1931.

986. Fuel oil from California ports is at present available at a low price.[24] It is generally used when wood fuel is not available. The report of the United States Geological Survey states the consumption of fuels other than wood in generating electric power for public use in Oregon during 1930 to have been as follows: Oil, 431,908 barrels; coal, 307 tons; natural gas, none.

987. No Oregon coal is readily available. Mines in the Puget Sound country of Washington are capable of producing large quantities should the price of oil advance to a point that would make it economically feasible to mine and transport coal in competition with oil.

988. There is no important known supply of natural gas in this region. Some gas has been found near Kennewick, Wash. It is being developed by the Northwest Natural Gas Co. but does not give evidence of being present in sufficient quantity to be commercially important as a fuel for generating electricity. The delivery of gas from the California fields to Portland and Columbia River points would require a pipe line of such great length through territory that yields little contributing business that such a venture appears impracticable.

989. *b. Hydro seasonal variations, etc.*—In the Cascade and Coast Ranges of Oregon and in the adjacent areas of Washington included within the Columbia River drainage there are a great number of water-power sites. Relatively few of these have been developed. Information regarding most of the unused sites is too meager to permit of drawing close comparisons of cost and merit between them and competitive sources of power.

990. The growth of the electric-power industry has had an important effect upon the selection of sites economical for development. The first need was for sites which could be brought into production with a small total expenditure of money. Compared with present-day standards these sites were of small capacity. This was frequently accompanied by construction cost per kilowatt of installed capacity and operating cost per kilowatt-hour that would make them uneconomical if they were to be built today. With some of them their small size has made the operating cost so high that they have now been abandoned.

991. Production of electricity has been increasing at a compounding rate. Larger annual increments of load have made it possible to build larger power plants and to absorb their potential output within a reasonable time before the accumulation of carrying charges became unduly burdensome. This trend is shown on the diagrams showing the loads and capacities of the several utilities. The economic trend has been toward a lower cost of producing the kilowatt-hour, the normal result of mass production. Further progress in this direction appears possible.

992. Present hydro plants in this district are generally dependent on natural stream flow. The flow of the coastal streams and of those of the Cascades follows closely the seasonal precipitation with winter maximums and summer minimums. The load curves of the utilities using these streams have a similar but much less extreme seasonal variation. Auxiliary steam has become necessary in several instances for carrying summer loads even though the summer demands are smaller than those of winter.

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[24] Freight on cargo quantities of fuel oil adds 25 cents per barrel to the quoted price at Los Angeles Harbor.

993. Little regulatory storage has thus far been constructed. The first important example is that at Ariel on Lewis River, built to supply power to the Northwestern Electric Co. and the Pacific Power & Light Co. Portland General Electric Co. has plans under way for storage on the headwaters of Clackamas River, so located that it will benefit all the power sites on that stream. Good reservoir sites, favorably located with respect to water supply and altitude, are not plentiful in this region.

994. There is an important difference in the regimen of the streams of the Coast and Cascade Ranges within this district and that of the streams which contribute the main run-off to the Columbia. East of the Cascades the principal tributaries obtain their water from the higher altitudes. They are fed from snow fields that accumulate in the winter and gradually melt as summer advances. These rivers have a more regular regimen than those nearer the coast and a smaller percentage difference between maximums and minimums. The maximum flow occurs in the summer and the minimum in the winter. The power companies which supply the communities in the interior basin have developed irrigation pumping load to an extent that gives them a summer peak. Thus their seasonal requirements follow in general the water supply available at their hydroplants and the agreement has thus far been close enough to make it unnecessary to maintain large auxiliary steam plants.

995. Interconnection of the power systems lying east of the Cascades with systems to the west of those mountains such as it now in effect between the Washington Water Power Co. and the Puget Sound Power & Light Co. and between the Northwestern Electric Co. and the Pacific Power & Light Co. make possible a seasonal interchange of power developed by water to correspond with the available production of hydroplants and with load requirements. With the expansion of the electrical business such interconnection will become increasingly desirable and important.

996. *c. Oil engines.*—The place which internal-combustion engines have found for themselves in this area has thus far been unimportant and it is not likely to expand. These engines are in use in a few places supplying small loads or serving as stand-by capacity. As interconnection of systems progresses the occasion for their use will decrease.

### 2. COST AND SALES PRICE OF POWER AS AFFECTING MARKETS

997. Two primary sources are available to supply the power requirements of the Pacific Northwest—water and steam. Each has its place. Each is, within limits, adaptable to meet conditions which may exist. In some cases water power may prove to have an advantage; in other cases steam may be better adapted. In general, it is cost which determines whether steam or water should be used for generation. The determining cost is not only the initial investment but includes all elements that enter into the annual cost of delivering electric services to the consumer.

998. In considering the place that water power will occupy in the future it is well to observe that the cost of steam power fixes a definite limit to the economic availability of the water-power resources which are under consideration.

999. A steam plant has some important advantages. Its location can be chosen to fit the load it is to serve, giving due consideration to the supply of fuel and condensing water. Its size can also be chosen to fit the actual prospective load. The cost of constructing a steam plant may be materially less than the combined costs of the dam, water channels, and power house for a hydroelectric installation. A steam plant can be built quickly with standardized equipment to meet well-defined requirements, and extensions can follow on a scale and at the time actually needed without tying up large sums of money in idleness over long periods of time. Fuel can be stored and held in reserve to be promptly available for emergencies and for stand-by purposes. With these advantages go, of course, definite disadvantages. Among them are expensive fuel and high maintenance cost, a relatively short useful life, and correspondingly high rates for depreciation and amortization.

1000. Cost of steam power under modern conditions has recently been studied by the United States Bureau of Reclamation to determine the price at which Boulder Canyon hydroelectric power from the Colorado River could be sold in competition with power generated by steam.[25]

1001. Figures were based upon the experience of the new power plant known as "Long Beach No. 3 of the Southern California Edison Co.", containing generating units with individual capacities of 100,000 kilowatts. Such a plant constructed at tidewater where there are ample supplies of condensing water and using either oil or natural gas for fuel was found to require an investment of $77.50 per installed kilowatt. This same figure can be safely used as adapted to conditions which exist at Portland.

1002. The annual costs consist of fixed charges and operating expenses. Some modifications of the fixed charges have been made to adapt them to the present study. The experience of the Southern California Edison Co. has been utilized to arrive at probable fuel consumption and operating costs.

1003. Interest on the investment is the largest item among the fixed charges. In this report interest on money invested by the United States or a State has been calculated at 4 percent. A municipality can secure money for such construction at approximately 4.75 percent. A sound utility company will probably find money costing it 6 percent. Regulatory commissions are allowing such utilities to earn 7 or 7.5 percent on the investment; this affects the selling price to the public although not the cost to the utility. It is here assumed that a competitive steam plant would be constructed by private capital and not by the United States or a State. Therefore, in the example that has been computed and which is shown graphically in plate 112 [2] (cost of generating steam power at varying load factors), 6 percent has been used as the rate of interest.

1004. For a steam plant a reasonable depreciation rate is considered to be one that allows approximately a 16-year life. On a sinking-fund basis for the case of a utility company, interest on the sinking fund

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[2] Not printed.

[25] Department of the Interior, Bureau of Reclamation. Boulder Canyon project—Rate which public and private corporations can afford to pay for power at Boulder Canyon, and rate which will produce sufficient revenue to repay cost of Boulder Canyon Dam and power plant in 50 years, with interest. Sept. 10, 1929. (Not published.)

being computed at 6 percent per annum, the depreciation rate selected for the present study is 4 percent.[26] An allowance of 1.5 percent of the investment is made for taxes. General expenses, while not strictly proportional to investment, may be so considered with a reasonable degree of accuracy. An allowance of 0.5 percent is made for them.

1005. Experience on the part of the Southern California Edison Co. with the Long Beach No. 3 plant has given a figure of $2.25 per year per kilowatt of capacity as a fair allowance for the cost of supervision, labor, and supplies necessary for operation and maintenance.

1006. The annual charges per kilowatt are summarized in the following table:

| | |
|---|---|
| Interest, $77.50 at 6 percent | $4.65 |
| Depreciation, $77.50, at 4 percent | 3.10 |
| Taxes, $77.50, at 1.5 percent | 1.1625 |
| General expense, $77.50, at 0.5 percent | .3875 |
| Total | 9.30 |
| Supervision, labor, and supplies | 2.25 |
| Total | 11.55 |

1007. All of the items of the total annual cost, except fuel, are determined almost solely by the size of the installation. They are not changed by the output of the power plant. These costs per kilowatt-hour are, therefore, inversely proportional to the load factor, assuming the installation to be properly proportioned to the peak load. Load factor also affects the cost per kilowatt-hour of the fuel consumed to provide for heat losses in the power plant.

1008. Fuel consumption has been assumed at 0.55 barrel of oil per kilowatt of capacity per year plus 0.002 barrel of oil per kilowatt-hour. If gas or coal is used for fuel, substitution may be made by comparing them with oil on a heat-unit basis. A barrel of fuel oil contains approximately 6,250,000 British thermal units. No difficulty is encountered in using natural gas and fuel oil interchangeably. Pulverized coal can be used with the same furnace settings but requires additional investment and labor for storing, pulverizing, and conveying equipment.

1009. The price of fuel varies with market conditions. At the present time the quoted price of fuel oil delivered in large quantities at Portland and vicinity is $1 or less per barrel. This is $0.25 per barrel higher than the price of the same oil at Los Angeles Harbor, Calif. The above figures may be summarized in formulas as follows:

Annual cost in dollars per kilowatt of steam-plant capacity—

$$C = 11.55 + .55\,P + .002\,PK$$

Cost per kilowatt-hour, in dollars—

$$c = \frac{11.55 + .55\,P}{K} + .002\,P$$

in which—

P = cost of fuel oil, in dollars, per barrel.

K = kilowatt-hours produced per year per kilowatt of plant capacity.

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[26] The Bureau of Reclamation allowed only 1.9 percent for depreciation in the case of private development. This arose from certain special considerations and is believed to be lower than is warranted by the probable useful life of a steam power plant.

1010. The cost of steam generated energy per kilowatt-hour (*c*) has been calculated from the above formula and plotted with load factor as the abscissa for several prices of fuel oil, as shown in plate 112.[2] In this graph it has been assumed that the peak load is equal to the capacity of the steam plant—in other words that the capacity factor and the load factor are the same.

1011. The above determination of the cost of competitive steam power fixes a limit to the value of hydroelectric energy when delivered at load centers. The principal centers will be at tide water. It next becomes necessary to know the cost of transmitting power from the proposed power sites to the load center.

1012. Mr. E. A. Loew has prepared a solution of the transmission problem which is set out in appendix 2 of part 1, the division engineer's report. In the estimates for the transmission lines are included the cost of transformers and substation equipment at each end of a transmission line as well as the lines themselves.

1013. The distances involved and the amount of energy to be transmitted make it appear certain that the transmission lines will operate at 220,000 volts. The number of lines will be such that under peak conditions each will be loaded approximately to its capacity. Cost per kilowatt-hour varies with the length of line and with the load factor. Computations have been made for two cases. One considers that the lines will be financed by utility corporations borrowing money at 6 percent. The other assumes public financing with 4 percent money. The conclusions regarding cost per kilowatt-hour are shown in table 39-A and 39-B and in plate 113.[2] Subtraction of the cost of transmission from the cost of steam power gives the limiting price for hydroelectric energy at the bus bars of the generating station.

TABLE 39.—*Cost of transmission per kilowatt-hour for 220,000 volt lines of different lengths*

6-PERCENT MONEY

| Load factor, percent | Length of line (miles) | | | | Load factor, percent | Length of line (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 |
| 4-PERCENT MONEY | | | | | | | | | |
| 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 |

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[2] Not printed.

## D. GROWTH OF POWER BUSINESS IN UNITED STATES AS A WHOLE AND ON PACIFIC COAST, COMPARED WITH THIS TERRITORY

### 1. INVESTMENT AND REVENUE

1014. The figures of investment in the electrical industry, compiled by the Bureau of the Census as given in table 40, purport to show the value of the plant and equipment of central station electric utilities. The table has been extended by using figures for invested capital as published by Electrical World. Figures of value and investment are difficult to obtain on a sound and comparative basis. An enormous amount of data is available in the records of taxing and regulatory bodies and in financial reports of the corporations. Compilations for the country as a whole and for various subdivisions would yield interesting results. Totals obtained from one source would probably vary widely from those of another. The difference made by the point of view has been clearly illustrated in many cases that have been before commissions and courts.

TABLE 40.—*Value of plant and equipment in light and power industry*

[Millions of dollars]

| Year | United States | Pacific States | Oregon | Idaho | Year | United States | Pacific States | Oregon | Idaho |
|---|---|---|---|---|---|---|---|---|---|
| 1902 | 505 | 45 | 5.2 | 0.8 | 1927 | 9,297 | | | |
| 1907 | 1,096 | 147 | 14.4 | 3.3 | 1928 | [1] 10,300 | | | |
| 1912 | 2,175 | 391 | 23.8 | 32.5 | 1929 | [1] 11,100 | | | |
| 1917 | 3,060 | 447 | 26.0 | 28.0 | 1930 | [1] 11,800 | | | |
| 1922 | 4,465 | 600 | 37.0 | 36.0 | | | | | |

[1] Capital invested from Electrical World, Jan. 3, 1931.

1015. Gross revenue is less dependent on personal opinion and prejudice but still involves difficulties to the compiler due to the many activities upon which some utilities have entered and the extent to which published figures are influenced by the showing which it is desired to make. The accompanying figures of the Bureau of the Census and Electrical World have been carefully prepared and are probably as nearly comparable as any that are available.

TABLE 41.—*Annual revenue from electric service*

[Millions of dollars]

| Year | United States | Pacific States | Oregon | Idaho | Year | United States | Pacific States | Oregon | Idaho |
|---|---|---|---|---|---|---|---|---|---|
| 1902 | 84.2 | 6.2 | 0.67 | 0.190 | 1927 | 1,802.7 | 172.8 | 13.90 | 5.41 |
| 1907 | 169.6 | 19.0 | 1.84 | .692 | 1928 | 1,941.9 | 186.7 | | |
| 1912 | 287.1 | 30.8 | 1.38 | 1.580 | 1929 | 2,105.9 | 203.0 | | |
| 1917 | 502.1 | 45.4 | 2.45 | 2.200 | 1930 | 2,155.0 | 209.0 | | |
| 1922 | 1,020.4 | 99.3 | 4.85 | 4.220 | | | | | |

1902–27, Bureau of the Census. 1928–30, Electrical World, Jan. 3, 1931.

### 2. INSTALLED CAPACITY, KILOWATTS

1016. Beginning in 1902 inventories of the capacity of generating equipment have been taken at frequent intervals, first by the Bureau of the Census and in later years by the United States Geological Survey.

From time to time, particularly in the earlier years, modifications were made in the basis for classification. While these influence detailed comparisions drawn from the figures it is believed that for the purpose of illustrating the general trend the figures given will be useful. In table 42 the installed capacity is shown in kilowatts of generator rating. It varies somewhat from the rating of the prime movers—water wheels, steam engines, steam turbines, and gas engines.

TABLE 42.—*Generator rating in 1,000 kilowatts installed in central power stations*

| Year | United States | Pacific States | Oregon | Idaho | Year | United States | Pacific States | Oregon | Idaho |
|---|---|---|---|---|---|---|---|---|---|
| 1902 | 1,212 | 107 | 11 | 3 | 1924 | 17,369 | 1,873 | 166 | 158 |
| 1907 | 4,432 | 411 | 35 | 7 | 1925 | 19,519 | 2,116 | 200 | 171 |
| 1912 | 7,671 | 894 | 71 | 36 | 1926 | 23,619 | 2,536 | 213 | 177 |
| 1917 | 11,919 | 1,233 | 113 | 37 | 1927 | 25,398 | 2,738 | 233 | 189 |
| 1920 | 13,094 | 1,266 | 119 | 115 | 1928 | 27,691 | 2,929 | 238 | 223 |
| 1921 | 14,399 | 1,387 | 125 | 137 | 1929 | 29,630 | 3,382 | 268 | 224 |
| 1922 | 15,483 | 1,537 | 141 | 148 | 1930 | 31,952 | 3,672 | 284 | 226 |
| 1923 | 15,971 | 1,695 | 150 | 157 | | | | | |

1902-17 Bureau of Census, Central Electric Light & Power stations.
1920-30 U.S. Geological Survey.

### 3. OUTPUT IN KILOWATT-HOURS

1017. Production of electric power is measured directly in kilowatt-hours. The industry has been fortunate in having at its command since early days a simple mechanical device of great accuracy for metering its product. As a result the figures available are very satisfactory. They are, in large measure, free from the assumption and approximation which frequently introduce uncertainties into compiled statistical data.

1018. Records of production by the Bureau of the Census and United States Geological Survey are accepted as authoritative and thoroughly reliable. Taken with the reports of installed generator capacity they show the stride that has been made by the industry in the United States and its subdivisions. In table 43 are given the figures for the States of the Northwest which lie within the north Pacific power zone.

TABLE 43.—*Production of electric central power stations*

[Millions of kilowatt-hours]

| Year | United States | Pacific States | Washington | Oregon | Idaho | Montana |
|---|---|---|---|---|---|---|
| 1902 | 4,768 | 3,889 | 0.9 | 0.6 | 0.2 | 0.7 |
| 1907 | 10,621 | 1.149 | 283.0 | 93.0 | 10.0 | 137.0 |
| 1912 | 17,572 | 2,498 | 511.0 | 228.0 | 116.0 | 381.0 |
| 1917 | 32,679 | 3,954 | 869.0 | 325.0 | 145.0 | 965.0 |
| 1920 | 43,555 | 5,408 | 1,197.0 | 476.0 | 591.0 | 1,126.0 |
| 1921 | 40,976 | 5,628 | 1,177.0 | 469.0 | 550.0 | 597.0 |
| 1922 | 47,653 | 6,178 | 1,286.0 | 513.0 | 616.0 | 985.0 |
| 1923 | 55,665 | 7,109 | 1,447.0 | 594.0 | 695.0 | 1,139.0 |
| 1924 | 59,014 | 7,748 | 1,504.0 | 678.0 | 793.0 | 1,145.0 |
| 1925 | 65,870 | 8,569 | 1,623.0 | 730.0 | 754.0 | 1,263.0 |
| 1926 | 73,791 | 9,337 | 1,807.0 | 831.0 | 811.0 | 1,408.0 |
| 1927 | 80,205 | 10,322 | 2,122.0 | 845.0 | 806.0 | 1,395.0 |
| 1928 | 87,850 | 11,382 | 2,361.0 | 1,041.0 | 948.0 | 1,619.0 |
| 1929 | 97,352 | 12,563 | 2,552.0 | 1,161.0 | 894.0 | 1,614.0 |
| 1930 | 95.936 | 12,723 | 2,555.0 | 1,219.0 | 912.0 | 1,320.0 |

1902–17 (inclusive) Bureau of Census; Central Electric Light & Power stations.
1920–30 U.S. Geological Survey.

1019. While the consumption of electricity in the United States has reached enormous totals and in fact is probably greater than in all the rest of the world combined, yet it is interesting to note that in spite of this supremacy the United States is by no means the leader in the per capita use of electricity. Three countries exceed it in this respect, as follows:[27]

| Country: | *Kilowatt-hours per capita* |
|---|---|
| Norway | 3, 560 |
| Canada | 2, 124 |
| Switzerland | 1, 043 |
| United States | 1, 025 |

1020. The relative positions shown above have been maintained by these countries for many years. While no explanation is made of the difference between the per capita consumption indicated in the above table and that shown by Government statistics, which are quoted below, the figures make an interesting exhibit in considering the future that is ahead of the electrical industry in the United States.

1021. Production by electric central stations during 1930 in the United States and in the States of the Pacific Northwest, as shown by the United States Geological Survey, when reduced to a per capita basis gives the results shown in table 44. In figures for individual States some distortion is caused by the energy that is generated in one State and used in another.

TABLE 44.—*Relative production of energy in kilowatt-hours per capita*

| | Population 1930 [1] | Total kilowatt-hours [2] | Kilowatt-hours per capita |
|---|---|---|---|
| United States | 122, 774, 193 | 95, 936 | 780 |
| Pacific States | 8, 194, 433 | 12, 723 | 1, 556 |
| Washington | 1, 563, 396 | 2, 555 | 1, 632 |
| Oregon | 953, 786 | 1, 219 | 1, 279 |
| Idaho | 445, 032 | 912 | 2, 050 |
| Montana | 537, 606 | 1, 320 | 2, 450 |
| California | 5, 677, 251 | 8, 948 | 1, 575 |

[1] U.S. Census. [2] U.S. Geological Survey; figures in millions of kilowatt-hours.

## II. PROBABLE FUTURE EXPANSION

### (A) BASED ON PAST RECORDS

1022. Since 1920 the electrical industry has felt the effects of two major business depressions—1921 and 1930—and one minor depression—1924. In 1921 there was a contraction of 5.9 percent in the generation of electrical energy in the United States as a whole. In the Northwestern area in which Columbia River power can be marketed; that is, Washington, Oregon, northern Idaho, and western Montana, the contraction was 5.3 percent. The depression of 1924 resulted only in a somewhat lessened growth. In 1930 power generation decreased 1.5 percent in the United States. In the area which is considered to be the market for Columbia River power there was an increase of 1.7 percent.

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[27] See Electrical World, Jan. 3, 1931, p. 48.

1023. Such figures are influenced by the period of the year in which the depression centers. The weight which depressions have in determining trends can be examined by graphical presentation of production figures on accompanying charts. It is generally recognized that there is a cyclic tendency in the progress of American industry. Therefore, it is reasonable to expect that periods of prosperity and depression will continue to alternate in the future as in the past. The periodicity is irregular. Trend of industry and the related trend of production of electrical energy in the past must be determined by consideration of a period long enough to properly weigh the irregularities.

1024. Comparable figures showing electrical production in the entire area which will form the market for Columbia River power are available only back to 1920. However, earlier figures for individual utilities indicate that the rate of growth during the past decade has been consistent with the former trend of the business.

1025. Obviously inconsistent results are obtained if the trend is computed by comparing the prosperous year of 1920 with the depression year of 1930, either for the entire market or for Oregon alone. A logical comparison is that of 1920 with 1929 or of 1921 with 1930. The figures are given in the following tables 45 and 46. They point to the conclusion that the normal annual increase for the past decade has been between about 9.5 percent for the entire market area and about 11 percent for the State of Oregon.

TABLE 45.—*Generation of electrical energy*

| Year | Market area for Columbia River power | | State of Oregon, from U.S. Geological Survey reports | |
|---|---|---|---|---|
| | Generation in average kilowatts | Percent increase over preceding year | Generation in average kilowatts | Percent increase over preceding year |
| 1920 | 210,192 | | 54,173 | |
| 1921 | 199,103 | −5.3 | 53,647 | −1.0 |
| 1922 | | 10.6 | 58,518 | 9.1 |
| 1923 | | 16.3 | 67,835 | 15.9 |
| 1924 | | 7.1 | 77,230 | 13.8 |
| 1925 | | 8.6 | 83,288 | 7.8 |
| 1926 | | 10.5 | 94,844 | 13.9 |
| 1927 | | 10.3 | 96,388 | 1.6 |
| 1928 | | 15.7 | 118,116 | 22.5 |
| 1929 | 453,803 | 7.9 | 132,532 | 12.2 |
| 1930 | 461,333 | 1.7 | 139,178 | 5.0 |

TABLE 46.—*Trend of growth of electrical generation*

| Interval | Market area for Columbia River power | | State of Oregon, from U.S. Geological Survey reports | |
|---|---|---|---|---|
| | Percent increase for period | Average annual growth in percent[1] | Percent increase for period | Average annual growth in percent[1] |
| 1920–30 | 119 | 8.2 | 156.8 | 9.9 |
| 1920–29 | 115 | 9.0 | 144.6 | 10.7 |
| 1921–30 | 131 | 9.9 | 159.3 | 11.3 |

[1] Compounded.

1026. Should there be maintained an annual growth of 9.5 percent the load will double in 7.6 years and quadruple in 15.2 years. An annual growth of 11 percent will cause the load to double in 6.7 years and quadruple in 13.4 years.

### (B) SPECIAL CONDITIONS WHICH MAY AFFECT FUTURE GROWTH

1027. The impressive growth in the output of the electrical industry has been based upon an ever broadening use of electricity in all fields of human activity. The expansion seems to be continuing without cessation.

1028. American homes increased their use of electricity at an average rate of 14.5 percent per year during the past decade. The year-to-year increase seems to have been little affected by "hard times." Practically the same statement applies to retail commercial consumers of electricity. The small consumers in both these classes furnish a backlog of business that has carried the electrical utilities through depression years with remarkable records. Together they absorbed 36.6 percent of the energy sold in 1930 and furnished 61.7 percent of the revenue of the electrical utilities of the United States. It is probable that the results in Oregon and in the Northwest are somewhat similar to those in the United States as a whole.

1029. The growth of sales to small consumers has been more rapid than has the progress with large customers. As a result the relative importance of the "wholesale" customer has decreased in spite of the fact that sales to this class have doubled in the past decade. In 1920 in the United States such customers took 61.3 percent of the total sales. In 1930 their share was only 51.6 percent. Here again the local trend seems to approximate that of the Nation.

1030. In most manufacturing industries electricity has gained its place as a convenient mechanical power. In others it has been used in chemical reactions. As a means of producing heat, its field is expanding rapidly. New uses are constantly being found. The development of such new industrial uses has been largely done on the initiative of the industries themselves. To them the use of electricity has been an incident rather than an object. The search for alternative methods has been equally important. The business of the utilities has been growing at such a rate that they have not found it necessary to engage in research with the purpose of finding new outlets for their product. Should they seriously enter on such a task important opportunities for load building would undoubtedly be found.

1031. In the Pacific Northwest the past records have been made in the face of a declining lumber business. It is a favorable augury for the future that this has been accomplished. An incident in the lumber business is the large amount of waste that it produces. This is largely used as fuel in the vicinity of Portland, Oreg. A shrinking timber supply may be expected to encourage a more careful use and less wastage. Byproducts of various kinds are absorbing the waste wood in ways which result in giving it more value than it has as fuel. As the fuel is withdrawn the power it produced must be obtained from other sources.

### (C) POSSIBLE NEW INDUSTRIES ESPECIALLY THOSE WHICH MAY CONSUME LARGE QUANTITIES OF POWER

1032. The Pacific Northwest has considerable advantages in climate, natural resources, and transportation facilities which may be expected to lead to the establishment of new industries when other conditions are propitious. Nearly all modern industries are large users of electricity and additional demands result from the satellite or secondary industries and from the growth of population and of general business which they bring. Therefore, all expansion will be directly reflected in the consumption of electricity. However, for the purposes of this study particular interest attaches to those industries in which the direct use of electricity is especially important as a source of mechanical power or in electro-chemical and metallurgical processes.

1033. The large tonnage of ocean-going shipments of lumber from the ports of Oregon and Washington to all parts of the world is not now counterbalanced by incoming shipments approaching them in bulk. Incoming vessels commonly arrive in ballast. This condition creates an excellent opportunity to supplement local resources by the importation at low freight rates of ores and other raw materials from distant sources to be refined and manufactured in the Northwest.

1034. The progress of invention and development is so rapid that it is impossible to predict what products it may be found advantageous to manufacture in the Pacific Northwest or the extent to which they may utilize the available hydroelectric power. However, it has been possible to obtain perspective through the reports of Miss Bertha Nienburg, economic consultant, Washington, D.C., which will be found in appendix 1 of the report of the division engineer. Miss Nienburg's studies show that electrochemical industries alone consumed more than one tenth of the total electricity generated for industrial purposes during 1929. In excess of 7,000,000,000 kilowatt-hours were consumed in the production of some 50 substances. Many hundreds of others require the use of electricity in their manufacture. There is a wide difference in the quantities of various substances that can be utilized by the market. There is also a wide range in the amount of electrical energy required per unit of product.

1035. Aluminum and the ferro-alloys have large, well-established markets and also have a high consumption of electricity per ton of metal. Other important processes are the electrolytic precipitation of zinc from complex ores with the recovery of cadmium and other metals, the precipitation of copper from oxide and mixed ores, the manufacture of calcium carbide, silicon carbide, and fused alumina. The electrochemical manufacture of caustic soda and phosphoric acid must compete with other methods of manufacture, but the electrical production already consumes large amounts of electricity. Electrolytic production of oxygen and hydrogen has not yet assumed large proportions although future conditions may make it feasible in competition with other methods.

1036. Electrolytic refining of copper, electric melting, and refining of copper alloys, electric melting and heat treatment of steel ingots and iron and steel castings require a much smaller number of kilowatt-hours per ton handled than do many other electrical processes but the tonnage of these industries is so great that the total current requirements are heavy. All copper, except pure lake copper, is already electrolytically refined. In copper alloy mills, in steel works, and rolling mills the electric furnace is replacing coal-, oil-, and gas-fired equipment. In steel works and rolling mills the power requirements are very great even where no electrometallurgical processes are used. The following summary of the power requirements of electrochemical products and of wood pulp and paper is taken from the report of Miss Nienburg.

1037. Power requirements of electrochemical processes employed in the United States or in Canada and Europe are listed in table 47. The arc process securing nitrogen from air for use in the manufacture of nitric acid and nitrate fertilizers requires by far the largest number of kilowatt-hours per short ton of any electrochemical process. Since the original arc-process plants were built in Norway, however, less costly methods of nitrogen fixation have been developed; nitric acid is made by the oxidation of ammonia in the United States. The arc process is now regarded as uneconomical and new arc plants will probably not be built.

TABLE 47.—*Power requirements of electrochemical processes and consumption of electricity by such processes in the United States in 1929*

| Material[1] | Process | Kilowatt-hours required per short ton | Total kilowatt-hours consumed in 1929 in United States | Principal competing processes in United States or other countries |
|---|---|---|---|---|
| 1. Nitric acid | Arc | 61,000 | None | Oxidation of ammonia. |
| 2. Aluminum | Electrothermal reduction of bauxite to alumina. | 4,082 and up | None | Alkali reduction of bauxite to alumina. |
| 3. | Electrolytic reduction of alumina to aluminum. | 19,000-25,200 | 2,519,375,000 | None. |
| 4. Metallic magnesium. | Electrolysis of magnesium chloride in brine. | 16,000 | 10,640,000 | Electrolysis of magnesium chloride from mineral magnesite plus chlorine requiring 17,000 kilowatt-hours. |
| 5. Metallic sodium | Electrolysis of fused caustic soda. | 13,000 | (2) | Electrolysis of fused sodium chloride. |
| 6. Synthetic ammonia. | Electrolytic hydrogen; pressure synthesis. | 12,055 | 13,140,000 | Water-gas hydrogen; coke-oven gas hydrogen; by-product hydrogen. |
| 7. Fused quartz | Electrothermal fusion | 10,000–16,000 | (3) | None. |
| 8. Silicon | Electrothermal reduction. | 12,000 | (3) | None. |
| 9. Phosphorus | do | 9,000 | (4)<br>1,250,000 | None. |
| 10. Crystalline graphite | do | 7,600 | (4)<br>91,200,000 | None. |
| 11. Ferro-tungsten | Electrothermal smelting and refining. | 7,600 | 26,395,000 | None. |
| 12. Silicon carbide | Electrothermal reduction. | 6,666–8,333 | (5)<br>23,655,000 | None. |
| 13. Ferromolybdenum (70 percent). | Electrothermal smelting. | 8,000–9,000 | (6) | |
| 14. Ferrouranium | do | 6,000–10,000 | 228,258,000 | None. |
| 15. Ferrochromium (60 per cent). | do | 6,000 | ------------ | |
| 16. Ferrovanadium (30–35 per cent). | do | 6,800 | [4] 13,035,600 | Thermit reduction. |

[1] Does not include 15 rare metals or chemicals, the production of which is still on a very small scale.

[2] United States production not officially recorded. Estimated world electricity consumption in manufacture of metallic sodium in 1927 was 375,000,000 kilowatt-hours.

[3] United States production too small to be officially recorded.

[4] Estimated.

[5] Canadian and United States consumption in 1929 was 227,000,000 kilowatt-hours.

[6] Includes minor quantities of other ferro-alloys.

TABLE 47.—*Power requirements of electrochemical processes and consumption of electricity by such processes in the United States in 1929*—Continued

| Material | Process | Kilowatt hours required per short ton | Total kilowatt-hours consumed in 1929 in United States | Principal competing processes in United States or other countries |
|---|---|---|---|---|
| 17. Phosphoric acid | Electrothermal reduction. | 5, 400 | 81, 000, 000 | Sulphuric acid process. Blast furnace reduction. |
| 18. Ferrosilicon (50 percent). | Electrothermal smelting. | 5, 000 | 994, 011, 000 | Byproduct fused alumina production less than 12 percent silicon blast furnace reduction. |
| 19. Ferromanganese (80 percent). | Electrothermal reduction. | 4, 400 | None | Blast furnace reduction. |
| 20. Calcium carbide | do | 2, 600–3, 200 | 720, 000, 000 | None. |
| 21. Calcium cyanamide. | do | 2, 830 | [7] None | Do. |
| 22. Zinc | Electrolytic precipitation. | 2, 206–3, 200 | [8] 507, 115, 192 | Retort distillation. |
| 23. Copper | Copper precipitation from oxide and mixed ore. | 1, 700–2, 625 | 62, 848, 806 | Flotation and reverberatory smelting. |
| 24. Caustic-soda chlorine. | Electrolytic reduction of brine. | [9] 2, 328–2, 984 | 660, 000, 000 | Lime-soda ash process. |
| 25. Cadmium | Electrolytic precipitation of zinc residue. | 2, 000–2, 500 | 2, 730, 200 | None. |
| 26. Fused alumina | Electrothermal fusion | 2, 000–2, 540 | [10] 43, 318, 000 | Do. |
| 27. Potassium hydroxide. | Electrolysis of potassium chloride. | 2, 100–2, 300 | 15, 831, 000 | Chemical process. |
| 28. Iron | Magnetite ore reduction in arc furnace. | 2, 000–2, 500 | None | Blast furnace. Electrodeposition. |
| 29. Potassium chlorate | Electrolysis of potassium chloride. | 1, 350 | (3) | Chemical process. |
| 30. Iron | Electrodeposition from ore. | 900 | None | Blast furnace. Electric furnace reduction. |
| 31. Carbon bisulphide | Electrothermal fusion | 850 | 30, 179, 250 | None. |
| 32. Sponge iron | Electrothermal low temperature ore reduction. | 400 | (3) | Oil or gas low temperature reduction. |
| 33. Steel castings | Electric melting solid charge. | 500–760 | [4] 281, 594, 000 | Open hearth furnace. Bessemer furnace. Crucible furnace. |
| 34. Steel ingot | Electric melting or refining or superrefining of molten charge. | 210 | 125, 218, 590 | Do. |
| 35. Steel | Electric annealing or hardening. | 182–286 | ------------ | Fuel-fired furnace. |
| 36. ------------ | Electric galvanizing or electrozincing. | 101–230 | ------------ | Fuel-hot process. |
| 37. Iron castings | Electric melting, duplex system, continuous. | 115–550 | (3) | Fuel-fired cupola melting. |
| 38. Copper | Electrolytic refining | 141–233 | 309, 351, 900 | None. Lake copper is not refined. |
| 39. Copper ingot | Melting | 310 | ------------ | Fuel-fired ovens. |
| 40. Copper alloy | Electric furnace melting. | 200–300 | [11] 220, 000, 000 | Fuel-fired pit furnaces. |
| 41. ------------ | Annealing | 50–100 | ------------ | Fuel-fired ovens. |
| 42. Silver | Electrolytic refining | 316–714 | 1, 283, 460 | Sulphuric acid process. |
| 43. Gold | do | 266 | 45, 300 | Do. |
| 44. Lead | do | 95–111 | 6, 180, 000 | |
| 45. Oxygen compressed. | Electrolytic reduction of water. | [12] 250 | 50, 575, 000 | Liquefaction process. |
| 46. Hydrogen | do | [12] 140 | (13) | Water-gas iron contact processes. |

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[3] United States production too small to be officially recorded.
[4] Estimated.
[7] The amount shipped to the United States in 1929 required 84,900,000 kilowatt-hours.
[8] Includes power required in operations immediately essential to electrolytic precipitation.
[9] Per ton caustic soda.
[10] Canadian and United States consumption in 1929 was 152,489,000 kilowatt-hours.
[11] Figures are for 1927.
[12] Per thousand cubic feet.
[13] Process employed chiefly in plants where hydrogen is consumed in major manufacturing processes.

1038. *Aluminum.*—In Europe, as in the United States, the largest total power load in electrochemical industries is carried by aluminum. During 1929 in this country, over 2,500,000,000 kilowatt-hours were consumed in the electrolytic reduction of aluminum from its oxide, alumina. This reduction also requires more power per ton than any other product manufactured in the United States, or from 19,000 to 25,200 kilowatt-hours per short ton. Latest developments in aluminum plants, here and abroad, indicate that power requirements of aluminum plants will be increased. Whereas the oxide of aluminum has been extracted from the ore bauxite by chemical methods until a year or two ago, new plants are extracting the oxide by electrothermal processes requiring 4,000 kilowatt-hours of current and more. Furnace electrodes and furnace linings are also being produced electrothermally at newly constructed aluminum plants. Mechanical operations are all electrified. Wherever it is feasible to install rolling mills at aluminum reduction works, the power load is further increased by electrically heated melting furnaces and heat-treatment ovens as well as by the additional mechanical load.

1039. *Ferro-alloys.*—The ferro-alloys rank second in importance among electrochemical products in total energy demands. Ferrosilicon containing 12 percent or more silicon, ferrotungsten, ferrochromium, ferromolybdenum, and other alloys of these substances required by the steel industry are smelted only electrothermally. Ferrovanadium is produced in the electric furnace and also by the thermit process. Ferromanganese, alone of all the alloys which serve as scavengers in removing undesirable elements from steel or which improve the properties of steel, is not produced electrothermally in this country although it is so manufactured in Canada and Norway by American capital. The total energy consumed in ferro-alloy furnace smelting in 1929 was in excess of 1,260,000,000 kilowatt-hours. Almost 1,000,000,000 kilowatt-hours were consumed in ferrosilicon smelting, each ton requiring about 5,000 kilowatt-hours of current. Power forms from 13 to 14 percent of the market price of this alloy. Other ferro-alloys consume from 6,000 to 10,000 kilowatt-hours of electricity per ton but production is small; it is increasing, however.

1040. *Newsprint paper.*—The newsprint-paper industry in the United States including therein the mechanical and sulphite pulp manufactured at such paper mills, consumed almost 2,000,000,000 kilowatt-hours of electrical energy in 1929. Largest consumption occurs in the manufacture of mechanical pulp, approximately 1,280 kilowatt-hours of current being essential to reduce pulpwood to 1 ton mechanical pulp. When considered in terms of newsprint paper, the electric requirements for mechanical operations per ton of newsprint averages 1,340 kilowatt-hours. Such paper also required from 8,000 to 14,000 pounds of low steam pressure per ton which is still secured by fuels except in plants where hydraulic turbines drive the main electric generator. But electrical costs alone form over 11 percent of the cost of manufacturing newsprint paper, and 10 percent of the price at which newsprint paper is marketed. While the unit electric requirements per ton of newsprint paper are much lower than the unit current requirements of many electrochemical products, the larger tonnage of newsprint paper, the regular daily demand for paper, the long contracts entered into between newsprint-paper mills and newspaper publishers, make a modern newsprint mill manufacturing its mechanical pulp almost as constant a power load as are the major electrochemical factories.

1041. *Caustic soda and chlorine.*—In spite of the fact that less than a third of caustic soda consumed in the United States is manufactured by the electrolysis of brines, approximately 660,000,000 kilowatt-hours of energy were consumed in such production in 1929. The passage of 2,328 kilowatt-hours or more current through purified brine solutions produces simultaneously 1 ton caustic soda, approximately nine-tenth ton chlorine, and approximately 8,100 cubic feet hydrogen. If power costs are charged against caustic soda alone, they form 14 percent or more of the market price of soda; but if they are divided proportionately with chlorine, power costs are reduced to 8 percent of the combined marketable yield.

1042. *Other brine products.*—In 1930, all metallic magnesium manufactured in the United States was secured from the magnesium chloride extracted from well brines before such brines were electrolyzed into caustic soda and chlorine. Metallic magnesium is exceeded only by aluminum in the amount of current required per ton produced. It is still manufactured in pounds, however, rather than in tons, so that total power consumption in 1929 was but approximately 11,000,000 kilowatt-hours. Metallic sodium, also produced at electrochemical caustic soda plants, requires 13,000 kilowatt-hours of energy per ton. This, together with such sodium hypochlorite and such sodium chlorate as may be produced by electrolysis at electrochemical caustic soda and chlorine plants increases the power consumption of these plants. Separate industries have not been developed in the United States for the electrolytic manufacture of these three sodium products.

1043. *Calcium carbide.*—The production of calcium carbide, the basic material for acetylene and for calcium cyanamide, required almost 750,000,000 kilowatt-hours of electricity in 1929. Unit consumption varies from 2,600 kilowatt-hours to 3,200 kilowatt-hours in different furnaces. All calcium carbide manufactured in the United States is for acetylene, the acetylene being used for welding and cutting, for lighting, and as a basic chemical for acetic acid and other synthetic organic chemicals. Calcium carbide for calcium cyanide, used in fertilizer and other chemical production, is manufactured in Canada and in Europe. Had the cyanamide shipped to the United States been manufactured here, an additional 85,000,000 kilowatt-hours of energy would have been required for its production in this country.

1044. *Zinc and cadmium.*—Zinc is the principal metal secured from its ores by electrolysis. Although 70 percent of marketed zinc is still extracted by retort distillation, the zinc content of complex ores in the Northwest has been made available only through flotation and electrolytic processing. Zinc precipitation already ranks fifth among electrochemical processes in total amount of current consumed. In 1929, more than 507,000,000 kilowatt-hours were consumed in zinc electrolytic precipitation, from 2,206 to 3,200 kilowatt-hours being required per ton at electrolytic tanks.

1045. The power load at zinc plants is being increased by a recent demand for cadmium as a protective coating for other metals. Cadmium must be removed from zinc concentrates before zinc can be secured. Consequently, its electrolysis from zinc concentrate residue adds a valuable byproduct to electrolytic zinc production. Cadmium production required almost 3,000,000 kilowatt-hours of current in 1929.

1046. *Copper.*—The electrolytic refining of copper dates from 1885. Such refinement was essential for the recovery of valuable metals such as gold and silver and for the removal of objectionable metals such as bismuth and antimony from western copper. Today, all copper, save a small tonnage from the Lake Superior Peninsula in Michigan, is refined electrolytically. As such refinement requires only from 141 to 233 kilowatt-hours of electricity per ton, power is not a large item in the unit cost of copper refining. However, copper tonnage is sufficiently large to give copper refinement sixth place in total power consumption among electrolytic and electrothermal processes.

1047. A more promising power load is being developed in the Southwest by leaching and electrolytic precipitation of copper from oxide and mixed copper ores. Such precipitation requires from 1,700 to 2,625 kilowatt-hours per ton. In 1929 two American plants that have adopted this method consumed almost 63,000,000 kilowatt-hours of electricity.

1048. *Lead, gold, and silver.*—Lead electrolytic refining required over 6,000,000 kilowatt-hours. Such refining competes with pyrometallurgical and chemical refining processes but has the advantage of removing bismuth, which may be electrolytically refined for pharmaceutical purposes.

1049. Four fifths of all silver and one fourth of all gold is secured through the refining of copper, lead, or zinc ores. The precious metals are cast into anodes to be electrolytically refined chiefly at a few large copper or lead refineries and at United States mints. While the refining of silver and gold requires more kilowatt-hours per ton than the refining of copper or lead, gold and silver are produced by the fine ounce. As far as it is possible to determine, together their refinement required but a million and a third kilowatt-hours of energy in 1929.

1050. *Copper-alloy rolling mills and foundries.*—The power consumption in brass, bronze, and other copper-alloy rolling mills has approximated that required in copper refineries and is increasing. Until 1917 all melting and heat-treatment of copper and copper alloys was done in fuel-fired furnaces or ovens. Today, almost all brass and bronze melting in rolling mills and much in foundries is done in electric furnaces, the energy required varying with the alloy made from 195 to 300 kilowatt-hours per ton alloy melted. Such melting operations required in excess of 220,000,000 kilowatt-hours electricity per year. Pure copper ingot is only melted in electric furnaces to a limited extent at present as present electric-furnace lining life is short with metal containing more than 90 percent copper.

1051. In the process of drawing, rolling, or piercing copper and copper alloys into wire, tubes, and sheets the semifinished product must be softened by annealing. In products such as hard-drawn wire and tubing careful temperature control is essential and electric annealing furnaces are displacing wood-fired muffles. Such annealing furnaces consume from 50 to 100 kilowatt-hours per ton of copper alloy handled. While data concerning the actual number of installations of electric annealing ovens is not available, it is obvious that any general adoption of electric annealing furnaces would bring about a heavy increase in the power load of copper-alloy rolling mills.

1052. *Steel.*—Blast furnaces, steel works, and rolling mills out rank all other industries in installed horsepower, only three fourths of which is electric horsepower. This ranking position is due to the fact that iron and steel tonnage exceeds all other metal, chemical, or paper tonnage by many millions, rather than to unit power requirements of iron and steel products. But electrification of steel works and rolling mills is proceeding rapidly not only for mechanical operations but for heating processes. In 1929, 1 percent of steel ingots were refined in electrically heated furnaces requiring approximately 210 kilowatt-hours per ton molten charge. Such electric refinement consumed 125,000,000 kilowatt-hours of energy. Twenty-six percent of steel castings were melted in electric furnaces, consuming from 500 to 760 kilowatt-hours per ton cold charge. An increasing number of electric furnaces are employed in the heat treatment of alloy steels and carbon steels, specific operation requiring from 50 to 500 kilowatt-hours of current. Electrogalvanizing, electrozincing, and electroplating are also increasing. Probably the best measurement of the part all power, regardless of source, plays in steel works and rolling mills today and the part which electrical power and heat may play in the future is gained by a comparison of the present cost of fuels and electricity in steel works and rolling mills and the market value of all manufactures. Electricity and fuels form 6.6 percent of the total market value of products today.

1053. *Artificial abrasives and refractories.*—Closely associated with the development of hard alloy steels is the manufacture in electric furnaces of fused alumina and of silicon carbide, the latter being second only to the diamond in hardness. Both serve to grind metals and other substances and as refractories where high temperatures and difficult heating conditions must be met by furnace linings and equipment. Silicon carbide requires from 6,666 to 8,333 kilowatt-hours of energy per ton and fused alumina from 2,000 to 2,540 kilowatt-hours. American firms manufacture both abrasives in plants located in the United States and in Canada. While the crude materials are converted into marketable abrasives in this country, electrothermal processes are carried on more extensively in Canada than in the United States. Crude silicon carbide and fused alumina produced in electric furnaces in the United States in 1929 required less than 70,000,000 kilowatt-hours of energy whereas crude abrasives produced in both countries and consumed largely in the United States required 380,000,000 kilowatt-hours. Silicon, requiring approximately 12,000 kilowatt-hours per ton, is produced in small quantities at silicon carbide plants.

1054. *Graphite.*—Crystalline graphite in powdered and electrode form requires approximately 7,600 kilowatt-hours of electricity per ton. Although manufactured by one firm only until recently, firms engaged in the manufacture of other electric-furnace products are now offering it for sale, while firms requiring graphite electrodes in quantity for electrochemical production are manufacturing their own electrodes where petroleum coke is easily available.

1055. *Phosphoric acid and phosphorous.*—Although phosphoric acid has been manufactured electrothermally for only 10 years, chiefly for food and chemical industries, it already ranks eleventh among electrochemical industries in the total amount of electricity consumed. Current consumption totalled approximately 81,000,000 kilowatt-hours in 1929, while unit consumption averaged 5,400 kilowatt-hours. Electrothermal phosphoric-acid production will have to compete with blast-furnace phosphoric acid in markets requiring a pure acid, while chemical phosphoric acid still controls the fertilizer market. Phosphorous has been made in an electric furnace for many years. While power consumption is heavy, quantities produced are small.

1056. *Industrial gases and synthetic ammonia.*—The electrolysis of water produces approximately 2 parts of hydrogen and 1 part oxygen, 1,000 cubic feet of hydrogen requiring 140 kilowatt-hours and 1,000 cubic feet of oxygen about 250 killowatt-hours of electricity. These gases may each be manufactured by other methods. As manufacturing plants requiring large amounts of either gas produce their own gases, such production is not recorded and any electricity consumed is reported along with total power consumption of the specific product manufactured. We known only that about a sixth of the oxygen offered for sale was produced electrolytically and that such production consumed more than 50,000,000 kilowatt-hours of electricity, and that synthetic ammonia made from electrolytic hydrogen at ammonia plants in the United States consumed over 13,000,000 kilowatt-hours of energy.

1057. *Potassium compounds.*—Potassium hydroxide used in the manufacture of soft soaps, dyes, and other potassium compounds required over 2,000 kilowatt-hours of electricity to produce by electrolysis. Total power consumption in its manufacture exceeded 15,000,000 kilowatt-hours. Potassium chlorate requires approximately 1,350 kilowatt-hours per ton. Potassium permanganate and potassium persulphate are also produced electrolytically in this country but in small quantities.

1058. *Carbon bisulphide.*—Carbon-bisulphide manufacture consumed approximately 36,000,000 kilowatt-hours of current in 1929. This chemical is used as an insecticide, as a solvent of caoutchouc and fats and also in the extraction of essential oils.

1059. *Rare or minor electrochemical products.*—Fused quartz is finding extended application not only in equipment that must resist acids and sudden heat, but also in the manufacture of telescope and photograph lenses and in window glass which transmits ultraviolet and infrared rays. Its production requires from 10,000 to 16,000 kilowatt-hours per ton. Production is still on a poundage basis, however.

1060. Demand for materials reduced only at high temperatures and employment of high pressures in chemical industries have brought into the market several new electric furnace refractories. Mullite, electrically sintered magnesite, and other electrically combined substances, are being tried out in industry.

1061. Pure tungsten, for electric-lamp filaments and for ignition contact points, also requires large amounts of power per unit and hydrogen atmosphere furnaces, but production is still in small quantities. Molybdenum, tantalum, and barium are finding application in radio-tube manufacture. Cobalt is being alloyed with other metals to produce machine tools and acid-resistant equipment. Beryllium, cerium, and lithium are also alloyed with other metals.

Each product is manufactured electrochemically with high unit-current consumption. But each product is manufactured in small quantities today and has only potential significance in the development of the Nation's water power.

1062. In appendix B will be found a discussion by Mr. Ira Williams, consulting geologist, Portland, Oreg., of the mineral resources of lower Columbia and Snake River drainage basins and also a paper on western phosphate deposits by Mr. Frank H. Dickey, geologist, Seattle, Wash. These statements and similar discussions by Dean Henry Landes, consulting geologist, Seattle, attached to the report of the district engineer, Seattle district, give in brief outline the minerals available locally for use in obtaining the products utilized by modern industry. As has been previously pointed out ocean-going vessels returning after taking cargoes of lumber to all parts of the world are available to supplement the local resources by carrying raw materials in lieu of ballast.

1063. It seems evident that there are many new industries which may find the availability of ample hydroelectric power at low cost an important factor in causing them to locate in the Pacific Northwest.

### (D) COMMERCE AND DEVELOPMENT OF SEABOARD COMMUNITIES

1064. It is estimated elsewhere in this report that in 1960 the population of the States of Washington, Oregon, and Idaho will total 4,400,000. Probably over 3,000,000 of these people will reside west of Cascade Mountains. Such a growth will parallel the growth that has occurred on the North Atlantic seaboard of the United States.

1065. The opportunities of the Pacific Northwest have been emphasized by many writers. It is unnecessary to enlarge upon them here further than to point to the logic of a continuance of the growth that has occurred during the past 20 years both in commerce and industry.

1066. While the lumber business may have passed its peak, other industries are arising to take its place. In general they are based upon carrying farther the manufacture of timber products instead of exporting such a large proportion of logs and lumber to be manufactured elsewhere. This change may result in reducing the export tonnage but at the same time increasing the value of the exports. Economic development along such lines will aid in supporting the natural increase of population and will open new opportunities for secondary industries.

### (E) FORECAST OF PROBABLE FUTURE EXPANSION

1067. Examination of the conditions surrounding the past growth and future possibilities of the State of Oregon and of the Pacific Northwest leads to the conclusion that there is reason to expect a continued expansion along somewhat similar lines with a gradual broadening of the industrial foundation and further extension of the demands for electricity.

1068. Statistics for Oregon collected by the United States Geological Survey indicate a normal growth of approximately 11 percent per year. In the area which is considered to be the market for Columbia River power the growth has been approximately 9.5 percent per year. The large power plants of the lower Columbia must serve a large market in order to become economically feasible. Therefore, the growth in the larger area is considered the sounder basis for future predictions.

1069. In making comparative studies of power sites on the Columbia River it is necessary to have some reasonable basis for estimating the time that may elapse before the output can be absorbed by the probable power market. It is difficult to believe that the production of electrical energy can continue indefinitely to increase at the rate of 9.5 percent per year. Just what the rate of change will be cannot be known. After due consideration of the available information relating to the Pacific Northwest and the electrical industry in this region and in the United States a portion of a sine curve has been adopted to represent the rate of increase. According to this assumption the trend curve shows an increase of 9.5 percent in 1930, 4.75 percent in 1960 and finally reaches zero in 1990.

1070. In table 48 will be found figures and on plate 114 [2] a graphical presentation of the estimated future load curves as they appear in extension of the records of the past, computed and plotted in accordance with the curve adopted.

1071. It is not asserted that there is mathematical accuracy in the estimate, nor is it believed that it is possible to secure such accuracy in any industry in which the expansion of the market depends not alone upon the extension of past uses and the finding of new applications but upon the initiative and collective effort used in increasing the sales of the product.

TABLE 48.—*Estimated future electrical production within marketing distance of Columbia River power sites*

| Year | Kilowatt-hours | Average | Installed capacity |
|---|---|---|---|
| | | *Kilowatts* | *Kilowatts* |
| 1930 | 4,041,000 | 461,333 | |
| 1935 | 6,480,000 | 740,000 | 1,480,000 |
| 1940 | 10,230,000 | 1,168,000 | 2,336,000 |
| 1945 | 15,650,000 | 1,787,000 | 3,574,000 |
| 1950 | 22,930,000 | 2,617,000 | 5,234,000 |
| 1955 | 31,830,000 | 3,633,000 | 7,266,000 |
| 1960 | 41,630,000 | 4,752,000 | 9,504,000 |

## D. FLOOD CONTROL

### I. FLOODS

1072. Maximum discharge of the Columbia below the mouth of the Snake occurs annually during the three months' period May to July and is caused by the joining of high flows from the upper Columbia and the Snake. Maximum flow conditions in both the upper Columbia and Snake are caused by the melting of snow which has accumulated during the winter months in the mountainous regions along the upper reaches of those rivers and in the headwater areas of their tributaries, combined with the run-off of precipitation falling on the basin as a whole during the spring months. The melting of the snow blanket begins with the first warm weather in spring and continues more or less regularly until most of the snow has disappeared by the end of June. The effect on both the Columbia and Snake is clearly shown in their hydrographs which have a steady increase in discharge

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[2] Not printed.

beginning generally in March and reaching a maximum in May, June, or July. (See pl. 13-A.) [2]

### (A) MAGNITUDE

1073. The size and duration of these discharges and the characteristics of each are controlled by the amount of snow stored in the headwaters area, its water content, the variation of temperature affecting the manner of its melting, precipitation over the basin in general, and the extent to which the run-off from precipitation synchronizes with the discharge of snow water.

1074. Table 49 gives the date of maximum yearly discharge, the discharge in second-feet and the corresponding stage for the Columbia at The Dalles, Oreg., for each year since 1858 when observations were first recorded. The table also includes the date and maximum stage of the Willamette at Portland due to the effect of backwater from the Columbia.

1075. The Columbia may be considered to have reached the flood stage when the discharge at The Dalles amounts to 600,000 second-feet. When this discharge occurs, the Columbia at the mouth of the Willamette is at a stage of approximately 20 feet and the stage at Portland, due to the effect of backwater on the Willamette, is practically the same. Table 49 shows that frequently the yearly maximum does not reach flood discharge. Occasionally the discharge is abnormally low as was the case in 1926 and in 1930.

TABLE 49.—*Maximum yearly discharges of the Columbia at The Dalles, Oreg., and their effect on the stage of the Willamette at Portland, Oreg.*

[Observations by Oregon Steam Navigation Co.]

| Day | Year | Columbia at The Dalles | | Willamette at Portland | |
|---|---|---|---|---|---|
| | | Discharge | Stage | Day | Stage |
| | 1858 | 563,000 | 33.0 | No record | |
| | 1859 | 874,000 | 46.8 | do | |
| | 1860 | 688,000 | 37.8 | do | |
| | 1861 | 618,000 | 35.5 | do | |
| | 1862 | 948,000 | 50.0 | do | |
| | 1863 | 777,000 | 42.6 | do | |
| | 1864 | 654,000 | 37.2 | do | |
| | 1865 | 714,000 | 39.8 | do | |
| | 1866 | 839,000 | 45.3 | do | |
| | 1867 | 671,000 | 37.9 | do | |
| | 1868 | 483,000 | 29.1 | do | |
| | 1869 | 328,000 | 20.8 | do | |
| | 1870 | 777,000 | 42.6 | do | |
| | 1871 | 856,000 | 46.0 | do | |
| | 1872 | 737,000 | 40.8 | do | |
| | 1873 | 638,000 | 36.4 | do | |
| | 1874 | 582,000 | 33.9 | do | |
| | 1875 | 684,000 | 38.5 | do | |
| | 1876 | 958,000 | 50.4 | June 24 | 28.2 |
| | 1877 | 486,000 | 29.3 | No record | |
| June 12 | 1878 | 485,000 | 29.2 | do | |
| June 18 | 1879 | 643,000 | 36.7 | June 9 | 20.5 |
| June 30, July 1, 2 | 1880 | 914,000 | 48.5 | July 1 | 27.3 |
| June 17 | 1881 | 598,000 | 34.6 | June 16 | 19.7 |
| June 13, 14 | 1882 | 883,000 | 47.2 | June 15 | 26.2 |
| June 14 | 1883 | 573,000 | 33.5 | June 16 | 17.8 |
| June 13 | 1884 | 698,000 | 39.2 | June 15 | 20.2 |
| June 23 | 1885 | 482,000 | 29.1 | June 23 | 14.5 |
| June 9 | 1886 | 673,000 | 38.0 | June 10 | 20.0 |
| June 19 | 1887 | 896,000 | 47.7 | June 21 | 25.7 |
| June 18 | 1888 | 564,000 | 33.0 | June 20 | 18.2 |
| June 5, 8 | 1889 | 302,000 | 19.2 | May 20 | 9.6 |

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[2] Not printed.

TABLE 49.—*Maximum yearly discharges of the Columbia at The Dalles, Oreg., and their effect on the stage of the Willamette at Portland, Oreg.*—Continued

[Observations by Oregon Steam Navigation Co.]

| Day | Year | Columbia at The Dalles | | Willamette at Portland | |
|---|---|---|---|---|---|
| | | Discharge | Stage | Day | Stage |
| May 20 | 1890 | 633,000 | 36.2 | May 17 | 20.1 |
| June 2 | 1891 | 448,000 | 27.4 | June 5 | 13.9 |
| June 22, 23 | 1892 | 607,000 | 35.0 | June 24 | 19.2 |
| June 14 | 1893 | 679,000 | 38.3 | June 15 | 22.0 |
| June 6 | 1894 | 1,160,000 | 59.4 | June 7 | 33.0 |
| May 31 | 1895 | 475,000 | 28.7 | May 31 | 16.4 |
| June 22 | 1896 | 785,000 | 42.9 | June 23 | 24.0 |
| May 24 | 1897 | 780,000 | 42.7 | May 25 | 23.5 |
| June 20, 21 | 1898 | 649,000 | 36.9 | June 19 | 20.6 |
| June 22 | 1899 | 787,000 | 43.0 | June 23 | 24.1 |
| May 19 | 1900 | 547,000 | 32.2 | May 21 | 17.7 |
| June 1 | 1901 | 662,000 | 37.5 | June 5 | 20.7 |
| June 1 | 1902 | 644,000 | 36.7 | June 4 | 20.6 |
| June 18, 19 | 1903 | 787,000 | 43.0 | June 18 | 24.0 |
| May 26 | 1904 | 629,000 | 36.0 | May 27 | 20.9 |
| June 15 | 1905 | 412,000 | 25.5 | June 15 | 13.6 |
| June 1 | 1906 | 374,000 | 23.4 | June 7 | 13.3 |
| June 5 | 1907 | 587,000 | 34.1 | June 10 | 19.3 |
| June 18 | 1908 | 653,000 | 37.1 | June 20 | 21.2 |
| June 19 | 1909 | 675,000 | 38.1 | June 21 | 21.3 |
| May 14 | 1910 | 566,000 | 33.1 | May 15 | 19.1 |
| June 17, 18 | 1911 | 574,000 | 33.5 | June 20 | 19.2 |
| June 1 | 1912 | 568,000 | 33.2 | June 1 | 19.6 |
| June 12 | 1913 | 759,000 | 41.8 | June 14 | 23.8 |
| May 27 | 1914 | 493,000 | 29.6 | May 29 | 16.7 |
| June 1 | 1915 | 328,000 | 20.8 | do | 12.4 |
| July 1 | 1916 | 727,000 | 40.4 | July 4 | 23.9 |
| June 20 | 1917 | 727,000 | 40.4 | June 23 | 23.9 |
| June 25 | 1918 | 578,000 | 33.7 | June 26 | 19.3 |
| June 1 | 1919 | 553,000 | 32.5 | June 2 | 18.6 |
| June 26 | 1920 | 428,000 | 26.3 | June 21 | 14.8 |
| June 11 | 1921 | 773,000 | 42.4 | June 12 | 24.4 |
| June 9 | 1922 | 677,000 | 38.2 | June 11 | 22.5 |
| June 14, 15 | 1923 | 581,000 | 33.8 | June 16 | 19.6 |
| May 25, 26, 27 | 1924 | 433,000 | 26.6 | May 27 | 14.5 |
| May 24, 25 | 1925 | 642,000 | 36.6 | May 26 | 21.5 |
| May 8, 9 | 1926 | 269,000 | 17.1 | May 10 | 9.4 |
| June 18 | 1927 | 690,000 | 38.8 | June 19 | 22.8 |
| May 29 | 1928 | 766,000 | 42.1 | May 31 | 24.4 |
| June 19 | 1929 | 455,000 | 27.7 | June 20 | 17.0 |
| June 14 | 1930 | 332,000 | 21.0 | June 14 | 11.0 |

This table has been prepared from the discharge records published in the several water-supply papers under Part XIIC Lower Columbia Basin and Pacific Slope Drainage Basins in Oregon and from the unpublished discharge records from the Portland office of the United States Geological Survey.

1076. Occasionally there is a well-defined increase in the flow of the Columbia during the winter months but the maximum discharge at these times seldom reaches 300,000 second-feet. This increased flow is caused by winter rains in areas of lower elevations with accompanying flood discharges from the tributary basins affected. In some cases a warm or "chinook" wind will accompany heavy winter rains and cause considerable melting of snow. Such a combination causes the quick floods of the tributaries which produce an equivalent increase in the flow of the Columbia.

1077. The largest flood of which there is an authentic record occurred on June 6, 1894, when the crest discharge at The Dalles was estimated at 1,170,000 second-feet, and the average flow for 24 hours was equal to 1,160,000 second-feet. This flood, the climax of a wet spring, was caused by the approximate coincidence of flood peaks from the upper Columbia and the Snake. It reached a stage of 59.4 feet at The Dalles, 49.7 feet at the upper Cascade Locks and, due to backwater, caused the Willamette at Portland to reach a stage of 33 feet, the highest of record for that river.

1078. Another flood which may have been nearly equal in discharge to that of 1894 occurred in 1849. There is, however, no record of the actual discharge or stage reached at that time. Generally the peak discharge from the Snake at its mouth occurs from one to two weeks before that of the upper Columbia reaches the mouth of Snake River. Occasionally the two peak discharges come together at practically the same time, as was the case during the flood of 1894. (See table 50.) Such coincidence in the two peak discharges was undoubtedly the cause of the unusually high stages and discharges experienced during the floods of 1849, 1862, 1876, and 1880.

1079. Table 50 shows the maximum discharge of the Snake at Burbank-Riparia, Wash., and of the Columbia both at Wenatchee-Vernita, Wash., and at The Dalles, Oreg. Unfortunately the records only include the years indicated and do not extend far enough back to show comparative dates during the large floods prior to 1894.

TABLE 50.—*Dates of, and maximum discharges for Columbia and Snake Rivers as given in water supply papers under parts XII A, B and C; unpublished records of the U.S. Geological Survey and U.S. Weather Bureau records of gage heights*

| Year | Snake at Burbank-Riparia | | Columbia at Wenatchee-Vernita | | Columbia at The Dalles | |
|---|---|---|---|---|---|---|
| | Date | Discharge | Date | Discharge | Date | Discharge |
| 1894 | June 5 | 409,000 (R) | June 7 | 710,000 (W) | June 6 | 1,160,000 |
| 1900 | May 13 | (R) [1] | | | May 19 | 547,000 |
| 1901 | May 18 | (R) [1] | June 4-5 | (W) [1] | June 1 | 662,000 |
| 1902 | May 31 | (R) [1] | June 2 | (W) [1] | do | 644,000 |
| 1903 | | | June 18 | (W) [1] | June 18-19 | 787,000 |
| 1904 | May 24 | (R) [1] | June 9 | (W) [1] | May 26 | 629,000 |
| 1905 | | | June 16 | (W) [1] | June 15 | 412,000 |
| 1906 | May 13 | (R) [1] | July 14-15-16 | (W) [1] | June 1 | 374,000 |
| 1907 | | | June 4 and July 5-6. | (W) [1] | June 5 | 587,000 |
| 1908 | June 17 | (R) [1] | June 18 | (W) [1] | June 18 | 653,000 |
| 1909 | June 6 | (R) [1] | June 23-24 | (W) [1] | June 19 | 675,000 |
| 1910 | Apr. 28 | (R) [1] | May 16 | (W) [1] | May 14 | 566,000 |
| 1911 | June 15 | (R) [1] | June 24-25-26 | (W) [1] | June 17-18 | 574,000 |
| 1912 | June 10 | (R) [1] | June 2 | (W) [1] | June 1 | 568,000 |
| 1913 | May 29 | 293,000 (B) | June 15-16 | 528,000 (W) | June 12 | 759,000 |
| 1914 | May 25-26 | 175,000 (B) | June 21 | 343,000 (W) | May 27 | 493,000 |
| 1915 | May 20-21 | 122,000 (B) | May 31 | 232,000 (W) | June 1 | 328,000 |
| 1916 | June 20 | 248,000 (B) | June 30 and July 1. | 520,000 (W) | July 1 | 727,000 |
| 1917 | May 30 | 256,000 (R) | June 23 | 430,000 (V) | June 20 | 727,000 |
| 1918 | June 14-15 | 216,000 (R) | June 25-26-27 | 430,000 (V) | June 25 | 578,000 |
| 1919 | May 30 | 167,000 (R) | June 1-2 | 368,000 (V) | June 1 | 553,000 |
| 1920 | June 17 | 148,000 (R) | July 15-16-17-18. | 359,000 (V) | June 26 | 428,000 |
| 1921 | May 20 | 270,000 (R) | June 11 | 484,000 (V) | June 11 | 773,000 |
| 1922 | June 7 | 233,000 (R) | June 16-17-18 | 424,000 (V) | June 9 | 677,000 |
| 1923 | No record | | June 19 | 429,000 (V) | June 14-15 | 581,000 |
| 1924 | do | | May 25-26-27-28. | 337,000 (V) | May 25-26-27 | 433,000 |
| 1925 | do | | May 28-29 | 434,000 (V) | May 24-25 | 642,000 |
| 1926 | do | | May 8-9 | 195,000 (V) | May 8-9 | 269,000 |
| 1927 | do | | June 19-20-21 | 471,000 (V) | June 18 | 690,000 |
| 1928 | do | | May 31-June 1 | 523,000 (V) | May 29 | 766,000 |
| 1929 | do | | June 18-19 | 347,000 (V) | June 19 | 455,000 |
| 1930 | Apr. 26 | 95,600 (R) | June 16 | 270,000 (V) | June 14 | 332,000 |

[1] U.S. Weather Bureau gage height records. Discharges not figured.

The symbol (R) means that date and discharge are for gaging station at Riperia, Wash.
The symbol (B) means that date and discharge are for gaging station at Burbank, Wash.
The symbol (W) means that date and discharge are for gaging station at Wenatchee, Wash.
The symbol (V) means that date and discharge are for gaging station at Vernita, Wash.

1080. Table 10 (see par. 107) shows that during the three maximum flow months of May, June, and July the Columbia at The Dalles discharges an average of 52.6 percent of its total yearly flow. During the same 3 months Snake River, the largest tributary and the most directly influential in the maximum flow of the lower Columbia, discharges nearly 50 percent of its total for the year.

### (B) DURATION

1081. Plate 115 [2] shows, by hydrographs, the duration of flood flows in excess of 700,000 second-feet as given in table 49. As no daily records were kept previous to 1879, only the floods occurring since then are shown. Floods between 600,000 and 700,000 second-feet are not shown as they cause little damage. Since 1879, floods in excess of 700,000 second-feet discharge have occurred 13 times. These flood hydrographs show that when discharges of over 700,000 second-feet occur at The Dalles, the resulting flood stage may be expected to last for periods of from 4 to 42 days with an average of 20 days for the 13 floods.

### (C) FREQUENCY

1082. During the 73 years that records have been kept of the Columbia at The Dalles, on four occasions only did the flow exceed 900,000 second-feet, namely 1862, 1876, 1880, and 1894. In the period of 36 years preceding the flood of 1894 there occurred 24 floods which exceeded 600,000 second-feet and of this total 8 exceeded 800,000 second-feet. Since the 1894 flood, another period of 36 years, only 18 floods have discharged above 600,000 second-feet and none have exceeded 800,000 second-feet.

1083. During this second period much irrigation development has taken place. Diversion from the Columbia and its tributaries, particularly the Snake, for this purpose, has undoubtedly resulted in a decrease in the maximum discharge of floods. Future irrigation development within the basin will tend to further reduce flood flows. This does not mean that floods such as were experienced in 1862, 1876, 1880, and 1894 will not occur again, but that irrigation diversions may be expected to make the occurrence of floods of 600,000 to 800,000 second-feet less frequent.

1084. Plate 116 [2] is a flood probability curve for the Columbia at The Dalles. The curve is based on the yearly maximum discharge given in table 49 and shows that on an average of once in a hundred years a flood of 1,060,000 second-feet may be expected and that once in a thousand years the maximum discharge will be 1,240,000 second-feet.

### (D) AREAS AFFECTED

1085. There are in the Columbia Basin below the mouth of the Snake approximately 266 square miles of arable lands below the crest elevation of the 1894 flood, which had an average discharge for 24 hours of 1,160,000 second-feet at The Dalles, Oreg. This area is distributed in small parcels along the Columbia between the mouth of Sandy River, 14 miles above Vancouver, Wash., and the Pacific Ocean, a distance of about 120 miles. Approximately 226

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[2] Not printed.

square miles of the area affected lie below the crest elevations of ordinary floods, or those having a discharge of 600,000 second-feet at The Dalles, Oreg. Above the mouth of Sandy River the Columbia flows in a fairly deep gorge and there is little arable land subject to overflow. (See pl. 123, p. 1671.)

1086. Table 51 shows the approximate acreage and locations of the flood areas by State, county, and river.

TABLE 51.—*Location of flood areas*

| State | County | River | Use | Acres |
|---|---|---|---|---|
| Oregon | Multnomah | Willamette | Industrial | 2,073 |
| Do | do | do | Agricultural | 2,527 |
| Do | do | Columbia | do | 35,600 |
| Do | Columbia | Willamette | do | 6,400 |
| Do | do | Columbia | do | 30,200 |
| Do | Clatsop | do | Industrial | 530 |
| Do | do | do | Agricultural | 27,170 |
| Washington | Clark | do | do | 19,400 |
| Do | do | Lewis | do | 500 |
| Do | Cowlitz | Columbia | Industrial | 1,500 |
| Do | do | do | Agricultural | 17,000 |
| Do | do | Lewis | Industrial | 200 |
| Do | do | do | Agricultural | 2,300 |
| Do | do | Cowlitz | Industrial | 2,106 |
| Do | do | do | Agricultural | 5,689 |
| Do | Wahkiakum | Columbia | do | 13,215 |
| Do | Pacific | do | do | 3,789 |

| | *Square miles* |
|---|---|
| Total in Oregon, 104,500 acres | 163 |
| Total in Washington, 65,699 acres | 103 |
| Grand total, 170,199, acres | 266 |

1087. The following tabulation shows approximately the areas into which the flood plain is divided by use.

*Distribution of flood areas, by use*

[See pl. 117]

| | Acres | Square miles (approximate) |
|---|---|---|
| 1894 flood area | 170,199 | 266 |
| Ordinary flood area | 144,900 | 226 |
| Protected flood area | 76,219 | 119 |
| Protected flood area, industrial | 6,409 | 10 |
| Protected flood area, truck farming | 445 | 1 |
| Protected flood area, general farming | 48,673 | 76 |
| Protected flood area, pasture | 20,692 | 32 |

## (E) LOSSES AND DAMAGES

1088. Practically no reliable data covering the actual losses from overflowing of lands during flood periods are available. In general, losses have been slight, and no records have been kept. As the approach of the freshet season each year is known in advance and the rise in the river is gradual, seldom exceeding 1 foot per day, there is always ample time to remove livestock from unprotected land to higher ground, and stock losses are of rare occurrence. For the same reason there is little loss of equipment and other movable property, and some measures can be taken for protection of other property.

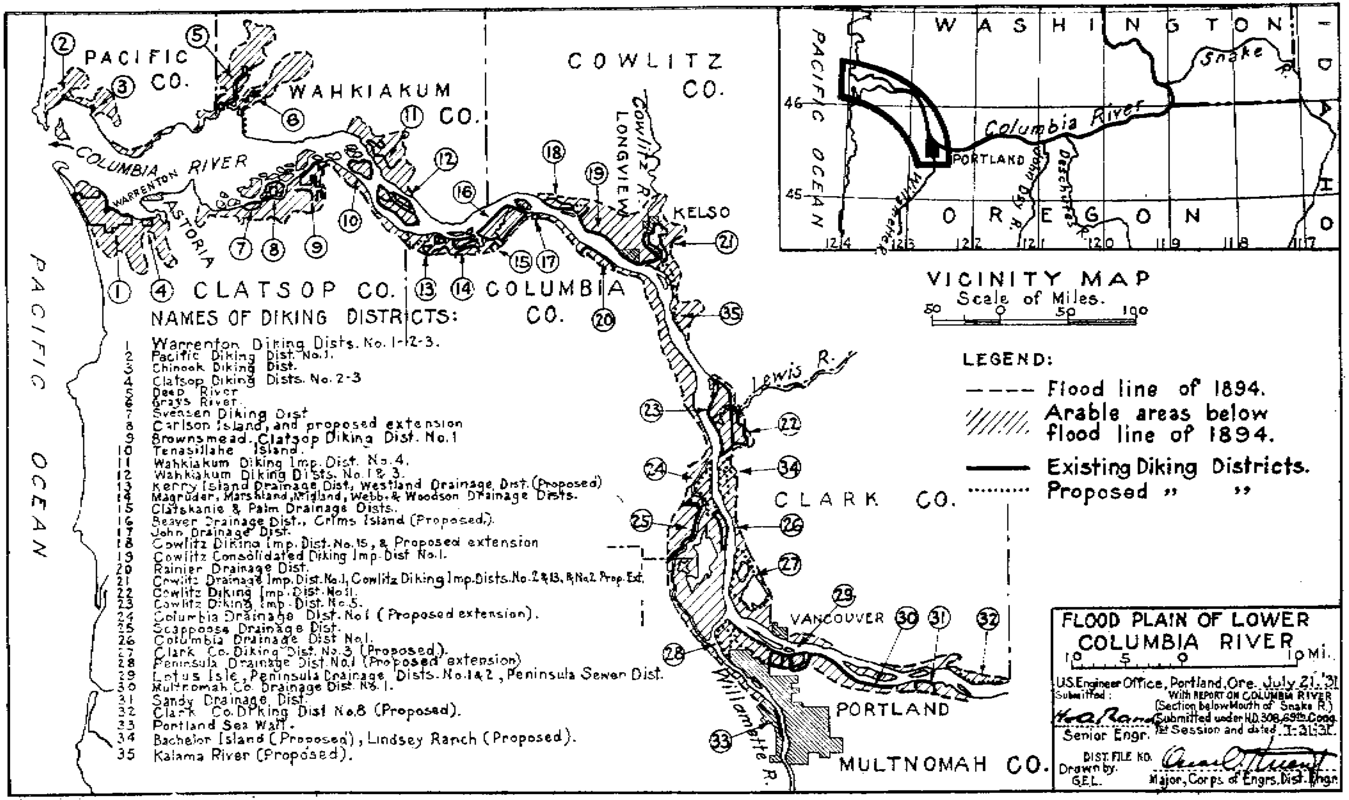
PACIFIC OCEAN
PACIFIC CO.
WAHKIAKUM CO.
COWLITZ CO.
CLATSOP CO.
COLUMBIA CO.
CLARK CO.
MULTNOMAH CO.
COLUMBIA RIVER
WARRENTON
ASTORIA
LONGVIEW
KELSO
Cowlitz R.
Lewis R.
VANCOUVER
PORTLAND
Willamette R.
① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩ ⑪ ⑫ ⑬ ⑭ ⑮ ⑯ ⑰ ⑱ ⑲ ⑳ ㉑ ㉒ ㉓ ㉔ ㉕ ㉖ ㉗ ㉘ ㉙ ㉚ ㉛ ㉜ ㉝ ㉞ ㉟
NAMES OF DIKING DISTRICTS:
1 Warrenton Diking Dists. No. 1-2-3.
2 Pacific Diking Dist. No. 1.
3 Chinook Diking Dist.
4 Clatsop Diking Dists. No. 2-3
5 Deep River
6 Grays River.
7 Svensen Diking Dist
8 Carlson Island, and proposed extension
9 Brownsmead. Clatsop Diking Dist. No. 1
10 Tenasillahe Island.
11 Wahkiakum Diking Imp. Dist. No. 4.
12 Wahkiakum Diking Dists. No. 1 & 3.
13 Kerry Island Drainage Dist., Westland Drainage Dist. (Proposed)
14 Magruder, Marshland, Midland, Webb & Woodson Drainage Dists.
15 Clatskanie & Palm Drainage Dists.
16 Beaver Drainage Dist., Crims Island (Proposed).
17 John Drainage Dist.
18 Cowlitz Diking Imp. Dist. No. 15, & Proposed extension
19 Cowlitz Consolidated Diking Imp. Dist No. 1.
20 Rainier Drainage Dist.
21 Cowlitz Drainage Imp. Dist. No. 1, Cowlitz Diking Imp. Dists. No. 2 & 13, & No. 2 Prop. Ext.
22 Cowlitz Diking Imp. Dist. No. 1.
23 Cowlitz Diking Imp. Dist. No. 5.
24 Columbia Drainage Dist. No. 1 (Proposed extension).
25 Scappoose Drainage Dist.
26 Columbia Drainage Dist No. 1.
27 Clark Co. Diking Dist. No. 3 (Proposed).
28 Peninsula Drainage Dist. No. 1 (Proposed extension)
29 Lotus Isle, Peninsula Drainage Dists. No. 1 & 2, Peninsula Sewer Dist.
30 Multnomah Co. Drainage Dist. No. 1.
31 Sandy Drainage Dist.
32 Clark Co. Diking Dist No. 8 (Proposed).
33 Portland Sea Wall.
34 Bachelor Island (Proposed), Lindsey Ranch (Proposed).
35 Kalama River (Proposed).
VICINITY MAP
Scale of Miles.
50 0 50 100
WASHINGTON
IDAHO
OREGON
PACIFIC OCEAN
Columbia River
Snake R.
Deschutes R.
John Day R.
Willamette R.
PORTLAND
46
45
124 123 122 121 120 119 118 117
LEGEND:
---- Flood line of 1894.
▨ Arable areas below flood line of 1894.
━━ Existing Diking Districts.
...... Proposed " "
FLOOD PLAIN OF LOWER COLUMBIA RIVER
10 5 0 10 Mi.
U.S. Engineer Office, Portland, Ore. July 21, '31
Submitted:
With REPORT ON COLUMBIA RIVER
(Section below Mouth of Snake R.)
Submitted under H.D. 308, 69th Cong. 1st Session and dated 7-21-31.
Senior Engr.
DIST. FILE NO.
Drawn by: G.E.L.
Major, Corps of Engrs. Dist. Engr.

PLATE 117

On certain unprotected areas lying at average flood level good crops are grown after the annual flood crest has passed. However, land subject to overflow and not protected by levees is not usually cultivated; where cleared it is generally used for pasturage. When cultivated, portions of such lands are often seeded prior to arrival of flood crests; in the unusual cases when high floods of long duration follow, reseeding must be done, and crops may usually be grown after the flood crests have passed. Hence, actual losses of crops are small.

1089. During the flood of 1894, the highest known, many sections of railway track and numerous bridges between Hood River and Bonneville (through Columbia Gorge) were carried away. Train service was interrupted for about 60 days. This flood, occurring early in the active period of settlement, was influential in bringing about subsequent construction of railroads, highways, and other works at an elevation above ordinary flood levels. No material damage has been caused by floods through the Columbia Gorge section of the stream since that freshet.

1090. Table 52 shows the annual values of crops per acre for a number of typical districts of the areas subject to overflow. The average annual values per acre for the various types of crops for the districts listed are $88.88 for truck, $29.99 for general crops, and $23.75 for pasture. These figures are believed to be applicable in general to all of the overflow areas under cultivation.

TABLE 52.—*Annual crop values*

| | District | Truck | | General | | Pasture | |
|---|---|---|---|---|---|---|---|
| | | Acres | Value | Acres | Value | Acres | Value |
| See B-Bib 280 | Beaver drainage | | | 3,420 | $61,560 | 2,282 | $41,076 |
| See G-Bib 280 | Clatskanie drainage | | | 300 | 15,000 | | |
| See N-Bib 280 | Cowlitz diking improvement districts nos. 5-11. | 300 | $45,000 | 1,000 | 35,000 | 3,000 | 60,000 |
| | do | | | 1,000 | 30,000 | 1,200 | 3,600 |
| | do | | | 600 | 30,000 | | |
| See Z-Bib 280 | Magruder drainage | | | 200 | 10,000 | 392 | 19,600 |
| See a-Bib 280 | Marshland drainage | 300 | 15,000 | 300 | 15,000 | 433 | 21,650 |
| See b-Bib 280 | Midland drainage | 200 | 10,000 | 400 | 20,000 | 702 | 35,100 |
| See k-Bib 280 | Rainier drainage | 10 | 2,000 | | | | |
| See u-Bib 280 | Woodson drainage | | | | | 353 | 17,650 |
| | Total | 810 | 72,000 | 7,220 | 216,560 | 8,362 | 198,676 |
| | Average per acre | | 88.88 | | 29.99 | | 23.75 |

1091. Table 53 contains general estimates made by the United States Weather Bureau of the total losses due to overflow for stated years for the entire area between the mouth of Sandy River and the sea affected by Columbia River floods. There were no estimates published for the year 1919, and as the volume of flow at the peak period was moderate, it is probable that the losses for that year amounted to little or nothing.

TABLE 53.—*Annual flood losses due to overflow*

[From estimates by U.S. Weather Bureau]

| Year | The peak at The Dalles (cubic feet per second) | Losses | Year | The peak at The Dalles (cubic feet per second) | Losses |
|---|---|---|---|---|---|
| 1918 | 578,000 | $14,000 | 1925 | 642,000 | $97,000 |
| 1919 | 553,000 | No record | 1926 | 269,000 | None |
| 1920 | 428,000 | None | 1927 | 690,000 | $241,000 |
| 1921 | 773,000 | $658,000 | 1928 | 766,000 | $296,000 |
| 1922 | 677,000 | $126,000 | 1929 | 455,000 | None |
| 1923 | 581,000 | $47,000 | 1930 | 332,000 | None |
| 1924 | 433,000 | None | | | |

1092. This table indicates that for the 13-year period, 1918 to 1930, there was a total loss amounting to $1,479,000, or about $114,000 a year. While flood heights greater than those of this period will probably occur, it is believed that the damages will not increase proportionally. Actual losses that occur are not accurately recorded (for example, the figures in the table represent general estimates made by the Weather Bureau) and, therefore, estimates of the probable future losses may vary widely. However, under existing levee conditions it is believed the probable future flood damage of all kinds due to overflow will not average more than $150,000 a year.

1093. Besides damages and losses due to overflow of low lands there is another source of loss and damage that occurs at some places at various stages of water, usually most pronounced at high water, and therefore properly classifiable as flood damage. This source of damage is bank erosion and is caused by wave and current action. Approximately 44,000 acres are protected by levees subject to bank erosion, and it is estimated that the total damage from this source will not exceed $47,000 a year, or about $1.06 per acre of land affected. In some cases local interests have undertaken bank stabilization to protect threatened levees.

1094. In connection with the improvement of the channel for navigation, bank line surveys were made at two points where erosion was most noticeable, namely, along the southwest side of Puget Island, 70 miles below Portland, and along the right bank in the bend above Bachelor Island, about 20 miles below Portland. (See map 2, appendix A.[2]) The surveys at Puget Island covering a period of 3 years (1921 to 1924) showed an average cutting in a distance of 1½ miles of less than 5 feet in the period, or 1.6 feet per annum. The greatest cutting record at any one point was 19 feet in the 3 years, or 6⅓ feet per annum. Above Bachelor Island over a distance of about one half mile of the worst cutting the erosion amounted to an average of 15.4 feet in two seasons, or 7.7 feet per annum. The greatest cut in this section was 15 feet per annum. Assuming that these sections are characteristic of others where erosion is taking place (although it is believed that the erosion in these sections is greatly in excess of the average for the river) the total area lost annually through erosion, in the 70 miles of bank line estimated as subject to such action, would be less than 40 acres of land. The actual annual loss of land is probably not in excess of half this amount. The losses sustained, however, through bank erosion are largely im-

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[2] Not printed. See p. 1750 for explanation.

material until they reach the point of breaching the levees, with resultant flooding of crops and pasture lands. There have been few cases of this kind. Clatsop district no. 1 and Svenson district, both of which are located on islands in the estuary of the Columbia 83 and 88 miles, respectively, below Portland, have had levees breached.

## II. Existing Protective Works

### (a) DISTRICTS

1095. The greater portion of the areas on which flood-protection work has been done is organized in diking or drainage districts under State laws, which permit the bonding of the districts to carry on the work. In a few instances, where extensive areas are held under a single ownership, works have been constructed by the owners as private enterprises (pl. 118). In other instances flood protection has been undertaken by municipalities. The industrial city of Longview, Wash., situated on an extensive area of bottom land at the confluence of Cowlitz River with the Columbia, is protected by a levee designed to be secure against the equivalent of the 1894 Columbia flood. The city of Kelso, Wash., situated on Cowlitz River near the confluence of the Cowlitz with the Columbia and adjoining Longview, is protected by levees constructed to elevations little above ordinary flood crests. The city of Portland, Oreg., on Willamette River, about 12 miles above its confluence with the Columbia, is subject to backwater flood due to freshets in the latter stream, and has constructed a sea wall to a height of 29.3 feet above low water for a distance of 5,100 feet along the portion of the river front in the business section, with intercepting sewer and pumping facilities. The top of the sea wall is 3.9 feet below the 1894 flood-crest elevation and is expected to cope with flood conditions 9 out of 10 years. The port of Portland, in connection with its improvement of the navigable channel and harbor in Willamette River, has, by the deposit of dredged materials, filled more than a thousand acres of bottom land to above the level of ordinary high water.

1096. Protection of flood lands in the lower Columbia River Basin for agricultural purposes began as a private enterprise near the site of the town of Warrenton, Clatsop County, Oreg., in 1895, where levees (locally known as "dikes") were constructed by hand, and were barely large and high enough to afford protection from the highest tides. Diking enterprises developed progressively upstream along Columbia River, and methods of construction advanced to the use of a dipper dredge at Tenasillahe Island in 1908. The first district was organized as Clatsop diking district no. 2, in 1912. By 1914 levee construction had extended to the mouth of the Cowlitz River in Washington. In this locality the Long Bell Lumber Co. employed port of Portland suction dredges in 1922, and built substantial levees of broad base with top elevations well above elevations equivalent to the crest of the 1894 flood (pl. 118). Values of unprotected flood lands vary between $10 and $50 per acre. When protected, these lands are worth $100 to $450 per acre for agricultural land, and some industrial sites, as at Kelso and Longview, Wash., are worth $10,000 to $20,000 per acre. The cost of protection varies between $3 and $625 per acre, depending upon the quantities of material used in levee

# EXISTING PROTECTIVE WORKS

| District | Location | | Legal Basis | Area - Acres | | | | | Levees | | | | | Pumps | | | Tide Gates | Cost of Protection | | Value of Lands. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | State | County | | Total | Industrial | Truck | General | Pasture | Lin. Ft. | Av. Height-Ft. Relative to Highest Water | Above Ground | Top Width Ft. | Slopes | No. | Capacity Gal. per Minute | Months of Operation | No. | Total | Average per Acre | Total | Average per Acre |
| Beaver Drainage District | Oregon | Columbia | Oregon laws | 5,702 | | | 3,420 | 2,282 | 87,000 | − 2 | 10 | 20 | 1/2 | 2 | | 4 | 2 | 234,570 | 41 | 91,200 | 159 |
| Brownsmead | '' | Clatsop | '' | 1,245 | | | 1,245 | | 84,000 | | | | | | | | | | | | |
| Carlson Island | '' | '' | Private | 333 | | | 333 | | 16,010 | + 2 | 7 | 10 | 1/3 | | | | 2 | 13,750 | 41 | 33,300 | 100 |
| Chinook | Washington | Pacific | '' | 1500 | | | | 1,500 | 1,000 | + 1 | 6 | 20 | 1/2 | | | | 1 | 5,000 | 3 | 75,000 | 50 |
| Clatskanie Drainage Dist. | Oregon | Columbia | '' | 300 | | | 300 | | 13,000 | + 2 | 10 | 20 | 1/2 | 1 | | | | 11,961 | 39 | 60,000 | 200 |
| Clatsop Diking Dist. No. 2 | '' | Clatsop | Oregon laws | 280 | | | 60 | 220 | 5,280 | + 1 | 5 | 4 | 1/1 | | | | 2 | 2,120 | 7 | 70,000 | 250 |
| " " " No. 3 | '' | '' | '' | 1,000 | | | 1,000 | | 5,280 | + 2 | 6 | 4 | 1/1 | | | | | 2,920 | 3 | 100,000 | 100 |
| " " " No. 4 | '' | '' | '' | 90 | | | | 90 | 7,224 | | 6 | 6 | 1/1.5 | | | | 3 | 7,051 | 78 | 13,500 | 150 |
| Columbia Drainage Dist. No. 1. | '' | Columbia | '' | 1,600 | | | 1,600 | | 48,000 | − 6 | 8 | 15 | 1/2-1/3-1/7 | 1 | 8,000 | 8 | 1 | 89,000 | 55 | 480,000 | 300 |
| Cowlitz Drainage Imp. Dist. No. 1 | Washington | Cowlitz | Wash. laws | 204 | 40 | | 164 | | | | | | | 2 | | | | 8,500 | 4 | | |
| Cowlitz Consolidated Diking Imp. Dist. No. 1. | '' | '' | '' | 10,000 | 3,000 | | 7,000 | | 76,560 | + 3 | 12 | 20 | 1/3 - 1/7 | 6 | 180,000 | 8 | 9 | 3,603,049 | 360 | 33,500,000 | 3,350 |
| Cowlitz Diking Imp. Dist. No. 2. | '' | '' | '' | 1,146 | 566 | | 580 | | 9,271 | − 3 | 12 | 10 | 1/2 | 3 | 22,500 | 8 | 4 | 113,757 | 99 | 3,033,000 | 2,646 |
| " " " Dists. No. 5 & 11. | '' | '' | '' | 7,300 | 200 | 300 | 2,600 | 4,200 | 68,640 | − 4 | 10 | 20 | 1/3.5 | 3 | 33,000 | 4 | 11 | 542,000 | 74 | 1,273,000 | 174 |
| " " " Dist. No. 13 | '' | '' | '' | 260 | | | 260 | | 9,600 | − 3 | 12 | 20 | 1/3 - 1/7 | 1 | | 4 | 1 | 22,000 | 84 | 104,000 | 400 |
| " " " Dist. No. 15. | '' | '' | '' | 845 | | | 845 | | 35,376 | − 5 | 9 | 20 | 1/2 | 1 | 6,000 | 4 | | 101,657 | 120 | 211,250 | 250 |
| Deep River. | '' | Wahkiakum | Private | 1,180 | | | 1,180 | | 27,000 | − 3 | 7 | 22 | 1/2 | | | | 9 | 52,000 | 44 | 177,000 | 150 |
| Grays River | '' | '' | '' | 1,750 | | | 1,750 | | 26,000 | − 3 | 6 | 20 | 1/2 | | | | 8 | 50,000 | 28 | 262,500 | 150 |
| John Drainage Dist | Oregon | Columbia | Oregon laws | 153 | | 75 | | 78 | 3,300 | − 2 | 9 | 7 | 1/2.5 | 1 | 2,500 | 6 | 1 | 10,060 | 65 | 15,300 | 100 |
| Kerry Island Drainage Dist. | '' | '' | Private | 108 | | | | 108 | 8,000 | − 4 | 12 | 12 | 1/2 - 1/3 | | | | | 3,780 | 35 | 18,900 | 175 |
| Lotus Isle | '' | Multnomah | '' | 80 | 80 | | | | 6,100 | − 2 | 10 | 24 | 1/5 | 2 | | 12 | | 50,000 | 625 | 80,000 | 1,000 |
| Magruder Drainage Dist. | '' | Columbia | Oregon laws | 592 | | | 592 | | 18,000 | + 2 | 10 | 15 | 1/2 | 1 | | 5 | | 33,680 | 56 | 59,200 | 100 |
| Marshland Drainage Dist. | '' | '' | '' | 1,033 | | | 1,033 | | 21,000 | + 2 | 10 | 20 | 1/2 | 1 | | | | 37,155 | 35 | 103,300 | 100 |
| Midland Drainage Dist | '' | '' | '' | 1,302 | | | 1,302 | | 34,000 | + 2 | 10 | 15 | 1/2 | 2 | | | | 52,080 | 40 | 143,220 | 110 |
| Multnomah County Drainage Dist. No. 1 | '' | Multnomah | '' | 8,417 | | | 8,417 | | 79,200 | − 5 | 10 | 20 | 1/7 | 8 | 87,900 | 8 | 5 | 284,564 | 33 | 4,208,500 | 500 |
| Pacific Diking Dist. No. 1. | Washington | Pacific | Wash. laws | 1,568 | | | | 1568 | 800 | + 1 | 6 | 20 | 1/2 | | | | 5 | 19,500 | 12 | 78,400 | 50 |
| Palm Drainage Dist. | Oregon | Columbia | Private | 21 | | | 21 | | 3,000 | + 2 | 10 | 20 | 1/2 | | | | | | | | |
| Peninsula Sewer Dist. | '' | Multnomah | City of Portland | 0 | | | | | 23,100 | − 3 | 12 | 14 | 1/3 | | | | 1 | 370,000 | | | |
| " Drainage Dist. No. 1. | '' | '' | Oregon laws | 951 | 80 | 30 | 457 | 384 | 25,000 | − 6 | 10 | 24 | 1/4.5 | 2 | 18,000 | 6 | | 60,135 | 63 | 190,200 | 200 |
| " " " No. 2. | '' | '' | '' | 1,425 | 380 | 40 | 505 | 500 | 34,000 | − 3 | 12 | 24 | 1/4 | 2 | 18,000 | 6 | 2 | 158,356 | 111 | 855,000 | 600 |
| Portland | '' | '' | City of Portland | 1,533 | 1,533 | | | | 5,100 | − 4 | 0 | 3 | 1/2/1-3/1 | 5 | 90,000 | | | 5,889,267 | 3 841 | 9,660,966 | 6302 |
| Rainier Drainage Dist. | '' | Columbia | Oregon laws | 1,325 | | | 1,325 | | 1,320 | − 6 | 13 | 10 | 1/2.5 | 1 | 7,500 | 3 | 4 | 36,700 | 27 | 198,750 | 150 |
| Sandy Drainage Dist. | '' | Multnomah | '' | 1,556 | | | 1,556 | | 26,400 | − 2 | 12 | 16 | | 1 | | 4 | 1 | 77,000 | 49 | 583,500 | 375 |
| Scappoose Drainage Dist. | '' | Columbia | '' | 5,800 | | | 5,800 | | 55,440 | − 2 | 12 | 8 | 1/7 | 3 | 82,000 | 6 | 2 | 548,000 | 94 | 1,305,000 | 225 |
| Svensen Diking Dist. | '' | Clatsop | Private | 350 | | | 350 | | 21,120 | + 1 | 10 | 6 | 1/2 | | | | 4 | 4,500 | 12 | 105,000 | 300 |
| Tenasillahe Island | '' | '' | '' | 1,596 | | | 325 | 1271 | 36,960 | | 8 | 13 | 1/1.5 | | | | 2 | | | 199,500 | 125 |
| Wahkiakum Diking Dists. No. 1-3. | Washington | Wahkiakum | Wash. laws | 4,300 | | | 4,300 | | 108,000 | + 2 | | 15 | 1/3 | | | | | 182,000 | 42 | 430,000 | 100 |
| " " Imp. Dist. No. 4 | '' | '' | '' | 2,000 | | | | 2,000 | 45,000 | + 2 | | 15 | 1/3 | | | | | 100,000 | 50 | 200,000 | 100 |
| Warrenton Diking Dists. No. 1-2-3. | Oregon | Clatsop | Oregon laws | 6,300 | 530 | | | 5,770 | 119,000 | 0 | 5 | 4 | 1/1 | | | | | | | | |
| Webb Drainage Dist. | '' | Columbia | Private | 721 | | | | 721 | 22,000 | + 2 | 10 | 20 | 1/2 | | | | 4 | 29,735 | 41 | 72,100 | 100 |
| Woodson Drainage Dist. | '' | '' | '' | 353 | | | 353 | | 16,000 | − 4 | 12 | 12 | 1/2 - 1/3 | | | | | 12,355 | 35 | 61,775 | 175 |
| | | | | 76,219<br>119 □ Mi. | 6,409<br>10 □ Mi. | 445<br>1 □ Mi. | 48,673<br>76 □ Mi. | 20,692<br>32 □ Mi. | 231,081<br>233 Mi. | | | | | | | | | | | | |

PLATE 118

construction, quantity and quality of material used in the installation of pumping plants and tide gates, amount of ditch excavation and other items. (See pl. 119.) Plate 118 shows the locations of the districts, their areas, divided approximately into use, the amount and kind of protective works, the approximate cost of protection and value of the protected land.

### (B) LEVEES

1097. About 119 square miles of the areas subject to flood have been protected by levees. The maximum elevation of levees now in use is about 2 feet above the crest elevation of the 1894 flood. In some instances the levees have been built to elevations little higher than ordinary flood crests. Altogether, there are about 233 miles of levees. (See pl. 118.) Some of the levees are used as roadways. In some instances railroad embankments serve as levees. In general, levees are constructed of earth dredged from the bank between the levees and the river. In some cases sand from the river bottom is used. In a few instances they have been constructed by hand. The cross section varies with the method used in construction.

1098. Levees constructed by dipper dredges will average 15 feet wide on top, with slopes of 1 vertical to 2 horizontal on the river side and 1 vertical to 3 horizontal on the land side. The top elevations are usually about 2 feet above the highest flood levels against which protection is designed. The flatter slopes are generally on the land side and are for the purpose of adding strength to the levee to counteract pressure from the river. The cost of this type of levee is approximately $0.30 per cubic yard.

1099. Levees constructed by suction dredges, as at Longview, Wash., will average 20 feet wide on top, with slopes of 1 vertical to 3 horizontal on the river side and 1 vertical to 7 horizontal on the land side, and a top elevation approximately 3 feet above the highest flood levels against which protection is designed. By use of suction dredges, material can be placed in levees at distances up to 4,000 feet from the dredge for approximately $0.15 per cubic yard. Trestles are used to carry the pipe lines, and can be constructed for approximately $0.62 per lineal foot. Columbia River sand in the vicinity of Longview, Wash., will take a slope of about 1 vertical to 7 horizontal without the use of bulkheads when placed by suction dredges. Steeper slopes are obtained by use of bulkheads. Bulkheads with a 5-foot lift can be constructed for approximately $0.61 per lineal foot. (See pl. 119.) Slopes of 1 vertical to 2 horizontal are the steepest in general use along Columbia River. In some localities the bank is composed of light silt and is easily eroded. It has been recommended that levees paralleling the river in these localities be protected by constructing light slopes of coarse river sand, extending from the river to the tops of the levees to form a beach which will break wave action during high water.

1100. In a few instances levees have been constructed by hand. These levees have an average top width of 4 feet, with slopes of 1 vertical to 2 horizontal, and a top elevation about level with ordinary high water. They are located in the region near the mouth of the river and are protected from wave action by long tide flats. The cost of maintenance, which consists of placing earth on top to replace shrinkage and the excavation of rodents, is light.

## LEVEE ANALYSIS

(For one lineal foot of levee ten feet wide on top)

| Type Dredge & Slopes. S=Suction Dredge D=Dipper Dredge | | | 5 Ft. High | | | 7 Ft. High | | | 8 Ft. High | | | 9 Ft. High | | | 11 Ft. High | | | 12 Ft. High | | | 16 Ft. High | | | 22 Ft. High | | | 24 Ft. High | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | No. of Bulkheads | C.Y. | Cost | No. of Bulkheads | C.Y. | Cost | No. of Bulkheads | C.Y. | Cost | No. of Bulkheads | C.Y. | Cost | No. of Bulkheads | C.Y. | Cost | No. of Bulkheads | C.Y. | Cost | No. of Bulkheads | C.Y. | Cost | No. of Bulkheads | C.Y. | Cost | No. of Bulkheads | C.Y. | Cost |
| S | 1/7 | 1/7 | | 8.3 | 1.86 | | 15.2 | 2.88 | | 19.5 | 3.54 | | 24.3 | 4.26 | | 35.4 | 5.93 | | 41.7 | 6.87 | | 72.2 | 11.45 | | 133.6 | 20.66 | | 158.2 | 24.35 |
| D | 1/7 | 1/7 | | 8.3 | 2.49 | | 15.2 | 4.66 | | 19.5 | 5.85 | | 24.3 | 7.29 | | 35.4 | 10.62 | | 41.7 | 12.51 | | 72.2 | 21.66 | | 133.6 | 40.08 | | 158.2 | 47.46 |
| S | 1/3 | 1/7 | 1 | 6.4 | 2.19 | 1 | 11.6 | 2.97 | 2 | 14.8 | 4.06 | 2 | 18.3 | 4.58 | 2 | 26.4 | 4.80 | 3 | 31.1 | 7.11 | 3 | 53.3 | 10.44 | 4 | 97.7 | 17.71 | 5 | 115.5 | 20.99 |
| D | 1/3 | 1/7 | | 6.4 | 1.92 | | 11.6 | 3.48 | | 14.8 | 4.44 | | 18.3 | 5.49 | | 26.4 | 7.92 | | 31.1 | 9.33 | | 53.3 | 15.99 | | 97.7 | 29.31 | | 115.5 | 34.65 |
| S | 1/2 | 1/7 | 1 | 6.0 | 2.13 | 1 | 10.7 | 2.83 | 2 | 13.6 | 3.88 | 2 | 16.8 | 4.36 | 2 | 24.2 | 4.47 | 3 | 28.4 | 6.71 | 3 | 48.5 | 9.72 | 4 | 88.8 | 16.38 | 5 | 104.8 | 19.39 |
| D | 1/2 | 1/7 | | 6.0 | 1.80 | | 10.7 | 3.21 | | 13.6 | 4.08 | | 16.8 | 5.04 | | 24.2 | 7.26 | | 28.4 | 8.52 | | 48.5 | 14.55 | | 88.8 | 26.64 | | 104.8 | 31.44 |
| S | 1/3 | 1/3 | 2 | 4.6 | 2.53 | 2 | 8.0 | 3.04 | 4 | 10.0 | 4.56 | 4 | 12.3 | 4.90 | 4 | 17.5 | 5.68 | 6 | 20.4 | 7.34 | 6 | 34.3 | 9.42 | 8 | 61.9 | 14.78 | 10 | 72.8 | 17.64 |
| D | 1/3 | 1/3 | | 4.6 | 1.38 | | 8.0 | 2.40 | | 10.0 | 3.00 | | 12.3 | 3.69 | | 17.5 | 5.25 | | 20.4 | 6.12 | | 34.3 | 10.29 | | 61.9 | 18.57 | | 72.8 | 21.84 |
| S | 1/2 | 1/3 | 2 | 4.1 | 2.45 | 2 | 7.1 | 2.90 | 4 | 8.8 | 4.38 | 4 | 10.8 | 4.68 | 4 | 15.2 | 5.34 | 6 | 17.7 | 6.93 | 6 | 29.6 | 8.72 | 8 | 52.9 | 13.43 | 10 | 62.2 | 16.05 |
| D | 1/2 | 1/3 | | 4.1 | 1.23 | | 7.1 | 2.13 | | 8.8 | 2.64 | | 10.8 | 3.24 | | 15.2 | 4.56 | | 17.7 | 5.31 | | 29.6 | 8.88 | | 52.9 | 15.87 | | 62.2 | 18.66 |
| S | 1/2 | 1/2 | 2 | 3.7 | 2.39 | 2 | 6.2 | 2.77 | 4 | 7.7 | 4.21 | 4 | 9.3 | 4.45 | 4 | 13.0 | 5.01 | 6 | 15.1 | 6.54 | 6 | 24.8 | 8.00 | 8 | 44.0 | 12.10 | 10 | 51.5 | 14.44 |
| D | 1/2 | 1/2 | | 3.7 | 1.11 | | 6.2 | 1.86 | | 7.7 | 2.31 | | 9.3 | 2.79 | | 13.0 | 3.90 | | 15.1 | 4.53 | | 24.8 | 7.44 | | 44.0 | 13.20 | | 51.5 | 15.45 |

Note:

Cost per Lin. Ft. of most economical type of levee is underlined.
1/7 is natural slope of lower Columbia River sand when wet.
Width of 10 feet on top of Levee is minimum for roadway.
Suction dredging at $0.15 per Cu. Yd.; $0.62 per Lin. Ft. for pipe trestle; $0.61 per Lin. Ft. for bulkhead of 5 foot lift from Port of Portland report on Long-Bell diking project Aug., 1922 for suction dredges
Dipper dredging at $0.30 per cubic yard quoted by R.E. Hickson, Sr. Engineer, U.S.E.D., Portland, Ore.

PLATE 119

1101. As has been stated above (par. 1097), the maximum heights of existing levees are about 2 feet above the crest elevation of the 1894 flood and in some areas levee heights are of little more than ordinary flood crests. Inasmuch as the floods of the period 1918 to 1930 for which flood damages have been estimated have been much smaller than the 1894 flood, it is judged that the bulk of the damage must have occurred in those areas where the levees were lower than the maximum heights. If all the levees had been built to the same elevation as the highest existing levees, it is believed that the bulk of the flood damage occurring between 1918 and 1930 would have been avoided.

1102. A study of the probable effects of contractions of Columbia River in the vicinity of Rainier, Oreg., indicate that for a flood discharge of 1,160,000 cubic feet per second at The Dalles, Oreg., the additional protective works would increase the gage height by 1.5 feet over that normally reached in the uncontracted flood channel. A similar study of Columbia River near Eureka, Wash., Jetty No. 62.1, which is 50.9 miles from the mouth of the river, indicates approximately the same increase in gage height. Also, it has been found that for earth levees a height of 4 feet above the expected flood crest is required for reasonable safety. Taking this factor into account, together with the effect of the channel contraction, the maximum existing levee heights would safely protect against a flood of 1,020,000 second-feet. A flood of this size may be expected at least once in 55 years. In order to protect against a flood equivalent to the 1894 flood, it is estimated that 216 miles of earth levees would have to be raised by an average height of 7 feet and 17 miles of new earth levees with an average height of 17 feet would have to be built.

1103. Apparently, in the location of many of the levees, erosion of the banks was not given very serious consideration. Various sections, totaling about 17 miles, were placed too close to the bank and are in some places threatened. To insure their safety these sections should be reconstructed at an average distance of about 150 feet back from bank line. Were the new sections constructed of same cross section as present levees the productive area lost would total about 300 acres. If, as is probable, levees constructed by suction dredges were to replace the present levees which have been constructed by dipper dredges, due to the greater width of section of the former, the productive area lost would be somewhat greater.

1104. As a means of protecting banks from erosion due to river currents, permeable spur dikes properly located and constructed constitute probably the most economical form of protection for the Columbia River. As a protection against wave action, however, such works are not very effective, except to the extent that they keep vessels at a distance from the bank. Against wave action and steamer wash, riprap is probably the most effective and permanent form of protection. And this is also very effective against current erosion and undercutting if carried down under water to the bottom of the slope. Such riprap protection would be much more expensive, however, than dike construction per foot of bank protected. Flat fills of coarse sand are effective against wave action but would not give a permanent protection against current erosion. In many places where spur dikes have been constructed for channel improvement, young willows and other brush have sprung up on the deposits between the dikes. This growth forms a very good protection for the main banks against wave action. Where banks are not too steep and water is not too deep, such spur dikes, with a growth of brush between, form probably the best and most practical form of protection.

1105. Below are given figures showing estimated cost of raising present levees and constructing new levee to replace various sections now endangered by bank erosion. Two estimates are given; the first assumes levees 2 feet above the profile marked out by the 1894 flood, the second assumes levees 4 feet above the profile which a flood equal in volume to the 1894 flood, as influenced by present channel protective works, would mark out if occurring at this time.

| | |
|---|---|
| 1. To raise 216 miles of levee 2 feet above crest of 1894 flood | $818,000 |
| To construct to same specification 17 miles of new levee to avoid eroding banks | 757,000 |
| Land lost 300 acres at $300 | 90,000 |
| Total | 1,665,000 |
| Interest at 6 percent, $99,900. | |
| 2. To raise 216 miles of levee 4 feet above crest of flood equal to 1894 flood as elevated by present channel contraction | 5,654,000 |
| To construct to same specifications 17 miles of new levee to avoid eroding banks | 931,000 |
| Land lost 400 acres at $300 | 120,000 |
| Total | 6,705,000 |
| Interest at 6 percent, $402,300. | |

1106. In estimating the cost of additional protection for the business area in Portland, the temporary construction plans of the city engineer are taken as a basis. These plans contemplate a sandbag levee, reinforced by wood lagging, to be constructed when flood damage appears imminent. Permanent construction to protect against a flood as high as the 1894 flood is not considered economical. Such temporary construction would cost approximately $52,000 for floods occurring one in 55 years; and $104,000 for floods with crest heights equivalent to the flood of 1894.

### (C) PUMPING

1107. Below Puget Island, 39 miles from its mouth, Columbia River enters a broad area and flood crests are thus reduced. Low unprotected land in this area is covered by tidewater twice each day. The rise and fall of the tides is fairly uniform throughout the year. (See pl. 117, p. 1645.) Water accumulating behind the levees of protected land flows out through automatic tide gates during low-tide periods. When the tides become higher than the water surface behind the levees, the gates close automatically and prevent a back flow. Above Puget Island, tidal influences are less pronounced and flood crests from the upper river are more noticeable. Tide gates are used during low-water periods. However, the river will sometimes maintain flood heights for several days, during which time drainage water accumulates on the low ground behind the levees and must be removed by pumping. In general, pumps have proved to be reliable. No instance of pump failure has been found. Table 54 shows the costs, including construction and installation, of tide gates and pumps for typical districts.

TABLE 54.—*Costs of construction and installation of pumps and tide gates for typical districts*

| District | Area (acres) | Cost of pumps | | Tide gates | | |
|---|---|---|---|---|---|---|
| | | Total | Per acre | Number | Cost | |
| | | | | | Total | Each |
| Beaver drainage district | 5,702 | $11,000 | $1.92 | | | |
| Carlson Island | 333 | | | 2 | $300 | $150 |
| Clatskanie drainage district | 300 | 1,461 | 4.87 | | | |
| Clatsop diking district no. 2 | 280 | | | 2 | 120 | 60 |
| Clatsop diking district no. 4 | 90 | | | 3 | 192 | 64 |
| Do | | | | 2 | 190 | 95 |
| Cowlitz diking improvement district no. 2 | 1,146 | | | 4 | 10,000 | 2,500 |
| Cowlitz diking improvement district no. 5 to 11 | 7,300 | | | 11 | 22,000 | 2,000 |
| Cowlitz diking improvement district no. 15 | 845 | 8,000 | 9.46 | 1 | 2,000 | 2,000 |
| Deep River | 1,180 | | | 9 | 6,300 | 700 |
| Grays River | 1,750 | | | 8 | 5,600 | 700 |
| John drainage district | 153 | 4,000 | 6.12 | 1 | 1,000 | 1,000 |
| Magruder drainage district | 592 | 4,000 | 6.75 | | | |
| Marshland drainage district | 1,033 | 1,000 | .96 | | | |
| Midland drainage district | 1,302 | 4,000 | 3.07 | | | |
| Multnomah County drainage district no. 1 | 8,417 | 14,000 | 1.66 | 5 | 750 | 150 |
| Peninsula sewer district | | | | 1 | 10,000 | 10,000 |
| Peninsula drainage district no. 1 | 951 | 6,463 | 6.79 | | | |
| Peninsula drainage district no. 2 | 1,425 | 8,122 | 5.69 | 2 | 16,000 | 8,000 |
| Rainier drainage district | 1,325 | 1,250 | .94 | 4 | 508 | 127 |
| Scappoose drainage district | 5,800 | 50,000 | 8.62 | 2 | 15,000 | 7,500 |
| Tenasillahe Island | 1,596 | | | 1 | 2,000 | 2,000 |
| Do | | | | 1 | 3,900 | 3,900 |
| Webb drainage district | 721 | | | 4 | 4,500 | 1,125 |
| Total | | 113,296 | | 63 | 100,360 | |
| Average | | | 4.06 | | | 1,593 |

(See pl. 117, p. 1645).

1108. Table 55 shows the required capacity and cost of pumping for some of the districts. These figures are used as averages for other districts where pumps are used.

TABLE 55.—*Required capacity and cost of pumping, per year*

| District | Area (acres) | Capacity (gallons per minute) | | Number of months operated | Cost | |
|---|---|---|---|---|---|---|
| | | Total | Per acre | | Total | Per acre |
| Cowlitz consolidated diking improvement district no. 1 | 10,000 | 180,000 | 18.00 | 8 | $14,160 | $1.41 |
| Cowlitz diking improvement district no. 2 | 1,146 | 22,500 | 19.60 | 8 | 3,620 | 3.15 |
| Cowlitz diking improvement districts nos. 5–11 | 7,300 | 33,000 | 4.50 | 4 | 5,000 | .68 |
| Cowlitz diking improvement district no. 15 | 845 | 6,000 | 7.00 | 4 | 600 | .71 |
| Multnomah County drainage district no. 1 | 8,417 | 87,900 | 1.00 | 8 | 5,000 | .59 |
| Peninsula drainage district no. 1 | 951 | 18,000 | 18.92 | 6 | 2,340 | 2.46 |
| Peninsula drainage district no. 2 | 1,425 | 18,000 | 12.63 | 6 | 3,263 | 2.28 |
| Rainier drainage district | 1,325 | 7,500 | 5.60 | 3 | 1,200 | .90 |
| Scappoose drainage district | 5,800 | 82,000 | 14.10 | 6 | 5,000 | .86 |
| Total | 37,209 | 454,900 | | | 40,183 | |
| Average | | | 12.22 | 6 | | $1.07 |

## III. UNPROTECTED AREAS

### (A) LOCATION AND EXTENT

1109. There are about 147 square miles of unprotected areas below the crest elevation of the flood of 1894. Of these, about 23 square miles are of sufficient size and are so located that they may be logi-