

## HYDRO-ELECTRIC POWER IN WASHINGTON

To those familiar with the natural resources of Washington it is a well-known fact, that, aside from the land itself, the water resources—that is, water power and water for irrigation—head the list in future economic importance. In potential hydroelectric power Washington easily ranks first of all the States in the Union. The latest estimate by the U. S. Geological Survey, released Feb. 11, 1928, credits Washington, with 11,225,000 H.P. or 18.9% of the total water power resources of the United States, on the basis of power used 50 per cent of the time and at 70 per cent overall efficiency; an increase of 40 per cent on previous estimates. A recent compilation\* by Mr. Glen L. Parker, District Engineer, U. S. Geological Survey, of power data on the Columbia river shows that this stream alone has within the borders of Washington, 6,568,000 H.P., or almost as much available power as has generally been credited to the whole State. To readers not directly concerned with hydro-electric power, a comparative statement may be more illuminating than a table of statistical data. Thus the Columbia river, proper, limited to the part lying within the borders of the State of Washington, and exclusive of all its tributaries, has more than twenty-seven times the power developed by the famous Wilson Dam.

To gain insight into the hydroelectric power possibilities of any region, as the Pacific Coast or the State of Washington, it is essential first to acquire clear concepts of three fundamental factors: (a) land elevation or topography; (b) annual and monthly precipitation; (c) natural and artificial water storage. After a broad and comprehensive view of the region under consideration has been acquired, the more specific factors of stream flow, static head, available dam sites, and so on, pertaining to individual power developments, can be studied to best advantage because modern power plants are not isolated units but parts of large systems of inter-connected and, in a large measure, inter dependent power developments.

*Topography.*—Geographically, Washington may be considered as consisting of eight fairly distinct districts: the Olympic Mountains, the Puget Sound Basin, the Willapa Hills, the Cascade

\* Columbia River power possibilities between International boundary and tide-water. U.S.G. 1925.

Mountains, the Columbia Plateau, the Okanogan Highlands, the Selkirk Mountains, and the Blue Mountains.

Over two-thirds of the land area in Washington is mountainous and for the greater part extremely rugged. The mountainous regions, having more than five hundred glaciers, vast snowfields and timbered areas, form huge natural water-power-storage systems, as the precipitation during the winter months is held in congealed form until released by the summer heat. Mt. Rainier alone has twenty-two glaciers, which with extensive snowfields, form an enormous ice storage system that provides an unceasing flow of water and power to the White, Puyallup, Nisqually and Cowlitz rivers.

The Cascade Mountains form a huge ridge, dividing the State into an eastern and a western section, having strikingly different climatological and physiographic characteristics. The crest of the range varies from 3,500 to 6,500 feet in elevation, with an average of about 5,500 feet, but it has a number of higher peaks as Mt. Shuksan (9,038 feet), Mt. Stuart (9,470 feet), Star Peak (8,400 feet) Boston Peak (8,850 feet), Castle Mountain (8,840 feet), North Star Mountain (9,500 feet) etc. Rising above the geologically mature range, stand, like young sentinels, five snow-capped volcanic cones: Mt. Baker (10,750 feet), Glacier Peak (10,436 feet), Mt. Adams (12,307 feet), Mt. St. Helens (9,671 feet) and Mt. Rainier (14,408 feet). The range varies in width from 125 miles on the Canadian Border to about 50 miles on the Columbia river.

East of the Cascades along the northern border lie the Okanogan Highlands and, in the northeast corner, a small segment of the Selkirk Mountains. The surface formation consists of a series of ridges in a general north and south direction, having an elevation of from 5,000 to 6,000 feet.

In the southeast corner are the Blue Mountains, a spur of the Rocky Mountains, rising about 4,000 feet above the surrounding plateau and having an elevation of from 6,000 to 7,000 feet above sea level.

In the western part of the State, the Olympic Mountains form a well-defined geographic division having a general elevation of from 4,000 to 5,000 feet. Numerous peaks reach between 6,000 and 7,000 feet and the summit, Mt. Olympus, is 8,150 feet above sea level.

The Willapa Hills cover a comparatively small area in the southwest corner of the State. They are of irregular contour,

heavily timbered, and reach an elevation of about 3,000 feet. The Columbia Plateau, which lies to the east of the Cascade Mountains, was formed by an immense lava flow that covered almost the entire area; the beds in some places are 4,000 feet in thickness. Later geologic changes have caused warpings in the lava beds, which, with long-continued water and wind erosion, have developed irregularities in the earlier unbroken surface. The Columbia, Spokane, and Snake rivers have cut great gorges, or canyons, in places more than a thousand feet deep, through the lava beds. The Grand Coulee and other canyons and coulees were produced by stream erosion, being the abandoned beds of large rivers.

Between the Olympics and the Cascades lies the Puget Sound Basin, the belt of lowlands extending from the Canadian Border to the Columbia river. In the northern and central parts of the rolling plain the surface layer is glacial drift and comparatively level, while in the southern non-glacial section the topography is more irregular. Geologically, the Puget Sound Basin was formed by a great structural down-warp between the Cascades and the Olympics, followed by a submergence in which the major valleys, Puget Sound, were flooded.

While all the streams in the State empty either directly, or through intermediate waters, into the Pacific Ocean, the land surface is divided topographically into three watersheds or drainage areas: the Columbia river system, the Puget Sound Basin and the Pacific Coast Belt.

*Precipitation.*—More than passing notice must be given to the distribution and the seasonal variations of rainfall in order to appreciate fully the importance of water storage as a basic factor for hydroelectric power developments in Washington.

Three outstanding features are to be observed:

(a) The great variation in the annual rainfall as recorded by the several U. S. Weather Bureau stations: from over 137 inches at the Quinault station on the western slope of the Olympic Mountains to less than 7 inches in the Columbia Basin and in the Yakima Valley east of the Cascade range. Stream-flow data on the Quinault river indicate that in some areas in the Olympic Mountains the annual rainfall is more than 250 inches.

(b) The marked irregularity in the distribution of the annual rainfall even within regions of fairly uniform topography, as the lowlands of the Puget Sound Basin. Thus, the annual

rainfall in Olympia (54.96) is 60 per cent greater than in Seattle (34.0), while, in Everett (29.66), it is 13 per cent less.

(c) The large seasonal variation: in general, a wet-winter season with the greatest precipitation in November, December, and January, and a dry-summer season with a minimum rainfall in July and August.

The underlying causes for the wide variations in the rainfall in Washington are found in three basic factors:

(a) That the moisture-bearing winds come from the Pacific Ocean, from a west south-westerly direction.

(b) That the belt of "prevailing westerlies" over the Pacific Ocean covers the coast of Washington during the winter months but that it moves northward reaching Alaska during the summer.

(c) Topography: especially the geographic positions of both the Olympic Mountains and the Cascade Mountains.

The first and third factors largely account for the wide variation in the annual rainfall, while the seasonal range is in the main caused by the second factor. The moisture-laden winds coming from the Pacific Ocean pass up the western slopes of the Olympic and Cascade Mountains and, as the temperature decreases with elevation, this causes rapid condensation which produces heavy precipitation in these regions. On the eastern, lee-ward side, the air passing down the mountain slopes increases in temperature, with a corresponding rise in its moisture-carrying capacity and, as a consequence, the rainfall is comparatively light.

*Developed Hydroelectric Power in Washington.*—On the Chart-map, Fig. 1 are shown the location and installed capacity of hydroelectric power plants already constructed and in operation. The squares indicate the approximate location of the respective plants and the figures indicate, in each case, the rated horse power of the installed water wheels. The total installed capacity as listed in the figure is 699,367 horsepower, approximately 5 per cent of the available hydroelectric power in the State.

Power developments however desirable are of necessity limited to the amount of power that can be used economically. The demand for electric power in the State of Washington is, at present; increasing at the rate of approximately 50,000 H. P. a year and it is self evident that on a sound economic basis the development of new power units can not proceed at a greater rate than the increase in the consumption of electric power.

During the past four years five important power developments, with installed capacities of 197,700 H.P., have been completed and placed in operation.

Of these, the Newhalem or Gorge power plant, on the Skagit river, Seattle Municipal system, was completed first, and operation started in September, 1924. Generators with a rated capacity of 50,000 H.P. deliver power to Seattle over a hundred mile, three-phase transmission line at 165,000 volts. Construction work for additional power developments, on the Skagit river, is in progress.

The Lake Cushman power development, Tacoma Municipal power system on the Skokomish river, first delivered power to the city of Tacoma early in the winter of 1926. The Cushman plant has an installed generator capacity of 50,000 H.P. Power is transmitted to Tacoma at 110,000 volts and a distinctive feature of the transmission line is the 6241 ft., 6 in., long span across the Narrows, the longest power span in the world.

The Baker river power development is the third of the five important power plants recently constructed in the State. It is located on the Baker river near Concrete and is owned and operated by the Puget Sound Power & Light Co. More than 50,000 H.P. of electric energy are delivered over a 110,000 volt transmission line to Bellingham, Everett, Seattle and other industrial centers.

The fourth recent power development (17,500 H.P.) is at Glines Canyon on the Elwha river and relates specifically to the paper and pulp industry. It is claimed that the Glines Canyon plant has the distinction of being the largest automatically operated power station in the world.

The fifth and latest important power development, owned and operated by the Washington Water Power Co., is on the Chelan river and has in Lake Chelan, the premiere natural water storage basin in the State. The first unit of 32,200 H.P. was completed and placed in operation last September and a second unit of like capacity is at present under construction.

*Undeveloped Potential Power in Washington.*—On the chart Fig. 2, the location and estimated output of the more desirable undeveloped water-power sites in the State are shown. Only sites having estimated capacity of 10,000 H.P. or more, are included. It has been estimated that, excluding the Columbia river, more than one-third of the total available water-power in the



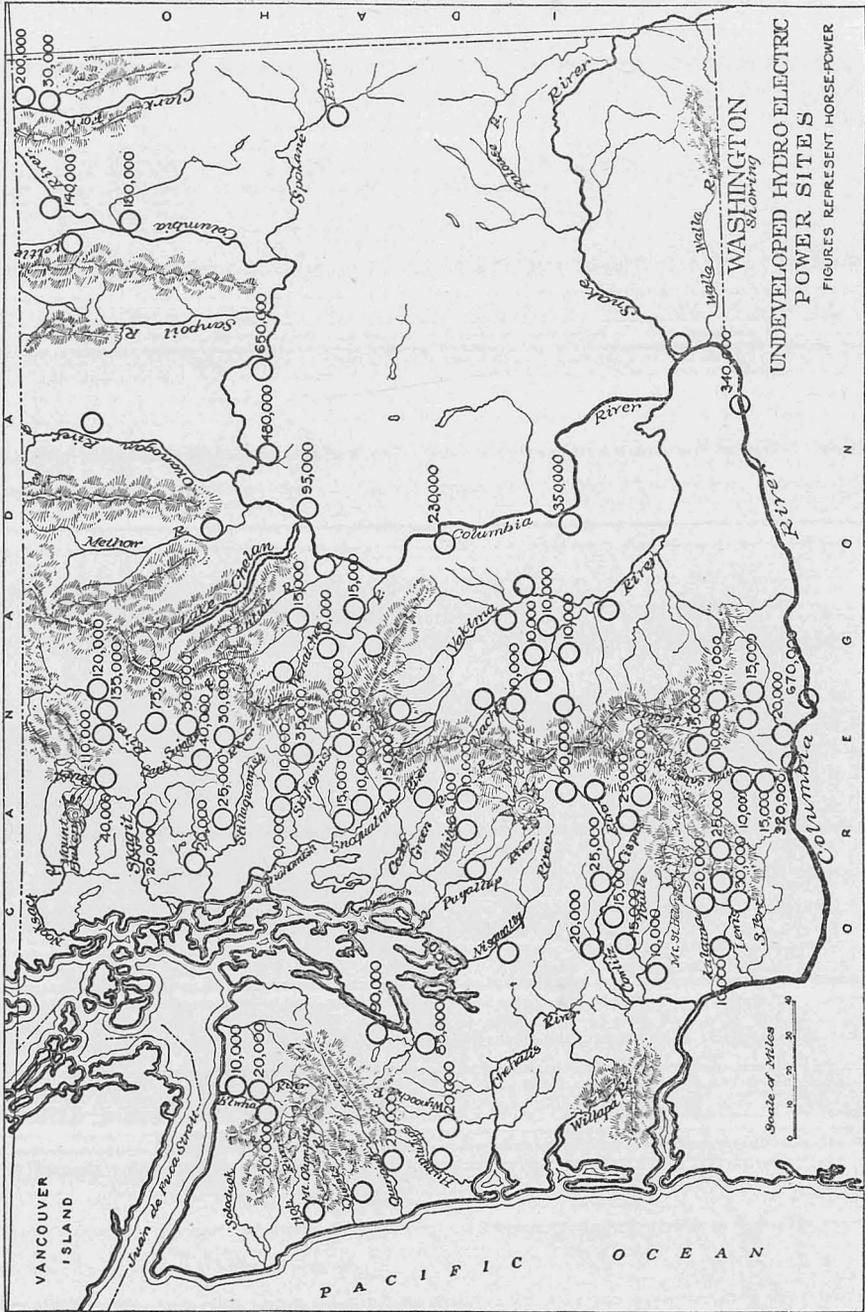


FIG. 2—Undeveloped Potential Power in Washington.

State is found on sites having less than 10,000 horsepower, the lower limit on the output of plants included in the figure.

To estimate the probable power output on any given power site that may be developed at a reasonable cost, is a difficult problem. To determine the location and cost of dam foundation, the extent of the storage facilities, and other factors, require extensive borings and detailed investigations of the geologic formations and other factors for each proposed site. Different assumptions as to available storage facilities, the cost of dam construction, and what should be considered a "reasonable cost" per horsepower, will often lead to widely differing estimates of the available power. Unfortunately, it has not been possible to coordinate the available data so as to use a common, clearly-defined basis for all sites. The figures attached to the power sites indicated on the chart, Fig. 2, represent, in general, horsepower available 90 per cent of the time at 70 per cent efficiency and, in some cases, without taking into consideration man-made storage.

Washington not only leads all other States in potential water power, but, what is likewise important, the concentration (water power per square mile of land area) is twice as great as in its nearest competitor—Oregon—more than two and a half times that of California, over ten times that of Wisconsin or Georgia and more than twenty times that of Minnesota. Moreover the geographic features are favorable for economic transportation of electric energy from all parts of the State to tidewater industrial centers. The general contour of the land and, in particular, the geographic lay of the Puget Sound Basin, in connection with the Cascade Mountain passes, make feasible the construction of trunk transmission lines by which it is possible to unite all the power plants and distribution systems into a super-power system covering the entire State. Although less than five per cent of the available water power has as yet been developed, two 110,000 volt transmission lines cross the Cascades, so that the generators on the Spokane river, at the eastern end of the State, already operate in synchronism with power plants in the Puget Sound Basin.

Interconnection of power plants is in general desirable, and in Washington especially advantageous, as minima stream-flows of the several rivers come at different seasons of the year. Thus all the rivers, except the Skagit, west of the Cascades, have maximum flow in the winter, the minimum in August and September, while conditions are essentially the reverse for the Skagit and the Columbia. Therefore, when completely developed the inter-

connected hydroelectric power plants will supplement each other so as to provide a continuous unfailing supply of power during the entire year, with little, if any, need of auxilliary stand-by steam plants.

While the natural water resources in Washington are very large and of basic economic importance, it must be kept in mind that to develop these resources whether for irrigation or electric power requires the expenditure of huge sums of money. It has been estimated that merely to develop the available hydroelectric power in the State, that is, generating stations and transmission lines, will require a capital investment of over a billion dollars. In addition, large sums will be required for substations and distribution systems necessary to retail the electric energy to individual customers. Concurrent with the development of the power resources must of necessity be a corresponding expansion in industry within the State. Factories, mills and a wide variety of industrial plants, requiring many times as much capital investment as the power developments, will be constructed and placed in operation within the State because dependable power is a prime requirement for present day industry.

Another important characteristic of hydroelectric power developments is the permanency of the investment. Hydroelectric power plants, transmission lines and distribution systems permanently increase the taxable wealth of the State. The permanent economic welfare of the people in the community served is closely interwoven with the best interests of hydroelectric power utilities. Gas, oil and even coal bring prosperity for a short period only, while water power is a permanent asset, everlasting as the hills. A golden key to Washington's future greatness and economic independence lies in the water resources that must be made productive through power developments and irrigation. With every year that passes hydroelectric power and irrigation in Washington, as measured by manufactured goods and agricultural products, will aid and supplement each other to a greater extent than is possible in any other State.

C. EDWARD MAGNUSSON