DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

WATER-SUPPLY PAPER 313

WATER POWERS OF THE CASCADE RANGE

PART II.—COWLITZ, NISQUALLY, PUYALLUP, WHITE, GREEN, AND CEDAR DRAINAGE BASINS

BY

FRED F. HENSHAW AND GLENN L. PARKER

PREPARED IN COOPERATION WITH THE WASHINGTON
STATE BOARD OF GEOLOGICAL SURVEY

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INTRODUCTION.

This report is the second of a series on the "Water powers of the Cascade Range," prepared by the United States Geological Survey under a cooperative agreement with the Washington State Board of Geological Survey, Prof. Henry Landes, State geologist. Part I, giving data on the drainage basins of Klickitat, White Salmon, Little White Salmon, Lewis, and Toutle rivers, in southwestern Washington, was prepared by John C. Stevens and has been published as Water-Supply Paper 253.

The drainage basins of Cowlitz (except the Toutle), Nisqually, Puyallup, White, Green, and Cedar rivers are treated in this volume. The matter presented includes all monthly estimates of river discharge derived from data that have been collected by the water-resources branch of the United States Geological Survey in cooperation with the Washington State Board of Geological Survey and by private parties. River plans and profiles made by the topographic branch of the Geological Survey are inserted at the end of the report. The power possibilities of the streams are described in as much detail as is warranted in a work of this kind. It is desired to emphasize at the outset the fact that complete surveys and plans for development of unused power privileges have not been attempted. Such work is more properly left to those who are contemplating actual development. The purposes of this work are rather to show the power resources of the basins described and to indicate in a general way the relative value of the individual power privileges.

The river surveys, which constitute one of the essential factors in the analysis of power, were made during the field season of 1910 by Bayard Knock and W. B. Lewis, of the topographic branch of the United States Geological Survey, under the direction of T. G. Gerdine, geographer.

A supplementary survey of the upper portion of Cispus River was made during August and September, 1911, by Charles Leidl and W. O. Harmon, under the direction of Fred F. Henshaw, district engineer.

Field reconnaissances were made in most of the basins to gather information relative to water supply, topographic features, and other general conditions which should be considered in the interpretation of stream-flow records and river-profile representations. These reconnaissances were made by G. L. Parker, assistant engineer of the United States Geological Survey.

The methods used in analyzing the stream-flow data are those ordinarily followed by the Geological Survey. They have been fully described in previous reports.[1] The streams investigated are considered in detail. Descriptions and outlines of present hydraulic development, together with short discussions of undeveloped possibilities, are given for each of the drainage basins. All discharge data available on the streams covered have been revised, and a large amount of data collected by private parties is presented for the first time.

The summaries of the available power in each basin were computed from the average flow for the lowest week on record and from the flow that could be realized from possible storage. The flow with storage was computed on the basis of the continuous discharge that can be maintained by the release of the storage during the most extreme drought on record, considering the length and severity of low-water periods. The power schedules are thus made on a slightly different basis from the first report, in which the average minimum discharge represented the mean of the minimum weekly values for a series of years.

COOPERATION AND ACKNOWLEDGMENTS.

The Washington State Board of Geological Survey, consisting of the governor, treasurer, secretary of state, and the presidents of the State University and the State Agricultural College, represents the State in this cooperative work. The board elected Henry Landes, professor of geology at the State University, as State geologist, and intrusted him with supervisory authority to represent the State in the details of these cooperative surveys.

The writers are indebted to Prof. Landes for his hearty cooperation in all matters pertaining to the joint work in the State, of which the material gathered for this report is a part.

Acknowledgments are due to the following companies, municipalities, and individuals for heretofore unpublished river-discharge

[1] Methods of conducting stream measurements and analyzing hydrographic data are discussed in the introduction of papers on the surface water supply of the United States, including Water-Supply Papers 261-272 and 281-292.

data, for cooperation in the maintenance of certain gaging stations, and for data relative to market conditions in the Puget Sound region: Valley Development Co., of Portland, Oreg.; the Water Department and the Lighting Department, city of Seattle; Department of Light and Water, city of Tacoma; Puget Sound Power Co., and Seattle Electric Co., of Seattle; Tacoma Railway & Power Co., Tacoma; Everett Railway, Light & Water Co., Everett; Stone & Webster Engineering Corporation, Boston and Seattle; Everett Gas Co., Everett; Portland Railway, Light & Power Co., Portland, Oreg.; Public Service Commission, State of Washington, Olympia; officials of the United States Forest Service and of the Mount Rainier National Park; T. A. Noble, consulting engineer, North Yakima; W. S. Dole, engineer for Valley Development Co., Portland, Oreg.; C. W. Harris, assistant professor of hydraulic engineering, Washington State University, Seattle; Robert Howes, consulting engineer, Seattle.

Acknowledgment is due to Prof. Edwin J. Saunders, assistant professor of geology, University of Washington, for the section on "Physiography of the drainage basins."

CONDITIONS AFFECTING STREAM FLOW.

The conditions which affect the regimen of flow of the streams which rise in the Cascades in Washington are discussed fully by Stevens[1] and will be only briefly summarized here.

All water supply is dependent on rainfall and the variations in rainfall from year to year are reflected in a general way by variation in stream flow. This effect follows such a devious course and is influenced to such a degree by local peculiarities of topography, geology, and soil that any statement of a relation between rainfall and run-off is difficult even under the most favorable conditions The amount of stored water in the drainage area, whether natural, in the forms of ground water and snows or glaciers, or artificial, the character of the storms and of the ground at the time they occur—all tend to diversify the quantity of run-off on the same area.

The porosity of the soil and of the underlying rock is perhaps the greatest factor in modifying the run-off from areas of equal precipitation. An area with a deep sandy soil, such as occurs on Loup and Niobrara rivers in Nebraska, or with a pumiceous soil underlain with vesicular lava, as is found on Deschutes River in Oregon and to some extent on all streams rising in the Cascades in Oregon, produces a very uniform flow. Bare slopes of impervious rock are the least favorable for the maintenance of the low-water discharge.

Topography is an important factor, but of relatively much less influence than soil.

[1] Stevens, J. C., Water powers of the Cascade Range, Part I: Water-Supply Paper U. S. Geol. Survey No. 253, 1910, pp. 14-17.

Vegetation, particularly forest cover, has been shown to exert a marked influence on the regimen of a stream, but investigations to determine the extent of this influence have never been carried on in the areas under discussion.

VARIATIONS IN STREAM FLOW.

In the studies embodied in the first unit of this report, Mr. Stevens was confronted by the fact that no record had ever been kept by the Geological Survey in the areas covered until the power investigation was undertaken. A few records kept by private parties on Klickitat and Little White Salmon rivers gave little assistance to any study of discharge variations.

In the absence of anything better, comparisons were made of the low-water discharge of 1909 with previous years for practically all streams in the Pacific Northwest on which the flow was not affected by diversion or storage and on which long-time records (six years and over) were available.

These streams included the Columbia and Clark Fork, which derives most of its water from areas 500 to 1,000 miles away, and John Day River, on which the average rainfall is perhaps one-fifth and the run-off one-twentieth that of the Cascades. The only stream having an area adjacent to those included in the power report was Tieton River.

It is but natural that when longer records become available on these particular streams the earlier conclusions were somewhat discredited. Thus, for Klickitat River, the lowest week in 1909 gave an average discharge of 807 second-feet. It was concluded from the comparisons mentioned above that 1909 gave a minimum below the average for a series of years and the notable average minimum was given as 970 second-feet.

Since 1909 a considerable amount of data has become available on Klickitat River and the lowest weekly discharge for each year is as follows:

Lowest discharge for one week of Klickitat River at Klickitat, Wash.

Year.	Period.	Discharge.	Variation from average.
		Sec.-ft.	*Per cent.*
1907	Nov. 5–12	[a] 875	+14
1908	Oct.–Nov	[a] 780	+ 2
1909	Oct. 24–30	755	− 2
1910	Sept. 26–Oct. 2	842	+10
1911	Oct. 26–Nov. 1	700	−10
1912	Jan. 1–7	655	−15
Mean		768	

[a] Records for 1907 and 1908 less reliable than those for later years.

The records for 1909 have been revised on the basis of later data, the mean for the lowest week changed from 807 to 755 second-feet. The above comparisons indicate that the year 1909 was practically a normal one, as far as low water is concerned.

On most of the streams covered by this second unit of the power report the Geological Survey installed no stations until 1910, but fortunately a number of records of several years' duration have been kept by private parties. The first station installed by the Survey, that on White River at Buckley, was established in 1899 but has not been maintained continuously.

The Geological Survey has kept records on Cedar River since 1902 and private records extend back to 1895. The Valley Development Co.'s records on the upper tributaries of Cowlitz River began in 1907, the Puget Sound Power Co.'s records for Puyallup River in 1909, and those of the city of Tacoma on Nisqually River in 1906.

These records have been analyzed with a view to discover laws controlling the fluctuations of average or minimum discharge from year to year, but no such laws are apparent. All of the basins except those of Cedar and Green rivers receive a large portion of their summer flow from glaciers. The basins of Cedar and Green rivers and several subdivisions of the other drainage areas, however, have no such regularizing influences. The diverse characteristics of stream flow are further accentuated by local differences in rainfall during the summer months. Streams with adjacent drainages often show considerable variation in run-off. An example of this condition may be cited from the records on White and Nisqually rivers. During the fall of 1911 White River at Buckley fell gradually until about November 1 and in the last week of October reached the lowest stage ever recorded. On the other hand, Nisqually River, rising on the opposite side of Mount Rainier, showed a fairly high discharge at the station below Little Nisqually River for October on account of early rain, so that the discharge did not reach as low stage as it did during the first two weeks in September.

RELATION OF IRRIGATION TO POWER DEVELOPMENT.

Very little irrigation is practiced at present in the Puget Sound basin or in any part of Washington west of the Cascades, but there are considerable areas that would be benefited by the application of water during the summer months. The precipitation at Tacoma averages only 0.66 inch for July and 0.70 inch for August (p. 20), and the records for other stations show values nearly as low or lower. The irrigating season would be short, perhaps not over 60 to 90 days. The soils which would derive the greatest benefit from irrigation are undoubtedly the prairies lying generally to the south of Tacoma. These areas are described by Mangum[1] as follows:

The surface of the extensive plain locally known as the "Prairie," which is located in the southwestern part of Pierce County, is gently rolling. The principal topographic features of this prairie region consist of low mounds, shallow basins, and more or less extensive terraces, which form flat-topped embankments from 1 to 20 feet in height. Sharp, rounded ridges which rise 75 to 100 feet above the level of the surrounding plain, occur at frequent intervals. With the exception of these ridges, which support a heavy growth of timber, the plain is treeless, or at most supports only a sparse growth of stunted fir, pine, or oak.

The natural prairies of the region, such as those about Tacoma, are for the most part too well drained for trees. The soil is almost pure gravel to a considerable depth and retains very little water. The plants are thus largely those which can complete their growth during the rainy spring season or very shortly after.

The prairies referred to are so located that many of them could be irrigated by water diverted from Nisqually and Puyallup rivers. An investigation of the irrigation possibilities was not made in connection with this report, and no details as to such possibilities are available. Almost all irrigation diversions would be made from the rivers below the present power developments and at such elevations that the undeveloped power would not be materially decreased.

The most feasible irrigation development from Puyallup River could probably be made by a diversion at the tailrace of the Electron power plant, into Lake Kapowsin, in the manner indicated on page 76 for section 4 of Puyallup River. Such an irrigation development might be carried on as an adjunct to the power project, as the minimum flow of Puyallup River probably never coincides with the maximum irrigation demand. For example, the minimum discharge for August was 318, 284, and 350 second-feet, respectively, for the three years 1909, 1910, and 1911, whereas the minimum weekly flow on which the power development was based is estimated as 125 second-feet at the headworks of the power plant and 160 second-feet at the proposed diversion into Lake Kapowsin.

PHYSIOGRAPHY OF THE DRAINAGE BASINS.

By Edwin J. Saunders.

GEOLOGY.

GENERAL FEATURES.

The basins drained by the Cedar, Green, White, Puyallup, Nisqually, and Cowlitz rivers lie on the western slope of the Cascade Mountains, which, with the Coast Ranges, form the sides of a great structural trough extending northward through Washington and occupied in part by Puget Sound. This valley is the northern part of

[1] Mangum, A. W., Reconnaissance soil survey of the eastern part of the Puget Sound basin, Wash.: Advance sheets, Bureau of Soils, 1909, U. S. Dept. Agr., 1911, pp. 11 and 34.

a great geosyncline represented in Oregon by the Willamette Valley and in California by the Sacramento and San Joaquin valleys. On the eastern limb of the geosyncline are numerous minor folds, few of which are parallel to the axis of the major folding. These minor folds govern to some extent the courses of the rivers mentioned and, having been eroded deeply by them, give rise to the western foothills of the Cascade Mountains.

GEOLOGIC HISTORY.

The general geology of this section may be best explained by a brief history of the conditions during the latest geologic periods of its formation. The age of the oldest rocks, composed of slates, schists, quartzites, and granites, is not easily determined, but since they are overlain by later Tertiary deposits they may be all grouped together as pre-Tertiary. In the upper part of their courses the rivers, working in this complex mass, have carved out deep valleys, leaving high rugged divides.

During the Eocene epoch, the earliest time division of the Tertiary, the entire basin was occupied by a large estuary with extensions into the area now part of the Cascade Mountains. On either side of this estuary were high hilly lands of older rock, which by rapid erosion supplied a great deal of sediment. This was laid down in a series of thick beds of sandstone, shale, and conglomerate, known as the Puget group. These rocks contain numerous fossils indicating changes from marine to brackish water conditions in the inclosed embayments. At different times during the epoch the bays were filled with sediments until large areas became great flat marshes. Vegetation flourished and collected in these marshes and by later subsidence was covered with sand or clay. This was repeated many times and each repetition gave rise to a bed of coal, more or less pure, ranging in thickness from 1 foot to 60 feet. The group contains more than 125 beds of coal, many of which are workable, and from these the coal for the Pacific coast trade is largely derived.

At the close of the Eocene a general uplift, with tilting, caused a shifting of the estuary toward the north. The uplift was accompanied by slight folding, which exposed portions of the Eocene beds to erosion, while other parts were still below sea level and were covered by thick beds of conglomerate, sandstone, and shale of later Tertiary age. The later Tertiary and the Eocene rocks were later subjected to intense folding and uplift, accompanied by many intrusions and extrusions of lava, forming the dikes and large masses of later igneous rock that are exposed in many localities. But before the close of the Tertiary strong erosion acting on this uplifted contorted mass had reduced it to a peneplain with gentle westward slope, and numerous shallow river valleys drained the area. It was at this time that the volcanism of the period reached its climax in the volcanic mountains—Rainier and St. Helens—both of which remained active during the following period of glaciation and built up great cones, the former about 14,400 feet high, the latter about 10,000 feet high, on the base-leveled mass of granite, older intrusives, and metamorphosed sediments. The lava flows, ash deposits, and intrusions from these volcanic centers are a very important factor in the formation of the soil in the different river valleys draining them. At the same time the whole mass of the Cascade Mountains was uplifted with warping and faulting. This caused the streams to become very active again and gave rise to deep valleys, especially in the softer sedimentary rocks.

Toward the close of the Tertiary period the climate changed considerably, becoming much colder, and the Quaternary opened with a period of glaciation. Deep snows collected on the newly formed mountains, and, filling the large valleys, crept down and merged into a great piedmont glacier, filling the Puget Sound basin as far south as Tenino and the Bald Hills with ice varying in thickness up to 4,000 feet. The glaciation of this section was not the result of a single advance of the ice but of two distinct advances with an interglacial stage, each advance doing its share in changing the topography of the country and the nature of the soil. The ice picked up much of the loose weathered rock débris in the upper part of its course and, carrying it down into the sound basin, left it scattered in irregular deposits of different form over the entire basin. This heavy drift deposit filled up many of the deeper valleys and thus maintained the surface of a great part of the sound basin above sea level. The postglacial valleys, however, follow the channels of the preglacial valleys to a great extent and the present uplands or plateaus represent in part the position of the preglacial divides.

The glacial deposits occur in the form of (1) thick veneering of ground moraine material; (2) broken irregular ridges of lateral moraines along the river valleys; (3) terminal moraines across the valleys and across the entire basin; (4) broad outwash plains of gravel and sand; (5) delta plains formed in temporary lakes during the recession of the ice; (6) valley trains formed by rivers loaded with sediment at the time the ice was melting; (7) eskers or irregular ridges of sediment collected in glacial stream channels when the ice was still present; and (8) many large bowlders or "erratics" carried by the ice from the mountains and dumped here and there throughout the area.

Naturally this great load of débris deposited in the lower parts of the river valleys interfered with the drainage and caused the formation of many small and a few larger lakes. The rivers in cutting down through these drift deposits followed their old channels in part, but in many places cut new channels, thus causing many striking changes in the drainage of the area. A good example of this is seen at the site of the new Seattle dam on Cedar River. Here the river seems to have shifted toward the south from its old channel and is now cutting a channel through hard rock, whereas its old channel is much deeper but is filled with glacial débris.

TOPOGRAPHY AND DRAINAGE.

The valleys of Cedar, Green, White, Puyallup, and Nisqually rivers are arranged somewhat radially about the head of Puget Sound, extending from the slopes of the Cascade Mountains in a northwesterly direction to the submerged portion of Puget Sound basin. The first four rivers named enter the sound by way of the Duwamish-Puyallup Valley, formerly part of the sound but now filled by silt from the rivers. The Cowlitz, with its various tributaries, also drains the slopes of the Cascades, but as it is situated south of the low divide between Columbia River drainage and the Puget Sound basin, it flows into Columbia River.

The upper parts of all these valleys are carved out of the older igneous and metamorphic rocks below the surface of the Cascade peneplain. Being cut since the last uplift of this peneplain, they are largely young, steep-walled, deep valleys, having numerous tributaries because of the abundant rainfall. These valleys have been modified by glaciation and the combined effect is a very irregular rugged topography, the rivers occupying steep-walled valleys with numerous cascading tributaries and heading in deep amphitheater-like basins under high, almost inaccessible cliffs.

Lower down in their courses they come into the sedimentary rocks and here the valleys seem to follow the embayments in which the sedimentary formations lie, the divides being formed by the more resistant igneous and metamorphic rocks. Narrow box canyons are formed at intervals where the streams cut through harder strata of the upturned sedimentary rocks or igneous intrusions. All these rivers have a strong gradient with a good supply of water and are therefore able to carry all the finer silt farther downstream and deposit it in the lower part of their courses where the gradient is less and the load greater. The erosive activity of the streams has been interfered with by the great amount of heavy glacial drift they have had to cut through in eroding their channels and the beds of the rivers are somewhat protected from rapid erosion by the heavy covering of bowlders collected in their channels.

Cedar River obtains a uniform supply of water from Cedar Lake which lies in a valley 3,000 feet below the crests of the surrounding mountains. This water is used by the city of Seattle for power and city supply, so that in the summer months the river below the intake is not very powerful. Green River, fed by numerous small streams from the Cascades near Stampede Pass, has cut a valley 3,000 feet deep in the igneous and metamorphic rocks above Palmer. Below this point it cuts through the folded rocks of the Puget group until it reaches the drift-filled portion of its valley. White River, having its source in the glaciers of Mount Rainier, has cut a valley to a depth of 4,000 feet below the surface of the granite platform on which Mount Rainier stands. Similarly, Carbon River, a tributary of the Puyallup, flows in a deep canyon, first through the igneous rocks and then through the sedimentary coal-bearing series at Melmont, Fairfax, and Carbonado. Puyallup and Nisqually rivers, also fed by glaciers on Mount Rainièr, occupy deep valleys cut below the general surface of the hard rock platform before coming out into the deeper glacial deposits. The Nisqually postglacial valley, 300 feet deep with almost vertical walls, is about 2 miles long. From Ashford, on the Nisqually, south to the Cowlitz a belt of soft sedimentary rocks affords a low pass to Cowlitz River.

All of these rivers, coming out of their deep canyons, cut through a mass of glacial drift composed largely of gravel and sand and whose surface forms a broad plateau. This wide belt of drift extends from the foothills of the Cascades to the more irregular hilly region near the Sound and from Cedar River on the north to Nisqually River on the south, at an elevation ranging from 500 feet to 750 feet above sea level. Thus between Cedar River and Green River is a large flat area known as the "Wilderness," containing a number of small lakes poorly drained and swampy in places. Still nearer Puget Sound the rivers cut through a belt of irregular hills of drift, rising from 50 to 150 feet above the general level and from 250 to 500 feet above the Sound. Among these hills are numerous lakes and swamps which have continued undrained since the glacial epoch. Some of the smaller rivers drain from this hilly region back into the plateau belt before entering the main streams.

The river valleys through this plateau and hilly region are broad flat-floored, steep-walled troughs in which the streams have built up silt flood plains. The depth of this silt filling can only be inferred from the fact that the land stood high enough, before the submergence which gave rise to Puget Sound, for river erosion to cut the valleys as deep as the bottom of the Sound. When the submergence occurred parts of the eroded plateau were left as islands in the Sound. Later the rivers filled up these extensions of the Sound and joined the islands to the mainland by delta and flood plain formation. A good example of this is the Duwamish-Puyallup valley, which Cedar, Green, White, and Puyallup rivers have combined to fill in behind Des Moines Island. They first built individual deltas into the Sound. These finally merged, forming shallow marshy tracts and the filling continued until the surface of the whole valley bottom was raised to the present level of the flood plain. The Puyallup and Duwamish are still extending their deltas into the Sound, slowly on account of the depth, and building up the lower part of their flood plains, although retarded by artificial barriers and dredging.

Cowlitz River, which receives its supply from the glaciers of Mount Rainier and Mount Adams and from smaller tributaries in the Cascades, has cut its valley through the rock platform and a series of rock hills unmodified by the effects of strong glaciation and heavy glacial drift. The upper valley has been subject to local glaciation, however, and the river, carrying a heavy load of fine glacial gravel and silt, has deposited it in the lower part of its valley, filling it up to a much higher level than the former floor of the valley.

SOILS AND VEGETATION.

In the upper part of the drainage basins, above 6,000 feet, there is scarcely any soil covering, most of the finer rock débris having been carried to lower levels by rain wash and creep. Steep talus slopes of large angular fragments are common at the base of the cliffs near the headwaters of many of the streams. There is very little, if any, vegetation because of the steep slopes, lack of soil, and the low temperature, and therefore nothing to hold the finer soil in place and prevent it from moving down to the lower valleys. What little soil remains on these slopes is largely residual—that is, it is composed of fragments of the underlying rocks, but it forms only a very thin covering and retains very little of the rain falling on the surface.

Between 6,000 feet and 4,000 feet above sea level the vegetation is sparse, and the soil cover becomes somewhat thicker as the vegetation checks its downward movement. The retention of the moisture favors more rapid rock decay and the formation of more soil. In this belt, too, the soil is residual in character and very coarse in texture, with a thin surface covering of spongy dark loam. In the region about Mount Rainier and Mount St. Helens a layer of volcanic ash from 6 inches to several feet in thickness lies below the surface cover of soil. The tree roots seem to spread out above this, and when the tree is uprooted the ash bed is left clearly exposed. This layer of ash is porous and is a good moisture retainer. From the lower mountain sides it has been partially removed and spread out over the river bottoms with other finer silt materials.

From an elevation of 4,000 feet to sea level the soil cover is much thicker, and the vegetation is very heavy, consisting of forests of cedar, fir, and hemlock, with a dense undergrowth, especially in the lower valleys, of vine maple, alder, devil's club, ferns, salal, huckleberry, and other shrubs and vines. This heavy surface growth, even without the larger trees, has the effect of preventing extensive soil wash on the slopes and of increasing the formation of soil by rock decay. It also forms a regular spongy mat over the surface which retains the moisture, thus decreasing the immediate run-off during heavy precipitation periods.

The soils in the lower part of these basins, below 3,000 feet, have been classified, and a full description of them may be found in the "Reconnaissance soil survey of the eastern part of Puget Sound basin," already published by the Bureau of Soils, United States Department of Agriculture, and a similar report on southwestern Washington, now in press. A description of their formation is also given in the Tacoma folio (No. 54) of the Geologic Atlas of the United States, published by the United States Geological Survey.

The soils most prominent in these basins, according to the classification used by the soil survey, might be divided as follows:

(1) Soils of the rough mountainous region.
(2) Soils derived from the weathering of glacial drift.
(3) Soils derived from glacial outwash materials.
(4) Soils from recent alluvial deposits.
(5) Soils deposited in basins of shallow lakes or swampy depressions.

The soils occupying the lower mountainous parts of the area vary from a sandy loam to a heavy clay loam containing numerous small bowlders and rock fragments. These soils (the first division of the above list) are chiefly derived from materials which have been spread over the area by the action of glaciers and streams, but the drift is in many places very thin, and material derived from the weathering of underlying rocks makes up a large part of the soil, especially on the slopes of the higher mountains. This admixture furnishes a good soil and generally carries a heavy growth of vegetation.

The second division comprises soils occupying the rolling uplands and lower foothills of the mountainous region. These are derived from glacial drift which has been more or less worked over by streams, and consists of sand and gravel, together with fine rock flour, which gives the surface soil a loamy texture. In some sections these soils have enough clay in them, and are so level as to be very poorly drained. Where the clay predominates the immediate run-off is greatly increased.

The third division is made up of glacial wash materials from which all the finer silt has been removed by water action, leaving only gravel and sand. A large area of the plains between Puyallup and Nisqually rivers is occupied by this material and forms the prairies of Washington. This area furnishes little surface run-off.

The recent alluvial deposits occupying the valley bottoms of the larger rivers form the fourth division. These deposits consist mainly of fine sand and silt formed from the grinding up of the older volcanic rocks by glaciers. This rock flour, together with local supplies of volcanic ash, has been carried down and deposited in a thick layer over the valley flood plains and delta flats. These soils always contain a high percentage of organic matter and enough fine sand to make a rich porous soil. The Puyallup-Duwamish Valley between Seattle and Tacoma is covered with this fine silt and is one of the largest and most fertile tracts of agricultural land in the region.

The fifth division consists of deposits made in poorly drained depressions in the glacial drift in which small lakes formerly existed but have since been filled or partially filled by sediment washed into them from the surrounding uplands, or by accumulations of vegetal material, or both. Such action gives rise to deep beds of fine muck soil or of peat, if the vegetation is more abundant. Such of these deposits as are situated along the river valleys become filled with water like a sponge, and thus check the immediate run-off.

In general the nature of the soil and vegetation in these basins is such that rapid run-off does not take place, except in the headwaters above the timber line, and the lower valleys are thereby protected from serious floods. The fact that the supply of water in White, Carbon, Puyallup, Nisqually, and Cowlitz rivers is obtained in part from glaciers also tends to keep the flow in these rivers more uniform throughout the year.

CLIMATE.

GENERAL CONDITIONS.

The whole Puget Sound drainage basin, situated on the western slope of the Cascade Mountains, directly in the path of the prevailing westerly winds, is subject to the moderating effects of the moisture-bearing winds from the Pacific Ocean. It is protected by the Cascade Mountains and the mountians of British Columbia from the climatic extremes characteristic of the interior that would otherwise be brought to it by occasional north and east winds.

The constant but irregular changes in the weather and in the climatic conditions from year to year are caused by the movements of areas of low atmospheric pressure. Toward these areas the air moves from all sides and passes spirally upward. Any moisture present is condensed as the air cools, in consequence of expansion resulting form decrease in pressure, either in the form of clouds or, if condensation is rapid enough, in the form of rain or snow. These storm areas alternate with anticyclonic or high-pressure areas in which the air is moving downward and outward in all directions. They bring with them clear weather, cold in winter and warm in summer. The general weather conditions during any month or season will vary with the intensity, number, and position of these cyclonic and anticyclonic areas passing over the region.

PRECIPITATION.

Statistics as to the precipitation in the Puget Sound region are presented in the publications of the United States Weather Bureau, to which the reader is referred for details.[1]

The names of rainfall stations within the area and a summary of the results are presented in the following tables:

Rainfall stations in and near Puget Sound basin.

Station.	County.	Latitude.	Longitude.	Elevation.	Length of record in years.
		° ′	° ′	*Feet.*	
Cedar River (Landsburg dam)	King	47 25	121 55	535	5
Stampede Pass	do	47 15	121 20	2,800	9
Lester	do	47 12	121 27	1,614	8
Seattle	do	47 38	122 20	123	20
Tacoma	Pierce	47 16	122 23	213	26
Olympia	Thurston	47 03	122 54	200	34
Centralia	Lewis	46 42	122 57	212	19
Ashford	Pierce	46 45	122 0	1,775	13

Average monthly precipitation in inches.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual rainfall (inches).	Annual snowfall (inches).
Cedar River (Landsburg dam)	5.95	5.93	3.70	3.43	4.15	1.51	0.97	1.76	3.02	4.11	9.67	6.31	50.67	17
Stampede Pass	8.92	5.03	5.57	5.00	3.92	2.75	.98	.75	2.43	6.22	10.58	7.67	59.82	150
Lester	6.20	5.70	3.92	2.95	2.97	1.19	.70	.60	3.38	4.61	8.68	5.80	49.95	84
Seattle	4.52	3.86	3.52	2.68	2.32	1.72	.69	.49	1.97	2.88	5.86	6.04	36.59	12
Tacoma	5.78	5.13	3.98	2.76	3.82	2.13	.66	.70	2.47	3.40	8.53	7.33	45.41	14
Olympia	7.91	6.82	5.18	3.79	2.64	1.77	.69	.66	2.79	4.42	8.88	9.68	55.23	10
Centralia	4.95	4.54	4.22	3.54	2.55	2.30	.63	.81	2.53	3.46	8.31	7.93	45.77	11.3
Ashford	8.25	7.16	5.73	4.63	5.37	3.94	1.53	1.66	3.72	5.36	11.87	11.02	70.24	67

West of the area under discussion the Olympic Mountains, a high rugged mass with a slightly longer northwest and southeast axis, extend southward along the coast from the Strait of Juan de Fuca, gradually becoming lower to the south and west until they give place to the broad, low gap occupied by the Chehalis River and Grays Harbor. South of the gap the mountains are of rather low relief, and are therefore less effective than the northern portion as a climatic factor. The warm, moisture-laden winds moving landward from the Pacific Ocean are forced up by the western and southern slopes of the Olympics and pass over the coast ranges. In thus ascending the air is cooled and the moisture contained is largely condensed, resulting in a precipitation of 60 to 140 inches a year in an irregular belt along the coast. This has been called the wet belt.

[1] Summary of climatological data for the United States by sections and the Monthly Weather Review.

The air in its general eastward movement coming into Puget Sound basin after it has been deprived of a large share of its moisture, in passing over the slopes of the coast ranges and the Olympics or through the Chehalis River valley, causes much lighter precipitation than in the coastal belt. The annual precipitation in this basin varies from 60 to 21 inches, and it has been called the moist belt. A large part of the drainage basins of the rivers discussed in this report lies in this belt, in which the precipitation varies from 55 inches at Olympia to 35 inches at Seattle and 50 inches at Lester and Cedar Falls.

As the air moves east of the Sound basin it is forced to ascend the steep slopes of the Cascade Mountains, and the increased cooling causes a gradual increase of precipitation until in a narrow irregular belt on either side of the summit of the range it exceeds 60 inches. Thus a second wet belt is produced, and it is from this belt that the rivers of the Cascade Range obtain their supply of water. The lack of stations near the summit on either side makes it impossible to give accurate figures for the precipitation at the summit, but no doubt it is over 100 inches.

For the river supply, however, the distribution of rainfall throughout the year is of more importance than the annual precipitation. In the preceding table the average monthly precipitation for different stations in the drainage basins, together with the average snowfall, is given. A study of the table shows that very little rainfall occurs during July and August and that less than 10 per cent of the total precipitation occurs during the months of June to September inclusive. During this period the streams must depend on water stored during the previous winter in glaciers, in snowbanks, and in the ground to keep the flow at all uniform.

Cowlitz, Nisqually, Puyallup, Carbon, and White rivers are supplied in part from glaciers, in part from the higher slopes of the Cascades, which, below 6,000 feet, have a good vegetable and soil cover that stores the water, and in part also from deep ravines in which snow collects during the winter and melts slowly during the summer months. Green and Cedar rivers lack the glacial water, but the supply is fairly constant, owing to the other favorable conditions.

During the eight months from October to May inclusive, 90 per cent of the total precipitation occurs and 75 per cent of the total comes in the six months from November to April inclusive. At the majority of the stations on the west slope of the Cascades November has the highest average precipitation for the year. Occasionally very heavy rainfall occurs during this month. In 1909 at Cedar Falls 16.75 inches were recorded in November and 14.50 inches at Lester. The lowest record at Cedar Falls for November is 6.03 inches and at

Lester 2.95 inches. At Ashford the average for November is 11.87 inches, and the highest record is 19.19 inches in 1897; the lowest is 3.49 inches in 1905.

As few heavy downpours of rain occur during these months and as the precipitation is fairly evenly distributed over the rainy period, the water is allowed to filter into the soil and in this way excessive run-off is prevented.

The reasons for the concentration of the precipitation in the winter months are: (1) The cyclonic or storm areas passing over the section from the west are more numerous and better developed in the winter than in the summer, thus causing more frequent and heavier precipitation in the winter months. (2) During the winter the ocean is warmer than the land, and the air laden with moisture, moving from the warmer ocean, is cooled quickly as it goes inland over the cooler land mass, thus causing rapid condensation and heavy precipitation. Condensation is increased as the air is forced to ascend rapidly in passing over the mountains. During the summer, however, the ocean is cooler than the land, and the air, moving from the cooler ocean to the warmer land, is not cooled sufficiently to cause the heavy precipitation that occurs in the winter. This effect is emphasized by the fact that the winter winds along the coast are prevailingly from the southwest and become cooler as they blow northward, thus causing more rapid condensation, whereas in the summer they are prevailingly from the northwest, becoming warmer as they blow southward and inland, and therefore do not cause heavy precipitation.

The November maximum of precipitation is no doubt due to the fact that during this month fewer prolonged cold periods interfere with the landward movement of moisture-laden air than during December and January and therefore heavy precipitation occurs on a greater number of days.

The average annual snowfall in the lower part of the basins is very light, from 10 to 17 inches, and it rarely exceeds 25 inches. It remains on the ground for only a very short time, and has therefore little effect on vegetation or climate. Farther up the valleys, however, and in the mountainous part of the drainage basins, the amount of snowfall rapidly increases. At Ashford the average fall is 67 inches and the maximum, as recorded, is 161 inches or 13 feet. At Lester the annual average is over 80 inches and the maximum over 160 inches. Several factors enter into the problem of the melting of the snows in these upper valleys and its effects on the streams. In the higher mountain valleys it may collect from year to year and form glaciers or ice fields; the supply of water then being uniform. If it falls on frozen ground it will find its way rapidly into the streams when it melts, but if on loose soil a great deal of the water will filter into the soil. If it collects evenly on open surfaces it will melt off more quickly than if it drifts or collects in deep, protected valleys. Large forest trees, which prevent drift and catch the snow on their outspreading branches, often cause more rapid disappearance of snow on the heavy forested slopes than on those covered with low underbrush, where the snow may collect in drifts. The exposure of the slopes or valleys in which it collects to the sun's rays and to the warm western winds is another factor determining the rate of melting. So it is not only the actual amount of snowfall but also the conditions under which it collects that govern the supply of water to the streams.

In general, then, the annual rainfall and snowfall being known, the topography, the nature of the vegetation and soil cover, the temperature, and the rate of precipitation must be taken into consideration when calculating probable stream conditions from the precipitation over the drainage basin.

TEMPERATURE.

The general uniformity characteristic of marine climate is shown by the temperature throughout the region. The average annual range of temperature between the coldest and warmest months is about 20° for the Sound stations and about 30° for stations higher up in the valleys. The highest temperatures recorded are 103° at Lester, 104° at Olympia, and 96° at Seattle. The lowest recorded temperatures are −2° at Lester and 3° at Seattle. The average temperature at Lester is below 40° for three months, December, January, and February, but at Seattle the average is below 40° only during December.

This remarkable uniformity is accounted for by the fact that the prevailing westerly winds come from the Pacific Ocean, which is warmer in the winter and cooler in the summer than the adjacent land areas, and consequently cause higher winter temperatures and lower summer temperatures in the coastal belt than would otherwise occur. The condensation of the moisture carried by these moisture-laden winds also causes a slight raising of the temperature of the air while it is taking place and thus increases the effect of the warm winds in the winter. For the latter reason the rainy days, which accompany the cyclonic or storm areas, of which there are a large number during the winter months, are particularly mild, especially when the rain is unaccompanied by strong winds. The clouds produced by condensation are also effective in helping to keep the air cool in the summer.

This moderating effect of the west winds and of condensation is noticeably absent during the passage of the anticyclonic or clear dry weather areas. At such times the air, coming from the interior over the Cascade Mountains, is sharp and frosty in the winter but warm and dry in the summer.


DRAINAGE MAP
OF
COWLITZ RIVER, WASHINGTON
Compiled from Land Office maps and special surveys;
also from surveys of the Valley Development Co.
Scale 1/250,000
5 0 5 10 Miles
1912
Regular gaging station
Miscellaneous gaging station
Weir station
PART OF RAINIER NATIONAL FOREST
MT RAINIER NATIONAL PARK
RAINIER NATIONAL FOREST
COLUMBIA NATIONAL FOREST
PIERCE CO
LEWIS CO
COWLITZ CO
SKAMANIA CO
YAKIMA CO
CLARKE CO
OREGON
COLUMBIA RIVER
COWLITZ RIVER
Mt Rainier 14363
Mt St Helens 9750
Mt Adams 12307
Ashford
Mineral
Randle
Vance
Kosmos
Mayfield
Mossy Rock
Toledo
Castle Rock
Kelso
Silver Lake
Spirit Lake
Packwood Lake
Walupt Lake
Cispus Castle
Tumwater Peak
Watch Mtn
Hatchet Mtn
Strawberry Mtn
Bismarck Mtn
R.4W. R.3W. R.2W. R.1W. R.1E. R.2E. R.3E. R.4E. R.5E. R.6E. R.7E. R.8E. R.9E. R.10E.
T.7N. T.8N. T.9N. T.10N. T.11N. T.12N. T.13N. T.14N. T.15N.

FROST.

The average dates of frost in spring and fall are important only as they affect vegetation and the condition of the surface soil, thus modifying run-off. There is great irregularity in the dates at which the heavy killing frosts occur, but within certain limits the dates may be given for different belts.

In a belt along the higher portions of the basins, including Ashford and Lester, frost may be expected any time after September 15 in the fall and as late as June 1 in the spring. In another belt, including Cedar Falls and a large part of the Cowlitz and Nisqually basins, frosts are apt to occur after October 15 and up to May 1. In the region about Puget Sound frosts are not apt to occur before November 1 nor after April 1.

Continued frosts occurring in these belts between these dates, followed by heavy rains or snow, is liable to cause excessive run-off, and serious floods in the lower parts of the valleys usually occur under such conditions.

SUMMARY.

The climate throughout the region and especially along the Sound is marine in character. The evenness of the temperature throughout the year, the slow and rather slight changes, and the decided winter maximum in precipitation are the most striking features of the climate. The idea that it rains all the time, even during the winter months, is decidedly erroneous. There are many clear, pleasant days during the months of maximum rainfall and the rainy days, except occasionally, when accompanied by high winds, are warm and pleasant. The conditions from May to October are ideal, with only 5 to 12 rainy days per month, few hot days, and no oppressively hot nights.

COWLITZ RIVER DRAINAGE BASIN.

GENERAL FEATURES.

The Cowlitz River basin (Pl. I) comprises a roughly rectangular area of 2,460 square miles. It is bounded on the east by a section of the Cascade Range 40 miles long, extending from Mount Rainier in the northeast corner to Mount Adams in the southeast corner. The western boundary is the crest of some foothills which constitute a southerly extension of the Olympic Range. Kalama and Lewis rivers on the south are tributary to Columbia River, and Chehalis and Nisqually rivers on the north empty into Grays Harbor and Puget Sound, respectively.

Cowlitz River is formed by the junction of Ohanapecosh River and Muddy Fork about 14 miles southeast of Mount Rainier. The former, with its tributaries Clear Fork and Summit Creek, receives the drainage of a portion of the Cascade Range and foothills lying between Mount Rainier and Cispus Pass. The latter is formed at the foot of the Cowlitz and Little Cowlitz glaciers situated on the southeastern slope of Mount Rainier. The river flows in a general westerly direction about 95 miles to a point about 2 miles east of Little Falls, near the western edge of the basin, and then turns almost due south, joining Columbia River near the town of Kelso, about 25 miles below.

The principal tributaries from the south and east are Cispus, Toutle, and Coweman rivers. The only important tributary from the north and west is Tilton River, which joins the main stream between the towns of Mossy Rock and Mayfield. Of these tributaries Cispus and Toutle rivers are the only streams of importance for water-power purposes.

Cispus River heads in Cispus Pass and receives a large part of its water supply from a stretch of the Cascade Range and surrounding foothills extending 25 miles north from Mount Adams. Muddy Fork of Cispus River, which enters the main stream about 15 miles southwest of Cispus Pass, is fed by Lava and Lyman glaciers, which lie on the north slope of Mount Adams. Below the mouth of Muddy Fork, Cispus River flows northwesterly about 30 miles to its confluence with the Cowlitz. Toutle River has been described in the first report on water powers in the Cascade Range (Water-Supply Paper 253, pp. 74–81).

The following statement of drainage areas of Cowlitz River and principal tributaries is the result of planimeter measurements made on the best available maps. As these maps are only approximate the figures are not precise.

Drainage areas in Cowlitz basin.

	Square miles.
Ohanapecosh River below Clear Fork	164
Cowlitz River below Muddy Fork	218
Cowlitz River below Smith Creek	373
Cowlitz River at Randle	519
Cowlitz River below Cispus River	1,030
Cowlitz River at Riffe	1,140
Cowlitz River at Mayfield	1,320
Cowlitz River at Toledo	1,440
Cowlitz River below Toutle River	2,210
Cowlitz at mouth	2,460
Clear Fork at mouth	48
Muddy Fork at mouth	40
Cispus River below Muddy Fork	92
Cispus River below North Fork	272
Cispus River at mouth	453
Tilton River at mouth	128
Toutle River at mouth	510
Coweman River at mouth	141

Elevations within the basin range from 14,363 feet at the crest of Mount Rainier to sea level. The peaks of the Cascades average about 6,500 feet in elevation. Nearly all of the large tributaries in the higher portion have cut deep canyons to the basaltic rock. Clear Fork, a tributary of Ohanapecosh River, furnishes a noteworthy example of this condition. The stream flows through a canyon with nearly perpendicular walls rising 800 to 900 feet above the bed of the stream.

The mountainous structure near the upper portion of the basin gradually changes in the lower portion into an area fairly well rounded by erosion except where denser compositions have withstood the elements more successfully. Mount St. Helens, of volcanic origin, rises to an elevation of 9,750 feet and presents a striking contrast to the surrounding lowland area. The west half of the basin shows very few marked topographic features.

From the confluence of Ohanapecosh River and Muddy Fork to Mayfield, a distance of 77 miles, the Cowlitz has a fairly uniform gradient of 13 feet to the mile. Throughout all except the lower 10 miles of this section the river winds from one side to the other of a broad valley filled with water-sorted gravel and glacial detritus. The only bedrock outcrop observed in this section extends about 2 miles below the mouth of the Cispus, where the valley is narrower than that above or below. In the vicinity of Mossy Rock and of Mayfield the valley narrows abruptly and the river has cut box canyons 150 to 300 feet deep through several basalt dikes.

The broad valley floor of Cowlitz River is characterized by old river terraces lying at different elevations and composed of gravel and clay cemented together and overlain by a shallow alluvial deposit. These terraces form level bench lands which are well adapted to farming. In the upper portion of the basin a covering of volcanic ash from 2 to 6 inches deep on the bench lands and the river valley is said to make the land fertile. Hay and grain of all kinds are grown successfully. Much attention has not yet been paid to intensive farming. Owing to the fact that the soil is shallow and underlain by gravel, ground-water storage is small and vegetation often suffers severely from lack of moisture during August and September. Therefore, it may be found advisable in the future to irrigate the bench land. The water supply and the grade of the river are such that this could be done to advantage if the farming lands in the valley occupied a greater area. The small units that would necessarily have to be developed, however, would make a high cost per acre.

The entire basin with the exception of small areas logged or burned off is covered with a dense growth of Douglas fir, mountain hemlock, and cedar. Willows and alders, together with an undergrowth of vine maple, salal, and numerous brambles, abound along the stream courses. In many places this offers an impenetrable thicket to those who leave the traveled trails.

The Rainier National Forest includes 891 square miles, the Columbia National Forest 150 square miles, and the Mount Rainier National Park 69 square miles of the Cowlitz drainage area.

The Cowlitz Valley has been settled for 20 to 30 years and practically all the land free to entry and suitable for farming has been patented. Transportation facilities are so poor, however, that agricultural development has been retarded. Roads have been built throughout the length of the valley and lead to the nearest railroad centers at Chehalis and Morton, but the heavy rainfall occurring during the winter months renders them almost impassable from October to May. The Tacoma Eastern Railroad enters the basin at the headwaters of Tilton River and has its present terminal at Morton. It is proposed to extend the road into the Cowlitz Valley and to build branches up and down the river. The main line of the Northern Pacific Railway between Portland and Seattle, used jointly by the Oregon-Washington Railroad & Navigation Co., parallels the portion of the river flowing southward below Little Falls. The greater part of the logged-off land is near this road and a considerable portion of it is being cleared for cultivation. Both Cowlitz and Toutle rivers are used for driving logs and shingle bolts down to the sawmills located near the railroad.

A number of metal-bearing ledges have been located near the Cascade ridges, but very little effective prospecting has been done to develop them. Coal of an excellent quality has also been found in the mountainous area,[1] but no mining has been attempted on account of the unfavorable transportation facilities. Hot mineral springs, reported to be of great medicinal value, rise on the left bank of Ohanapecosh River near the National Park boundary. They are in such an isolated section, however, that they are little used.

WATER SUPPLY.

RECORDS AVAILABLE.

Surveys and water-supply determinations were begun in the upper Cowlitz basin in 1907. The first work was done by engineers of the Valley Development Co. in connection with a study of the feasibility of power development in that region. Gaging stations were established during August of that year at the following locations:

Ohanapecosh River above Clear Fork.
Cowlitz River at Lewis Ferry.
Clear Fork at mouth.
Lake Creek at mouth.
Johnson Creek at mouth.

[1] Landes, Henry, and Ruddy, C. A., Washington Geol. Survey, vol. 2, 1902, pp. 247-255.

A station was established on Coal Creek November 5, 1910, and weirs were maintained during the low-water period of 1911 to measure the discharge of Lake, Hagar, Johnson, and Glacier creeks at points of proposed diversion. Measurements were obtained at the gaging stations by engineers of the development company and of the United States Geological Survey during 1907, 1910, and 1911. No flow measurements were made in 1908 and 1909; therefore, the gage records during that period are of somewhat uncertain value, because no estimate can be made of the possible effect of shifting channels. There is also a lack of sufficient high-water measurements to determine with accuracy the flood rating of the channels. The discharge for low-water periods, however, is more reliable, and as such data are of chief importance in water-power considerations the records serve present purposes very well.

In order to determine the yield of Cowlitz and Cispus rivers at lower points than those above named, three additional gaging stations were established by the United States Geological Survey during the summer and fall of 1910, when the power survey here reported was being made. They are located as follows:

Cowlitz River at Randle.
Cowlitz River at Mayfield.
Cispus River below McCoy Creek.

The following records consist largely of monthly estimates of flow, based on the observations made at the stations above enumerated. The full records are published in Water-Supply Paper 312. The accuracy column in the monthly-discharge tables does not apply to the maximum or minimum nor to any individual day, but to the monthly mean. It is based on the accuracy of the rating, the probable reliability of the observer, and knowledge of local conditions. In this column, A indicates that the mean monthly flow is probably accurate within 5 per cent; B, within 10 per cent; C, within 15 per cent; D, within 25 per cent. Special conditions are covered by footnotes.

OHANAPECOSH RIVER ABOVE CLEAR FORK, NEAR LEWIS, WASH.

The measurement station on Ohanapecosh River is located above Clear Fork, near Lewis, Wash. (See Pl. I.) The discharge has been computed by the Geological Survey from data furnished by the Valley Development Co.

Monthly discharge of Ohanapecosh River above Clear Fork, near Lewis, Wash., for 1907–1911.

[Drainage area, 116 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1907.							
August 19–31	198	115	144	1.24	.60	3,710	B.
September	320	115	146	1.26	1.41	8,690	B.
October	151	98	106	.914	1.05	6,520	B.
November	a 2,100	98	368	3.17	3.54	21,900	B.
December	a 1,130	240	579	4.99	5.75	35,600	B.
The period						76,400	
1908.							
January	320	133	231	1.99	2.29	14,200	B.
February	287	133	194	1.67	1.80	11,200	B.
March	3,800	151	607	5.23	6.03	37,300	B.
April	2,240	193	657	5.66	6.32	39,100	B.
May	1,390	405	803	6.92	7.98	49,400	B.
June	2,580	712	1,450	12.5	13.95	86,300	B.
July	2,410	327	1,290	11.1	12.80	79,300	B.
August	365	109	191	1.65	1.90	11,700	C.
September			120	1.03	1.15	7,140	D.
October			140	1.21	1.40	8,610	D.
November	1,600	84	401	3.46	3.86	23,900	C.
December	259	128	169	1.46	1.68	10,400	C.
The year	3,800		521	4.49	61.16	379,000	
		a Estimated.					
1909.							
January	1,990	128	400	3.45	3.98	24,600	C.
February	580	138	237	2.04	2.12	13,200	C.
March	309	159	207	1.78	2.05	12,700	C.
April	490	218	315	2.72	3.04	18,700	C.
May	1,750	385	843	7.27	8.38	51,800	B.
June	3,010	920	1,630	14.1	15.73	97,000	B.
July	1,420	327	743	6.41	7.39	45,700	B.
August	309	118	180	1.55	1.79	11,100	C.
September			135	1.16	1.29	8,030	D.
October			115	.991	1.14	7,070	D.
November	7,500	109	1,840	15.9	17.74	109,000	C.
December	1,860	203	512	4.41	5.08	31,500	C.
The year	7,500		595	5.13	69.73	430,000	
1910.							
January	1,940	110	388	3.34	3.85	23,900	C.
February	440	147	254	2.19	2.28	14,100	C.
March	a 2,180	a 380	916	7.90	9.11	56,300	C.
April	2,590	380	962	8.29	9.25	57,200	B.
May	2,860	750	1,460	12.6	14.53	89,800	B.
June	2,180	550	951	8.20	9.15	56,600	B.
July	720	245	454	3.91	4.51	27,900	B.
August	340	93	180	1.55	1.79	11,100	C.
September	157	93	120	1.03	1.15	7,140	C.
October	1,860	167	515	4.44	5.12	31,700	B.
November	2,820	245	867	7.47	8.33	51,600	B.
December	712	231	405	3.49	4.02	24,900	B.
The year	2,860	93	624	5.38	73.09	452,000	
	a Estimated.						
1911.							
January	365	138	215	1.85	2.13	13,200	B.
February	170	109	128	1.10	1.14	7,110	B.
March	800	92	268	2.31	2.66	16,500	B.
April	1,050	259	441	3.80	4.24	26,200	B.
May	1,830	535	799	6.89	7.94	49,100	B.
June	2,540	740	1,330	11.5	12.83	79,100	B.
July	1,180	231	596	5.14	5.93	36,600	B.
August	231	138	164	1.41	1.63	10,100	A.
September	405	118	196	1.69	1.89	11,700	A.
October	138	96	122	1.05	1.21	7,500	A.
November	1,250	92	431	3.72	4.15	25,600	B.
December	490	168	311	2.68	3.09	19,100	B.
The year	2,540	92	417	3.59	48.84	302,000	

COWLITZ RIVER AT LEWIS FERRY, WASH.

Though this gaging station on Cowlitz River at Lewis Ferry was established in 1907, the earlier records are unsatisfactory, and further study will be required before their discrepancies may be explained and eliminated. On this account only the estimates for last half of 1911, which are fairly satisfactory, are here submitted.

Monthly discharge of Cowlitz River at Lewis Ferry, Wash., for 1911.

[Drainage area, 275 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
July	2,940	950	1,740	6.33	7.30	107,000	B.
August	1,000	570	731	2.66	3.07	44,900	B.
September	1,270	390	653	2.37	2.64	38,900	B.
October	570	285	390	1.42	1.64	24,000	B.
November 1–17	2,030	285	830	3.02	1.91	28,000	B.

COWLITZ RIVER AT RANDLE, WASH.

This station is located on Cowlitz River at Randle, Wash., 11 miles above the mouth of Cispus River, and properly reports the flow of the entire basin above that point. The station was estabished October 1, 1910.

Monthly discharge of Cowlitz River at Randle, Wash., for 1910–11.

[Drainage area, 519 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1910.							
October	5,140	833	2,220	4.28	4.93	136,000	A.
November	26,100	1,140	7,020	13.5	15.06	418,000	C.
December	6,850	1,110	3,330	6.42	7.40	205,000	A.
1911.							
January	2,910	1,020	1,680	3.24	3.74	103,000	A.
February	2,290	628	1,100	2.12	2.21	61,100	A.
March	3,700	628	1,650	3.18	3.67	101,000	A.
April	3,810	1,380	2,460	4.74	5.29	146,000	A.
May	12,100	3,000	4,000	7.71	8.89	246,000	B.
June	13,100	3,390	5,840	11.3	12.61	348,000	B.
July	5,010	1,520	3,210	6.18	7.12	197,000	A.
August	1,450	1,020	1,160	2.24	2.58	71,300	A.
September	2,040	714	1,200	2.31	2.58	71,400	A.
October	808	550	647	1.25	1.44	39,800	A.
November	21,900	514	4,320	8.32	9.28	257,000	C.
December	3,390	1,520	2,460	4.74	5.46	151,000	A.
The year	21,900	514	2,480	4.78	64.87	1,790,000	

COWLITZ RIVER AT MAYFIELD, WASH.

This station was established August 25, 1910, and is located at the Mayfield highway bridge over Cowlitz River at Mayfield, Wash. The records are valuable as indicating the low-water discharge through the Mayfield Canyon, where, as will be later explained, a good power privilege is presented. The high-water records are only approximate.

Monthly discharge of Cowlitz River at Mayfield, Wash., for 1910–11.

[Drainage area, 1,320 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1910.							
August 25–31	1,360	1,260	1,310	0.992	0.26	18,200	B.
September	1,360	1,040	1,260	.955	1.07	75,000	B.
December	11,700	5,880	7,660	5.80	6.69	471,000	B.
The period						93,200	
1911.							
January	6,360	5,000	5,930	4.49	5.18	365,000	B.
February	3,800	3,160	3,690	2.80	2.92	205,000	B.
March	6,200	3,020	4,430	3.36	3.87	272,000	B.
April	7,900	4,200	5,210	3.95	4.41	310,000	B.
May	11,500	5,960	7,870	5.96	6.87	484,000	B.
June	12,500	5,400	7,980	6.05	6.75	475,000	B.
July	5,800	2,370	4,050	3.07	3.54	249,000	B.
August	2,070	1,770	1,900	1.44	1.66	117,000	B.
September	3,480	1,770	2,160	1.64	1.83	129,000	B.
October	1,770	1,660	1,710	1.30	1.50	105,000	B.
November	35,000	1,710	9,480	7.18	8.01	564,000	C.
The year	35,000	1,660	5,170	3.92	53.23	3,750,000	

CLEAR FORK NEAR LEWIS, WASH.

This station is located at the mouth of Clear Fork near Lewis, Wash., and was established by the Valley Development Co. The earlier records are somewhat unreliable on account of poor measuring conditions. Those for 1911 are better than in previous years. High-water records are approximate throughout.

Monthly discharge of Clear Fork of Cowlitz River at mouth, near Lewis, Wash., for 1907–1911.

[Drainage area, 48 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1907.							
August 20-31	....	....	a 93.2	1.94	0.87	2,220	C
September	165	71	89.1	1.86	2.08	5,300	C
October	71	53	63.5	1.32	1.52	3,900	C
November	b 950	62	156	3.25	3.63	9,280	C.
December	752	117	258	5.38	6.20	15,900	C.
1908.							
January	183	71	130	2.71	3.12	7,990	C.
February	156	71	97.2	2.02	2.18	5,590	C.
March	1,480	86	291	6.06	6.99	17,900	C.
April	823	104	265	5.52	6.16	15,800	C.
May	468	203	304	6.33	7.30	18,700	C.
June	752	266	461	9.60	10.71	27,400	C.
July	652	165	394	8.21	9.46	24,200	C.
August	183	81	125	2.60	3.00	7,690	C.
September	81	53	66.1	1.38	1.54	3,930	C.
October	336	53	85.8	1.79	2.06	5,280	C.
November	558	62	157	3.27	3.65	9,340	C.
December	165	62	87.4	1.82	2.10	5,370	C.
The year	1,480	53	206	4.29	58.27	149,000	
1909.							
January	718	76	194	4.04	4.66	11,900	C.
February	244	76	119	2.48	2.58	6,610	C.
March	124	81	95.5	1.99	2.29	5,870	C.
April	244	98	132	2.75	3.07	7,860	C.
May	498	174	280	5.83	6.72	17,200	C.
June	860	266	468	9.75	10.88	27,800	C.
July	374	124	220	4.58	5.28	13,500	C.
August	117	62	83.0	1.73	1.99	5,100	C.
September	110	49	61.8	1.29	1.44	3,680	C.
October	104	49	61.6	1.28	1.48	3,790	C.
November	2,530	71	647	13.5	15.06	38,500	C.
December	804	153	296	6.17	7.11	18,200	C.
The year	2,530	49	221	4.60	62.56	160,000	
1910.							
January	680	83	192	4.00	4.61	11,800	C.
February	300	89	169	3.52	3.66	9,390	C.
March	b 1,060	263	517	10.8	12.45	31,800	C.
April	980	228	434	9.04	10.09	25,800	C.
May	1,020	380	585	12.2	14.07	36,000	C.
June	680	276	387	8.06	8.99	23,000	C.
July	276	135	211	4.40	5.07	13,000	C.
August	135	77	101	2.10	2.42	6,210	C.
September	77	66	74.4	1.55	1.73	4,430	C.
October	822	83	252	5.25	6.05	15,500	C.
November	b 1,350	135	391	8.15	9.09	23,300	B.
December	326	144	215	4.48	5.16	13,200	B.
The year	1,350	66	295	6.15	83.39	213,000	
1911.							
January	228	96	133	2.77	3.19	8,180	B.
February	110	66	82.3	1.71	1.78	4,570	B.
March	288	61	129	2.69	3.10	7,930	B.
April	394	126	194	4.04	4.51	11,500	B.
May	646	276	360	7.50	8.65	22,100	B.
June	1,040	313	528	11.0	12.27	31,400	B.
July	366	135	242	5.04	5.81	14,900	B.
August	126	72	96.4	2.01	2.32	5,930	A.
September	228	77	110	2.29	2.56	6,540	A.
October	96	56	72.4	1.51	1.74	4,450	A.
November	b 1,700	56	354	7.38	8.23	21,100	B.
December	288	112	193	4.02	4.64	11,900	B.
The year	1,700	56	208	4.33	58.80	150,000	

a 12 days. b Estimated.

COAL CREEK AT MOUTH, NEAR LEWIS, WASH.

This station is located one-half mile above the mouth of Coal Creek, 4 miles above Lewis, Wash. Channel conditions are permanent and the results are believed to be reliable.

Monthly discharge of Coal Creek at mouth, near Lewis, Wash., for 1910–11.

Month.	Discharge in second-feet.			Run-off (in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1910.					
November 6–30	214	34	103	5,100	B.
December	107	34	60.5	3,720	B.
1911.					
January	70	15	33.1	2,040	B.
February	26	7	13.0	722	B.
March	114	7	41.6	2,560	B.
April	120	30	56.7	3,370	B.
May	164	59	87.0	5,350	B.
June	180	54	106	6,310	B.
July	88	9	39.4	2,420	B.
August	9	1.2	4.85	298	B.
September	59	.5	17.7	1,050	B.
October	15	5	9.16	563	B.
November	420	5	96.8	5,760	B.
December	94	20	52.1	3,200	B.
The year	420	.5	46.5	33,600	

LAKE CREEK AT OUTLET OF PACKWOOD LAKE, NEAR LEWIS, WASH.

This station is located on Lake Creek, at the mouth of Packwood Lake (Pl. II), and is principally valuable to show the lake discharge and thereby to determine the amount of water available for storage. Only three and one-half months' records are available to December 31, 1911.

Monthly discharge of Lake Creek at outlet of Packwood Lake, near Lewis, Wash., for 1911.

[Drainage area, 18 square miles.]

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.
September 21–30	66	43	52.9	2.94	1.09	1,050
October	44	30	37.7	2.09	2.41	2,320
November	304	30	103	5.72	6.38	6,130
December	106	56	74.8	4.16	4.80	4,600

LAKE CREEK AT MOUTH, NEAR LEWIS, WASH.

The records at this station at the mouth of Lake Creek, near Lewis, Wash., are fairly reliable except for flood periods.

Monthly discharge of Lake Creek at mouth, near Lewis, Wash., for 1907–1911.

[Drainage area, 26 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1907.							
August 21-31	103	63	78.0	3.00	1.23	1,700	B.
September	103	63	73.5	2.83	3.16	4,370	B.
October	63	46	52.9	2.03	2.34	3,250	B.
November	210	46	81.2	3.12	3.48	4,830	B.
December	325	87	151	5.81	6.70	9,280	B.
The period						23,400	
1908.							
January	121	68	96.9	3.73	4.30	5,960	B.
February	80	63	69.8	2.68	2.89	4,010	B.
March	1,440	54	215	8.27	9.53	13,200	B.
April	258	72	132	5.08	5.67	7,860	B.
May	170	122	143	5.50	6.34	8,790	B.
June	393	102	245	9.42	10.51	14,600	B.
July	428	145	306	11.8	13.60	18,800	B.
August	145	72	105	4.04	4.66	6,460	C.
September	72	40	55.5	2.13	2.38	3,300	C.
October	102	40	52.5	2.02	2.33	3,230	C.
November	122	40	69.6	2.68	2.99	4,140	C.
December	145	51	69.5	2.67	3.08	4,270	C.
The year	1,440	40	130	5.00	68.28	94,600	
1909.							
January	290	47	111	4.27	4.92	6,820	B.
February	134	51	79.0	3.04	3.17	4,390	C.
March	78	51	62.4	2.40	2.77	3,840	C.
April	78	51	62.0	2.38	2.66	3,690	C.
May	198	66	105	4.04	4.66	6,460	C.
June	428	184	273	10.5	11.71	16,200	B.
July	227	112	168	6.46	7.45	10,300	B.
August	112	66	82.8	3.18	3.67	5,090	C.
September	78	43	61.8	2.38	2.66	3,680	C.
October	66	43	51.8	1.99	2.29	3,190	C.
November	905	51	306	11.8	13.17	18,200	B.
December	428	66	160	6.15	7.09	9,840	B.
The year	905	43	127	4.88	66.22	91,700	
1910.							
January	170	43	81.3	3.13	3.61	5,000	C.
February	145	40	70.0	2.69	2.80	3,890	C.
March	714	102	247	9.50	10.95	15,200	B.
April	358	102	170	6.54	7.30	10,100	B.
May	376	170	239	9.19	10.60	14,700	B.
June	258	102	170	6.54	7.30	10,100	B.
July	170	85	117	4.50	5.19	7,190	B.
August	85	51	66.3	2.55	2.94	4,080	B.
September	56	36	42.5	1.63	1.82	2,530	B.
October	170	56	99.0	3.81	4.39	6,090	B.
November	393	72	184	7.08	7.90	10,900	B.
December	198	78	116	4.46	5.14	7,130	B.
The year	714	36	134.	5.15	69.94	96,900	
1911.							
January	94	60	74.9	2.88	3.32	4,610	B.
February	66	40	50.7	1.95	2.03	2,820	B.
March	274	40	58.0	2.23	2.57	3,570	B.
April	78	51	62.1	2.39	2.67	3,700	B.
May	393	66	126	4.85	5.59	7,750	A.
June	393	141	240	9.23	10.30	14,300	A.
July	227	122	171	6.58	7.59	10,500	A.
August	112	60	78.2	3.01	3.47	4,810	A.
September	102	47	72.0	2.77	3.09	4,280	A.
October	47	36	42.4	1.63	1.88	2,610	B.
November	464	36	147	5.65	6.30	8,750	A.
December	122	71	95.8	3.68	4.24	5,890	A.
The year	464	36	102	3.92	53.05	73,600	

HAGAR CREEK ABOVE NORTH FORK, NEAR LEWIS, WASH.

The Valley Development Co. established this station on Hagar Creek, near Lewis, Wash., just above North Fork, on August 16, 1911, for the purpose of determining the amount of water available to supplement the flow of Johnson Creek through diversion into Snyder Lake.

Monthly discharge of Hagar Creek above North Fork, near Lewis, Wash., for 1911.

Month.	Discharge in second-feet.			Run-off (in acre-feet).
	Maximum.	Minimum.	Mean.	
September 9-30	16.1	5.3	7.91	345
October	6.9	5.7	6.35	390
November	48	5.7	18.7	1,110
December	19.8	10.1	13.7	842

NOTE.—Average of daily discharges considered as mean for the month or partial month.

NORTH FORK OF HAGAR CREEK NEAR LEWIS, WASH.

This station was established on North Fork of Hagar Creek by the Valley Development Co. for the same purpose as that of the station on Hagar Creek proper, at a point about one-half mile above the mouth.

Monthly discharge of North Fork of Hagar Creek one-half mile above mouth, near Lewis, Wash., for 1911.

Month.	Discharge in second-feet.			Run-off (in acre-feet).
	Maximum.	Minimum.	Mean.	
September 9-30	5.3	2.5	3.51	153
October	3.2	2.9	3.02	186
November	14.0	2.9	6.64	395
December	6.7	4.6	5.19	319

NOTE.—Average of daily discharges considered as mean for month or partial month.

JOHNSON CREEK BELOW WEST FORK, NEAR LEWIS, WASH.

This station is located on Johnson Creek below the junction of West Fork and about 6 miles above the mouth of the creek. It was established in connection with Snyder Lake storage studies previously described.

Monthly discharge of Johnson Creek below West Fork, near Lewis, Wash., for 1911.

Month.	Discharge in second-feet.			Run-off (in acre-feet).
	Maximum.	Minimum.	Mean.	
September 9-30	79	1.5	31.8	1,390
October	34	18.8	26.5	1,630
November	335	18.8	111	6,600
December	101	36	66	4,060

NOTE.—Average of daily discharges considered as mean for month or partial month.

JOHNSON CREEK AT MOUTH, NEAR LEWIS, WASH.

This station is located below all tributaries and about 1 mile above its mouth. The records are valuable in Snyder Lake storage studies.

Monthly discharge of Johnson Creek at mouth, near Lewis, Wash., for 1907–1911.

Month.	Discharge in second-feet.			Run-off (in acre-feet).	Accuracy.
	Maximum.	Minimum.	Mean.		
1907.					
August 21–31	63	56	62.4	1,360	C.
September	80	48	55.6	3,310	C.
October	48	37	44.8	2,750	C.
November	283	37	88.2	5,250	B.
December	610	124	239	14,700	B.
The period				27,400	
1908.					
January	172	80	136	8,360	B.
February	124	90	104	5,980	B.
March	1,510	80	278	17,100	B.
April	690	124	266	15,800	B.
May	465	232	298	18,300	B.
June	690	232	439	26,100	B.
July	535	154	333	20,500	B.
August	154	63	95.0	5,840	C.
September	63	48	54.9	3,270	C.
October	124	42	64.3	3,950	C.
November	172	37	96.6	5,750	C.
December	189	63	89.4	5,500	C.
The year	1,510	37	188	136,000	
1909.					
January	690	63	196	12,100	B.
February	232	90	131	7,280	B.
March	139	100	117	7,190	B.
April	189	100	128	7,620	B.
May	465	139	245	15,100	B.
June	770	154	445	26,500	B.
July	283	112	177	10,900	B.
August	112	63	74.3	4,570	C.
September	90	42	53.9	3,210	C.
October	63	37	53.9	3,310	C.
November	1,830	63	533	31,700	B.
December	690	80	250	15,400	B.
The year	1,830	37	200	145,000	
1910.					
January	465	80	153	9,410	B.
February	232	72	110	6,110	B.
March	1,310	232	534	32,800	B.
April	810	189	380	22,600	B.
May	690	339	425	26,100	B.
June	465	139	250	14,900	B.
July	189	63	121	7,440	B.
August	63	48	54.7	3,360	C.
September	56	33	41.1	2,450	C.
October	283	63	123	7,560	B.
November	1,030	80	335	19,900	B.
December	398	70	200	12,300	B.
The year	1,310	33	228	165,000	
1911.					
January	170	92	124	7,620	B.
February	105	60	74.9	4,160	B.
March	283	60	126	7,750	B.
April	339	118	180	10,700	B.
May	572	189	314	19,300	B.
June	730	258	433	25,800	B.
July	283	81	169	10,400	B.
August	81	51	62.5	3,840	B.
September	92	44	57.4	3,420	B.
October	60	36	48.3	2,970	B.
Movember	650	36	210	12,500	B.
December	232	113	158	9,720	B.
The year	730	36	163	118,000	

GLACIER CREEK ONE-HALF MILE ABOVE MOUTH, NEAR LEWIS, WASH.

This station was established by the Valley Development Co., and records are available from September 6 to December 31, 1911. It consists of a sharp-crested weir 9.88 feet long, with end contractions. The records indicate the amount of water that will be intercepted by the proposed diversion conduit leading from Johnson Creek to Snyder Lake. The hydraulic gradient crosses the creek at elevation 2,250 feet. Discharges have been computed by the Geological Survey from data furnished by the Valley Development Co.

Monthly discharge of Glacier Creek one-half mile above mouth, near Lewis, Wash., for 1911.

Month.	Discharge in second-feet.			Run-off (total in acre-feet).
	Maximum.	Minimum.	Mean.	
September 9–30	15.2	11.5	12.6	550
October	12.6	11.2	11.9	732
November	38	11.2	20.6	1,230
December	38	26	32.8	2,020
The period				

NOTE.—Average of daily discharges considered as mean for month or partial month.

CISPUS RIVER BELOW M'COY CREEK, NEAR RANDLE, WASH.

This station is located near Randle, Wash., and its principal prospective use is in the determination of the yield of the Cispus basin for power development.

Monthly discharge of Cispus River below McCoy Creek, near Randle, Wash., for 1910–1912.

[Drainage area, 341 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1910.							
October 25–31	950	705	791	2.32	0.60	11,000	A.
November	6,400	705	1,950	5.72	6.38	116,000	B.
December	2,140	1,250	1,510	4.43	5.11	92,800	B.
1911.							
January	1,420	1,020	1,220	3.58	4.13	75,000	B.
February	1,090	820	939	2.75	2.86	52,100	B.
March	a 3,000	820	1,470	4.31	4.97	90,400	C.
April	a 3,100	1,250	1,860	5.45	6.08	111,000	C.
May	3,890	1,910	2,470	7.24	8.35	152,000	C.
June	3,600	1,030	1,950	5.72	6.38	116,000	C.
July	1,030	460	687	2.01	2.32	42,200	B.
August	460	325	378	1.11	1.28	23,200	A.
September	650	325	390	1.14	1.27	23,200	A.
October	365	295	329	.965	1.11	20,200	A.
November	2,650	295	956	2.80	3.12	56,900	B.
December	1,080	650	913	2.68	3.09	56,100	B.
The year	3,890	295	1,130	3.31	44.96	818,000	
1912.							
January	4,110	600	1,870	5.48	6.32	115,000	B.
February	3,080	1,440	2,130	6.25	6.74	123,000	C.

a Estimated by means of hydrograph comparison with Cowlitz River at Randle.

MISCELLANEOUS MEASUREMENTS.

The following miscellaneous discharge measurements were made in the Cowlitz River basin in 1910 and 1911:

Miscellaneous discharge measurements made in Cowlitz River basin.

[By Parker, Harris, and Harmon.]

Date.	Stream.	Tributary to—	Locality.	Gage height.	Discharge.
				Feet.	*Sec.-ft.*
Oct. 11, 1911	Ohanapecosh River...	Cowlitz River.......	2 miles above park boundary.	0.22	82.6
Do.......	Summit Creek........	.....do..............	Hot Springs trail crossing.	1.02	21.6
Aug. 27, 1910	Muddy Fork..........	.....do..............	Mouth................	1.55	293
Oct. 6, 1911	.....do..........	.....do..............	.....do..............	1.16	91.2
Aug. 28, 1911	Cispus River..........	.....do..............	Above Muddy Fork...	....	69.4
Do.......	Muddy Fork..........	Cispus River........	Mouth................	....	126
Aug. 20, 1911	Adams Creek..........	.....do..............	.....do..............	....	65.7
July 9, 1911	Tilton River..........	Cowlitz River.......	.....do..............	....	187
Oct. 18, 1911	.....do..............	.....do..............	.....do..............	....	201

SUMMARY OF MINIMUM DISCHARGE.

The discharge for the minimum day and the minimum week of each year for which low-water records are available has been summarized to show the relation of the gaging stations to each other and to the drainage area. The estimates of available power given and discussed in subsequent pages are based on discharges equivalent to that of the average observed for the lowest week during the period of record. The column headed "minimum week" is therefore fundamental to the entire subsequent discussion.

Summary of minimum discharge, by years, at gaging and weir stations in the Cowlitz basin.

Stream and location.	Drainage area.	Year.	Minimum day.	Minimum week.		Discharge per square mile.	
				Date.	Discharge.	Minimum day.	Minimum week.
	Sq. m.		*Sec.-ft.*		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
Ohanapecosh River above Clear Fork.	116	1907	98	Oct. 9-15..........	98	0.84	0.84
		1910	93	Sept. 9-15.........	102	.80	.88
		1911	92	Oct. 29-Nov. 4....	96	.79	.83
Cowlitz River at Lewis Ferry...	275	1907	450	....	....	275	1.63
		1911	285	Oct. 28-Nov. 3....	290	1.04	1.05
Cowlitz River at Randle........	519	1911	514	Oct. 30-Nov. 5....	556	.99	1.07
Cowlitz River at Mayfield......	1,320	1910	1,040	Sept. 12-18.........	1,170	.79	.89
		1911	1,660	Oct. 14-20..........	1,660	1.26	1.26
Clear Fork at mouth...........	48	1907	53	Oct. 22-28..........	54	1.10	1.12
		1908	53	Sept. 23-29.........	53	1.10	1.10
		1909	49	Sept. 13-19.........	51	1.02	1.06
		1910	66	Sept. 22-28.........	72	1.38	1.50
		1911	56	Oct. 18-Nov. 3....	57	1.17	1.19
Coal Creek at mouth...........	....	1911	.5	Aug. 29-Sept. 4...	1.8	....	....
Lake Creek at outlet of Packwood Lake.	18	1911	30	Oct. 29-Nov. 4....	30	1.67	1.67

Summary of minimum discharge, by years, at gaging and weir stations in the Cowlitz basin—Continued.

Stream and location.	Drainage area.	Year.	Minimum day.	Minimum week.		Discharge per square mile.	
				Date.	Discharge.	Minimum day.	Minimum week.
	Sq. m.		*Sec.-ft.*		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
Lake Creek at mouth	26	1907	46	Oct. 18-24	46	1.77	1.77
		1908	40	Oct. 6-12	40	1.54	1.54
		1909	43	Oct. 25-31	44	1.65	1.69
		1910	36	Sept. 8-14	36	1.38	1.38
		1911	36	Oct. 29-Nov. 4	37	1.38	1.42
Hagar Creek above North Fork		1911	5.7	do	5.7		
North Fork of Hagar Creek		1911	2.5	Oct. 23-29	2.9		
Johnson Creek below West Fork		1911	18.8	Oct. 29-Nov. 4	19		
Johnson Creek at mouth		1907	37	Oct. 21-27	37		
		1908	37	Oct. 6-12	42		
		1909	37	Sept. 13-19	45		
		1910	33	Sept. 21-27	34		
		1911	36	Oct. 29-Nov. 4	38		
Glacier Creek ½ mile above mouth.		1911	11.2	do	11.2		
Cispus River below McCoy Creek	341	1911	295	Oct. 25-31	295	.87	.87

WATER POWERS.

DEVELOPMENT.

The Cowlitz River basin has large water-power possibilities, practically all of which remain undeveloped. The evident reason for this is that the present areas of power consumption are supplied from sites more conveniently located than are those of the Cowlitz. The center of prospective power development in this basin lies near the mouth of Cispus River (Pl. III, *A*), the air-line distance from which to Portland is 65 miles, to Tacoma 55 miles, and to Seattle 80 miles. These distances lie well within the limit of economical transmission; indeed, they are relatively short. Therefore, the utilization of the Cowlitz powers depends largely on the growth of the market in the neighborhood of those cities. The growth of industry in the Puget Sound and the Willamette Valley regions has been rapid and it appears to be a matter of only a short time when the Cowlitz powers must be seriously considered.

The natural conditions in the Cowlitz basin determine rather sharply the logical types of prospective power development. In the upper tributaries the steep grades are favorable to the establishment of "high-head" units, and these will be especially effective where storage reservoir sites are available, the development of which will make possible the compensation of wide fluctuations in stream flow. In the middle portion of the basin, below the junction of Ohanapecosh River and Muddy Creek, and above Youngs Canyon, near Mossy Rock, "low-head" developments by long canal diversion seem best suited to the natural conditions. The even topography and gravelly

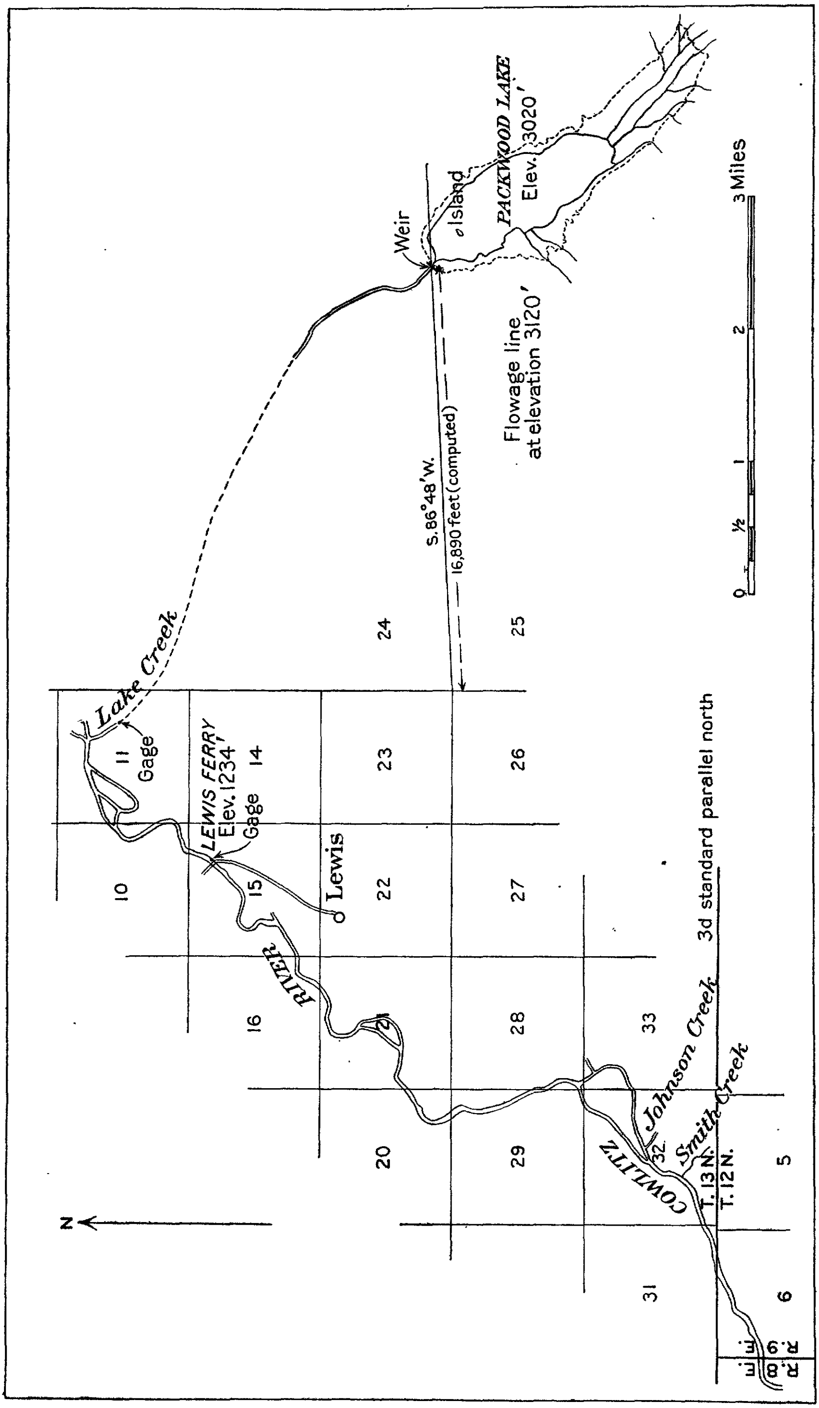


FIGURE 1.—Map showing relative location of Packwood Lake and the mouth of Lake Creek.

PACKWOOD LAKE.

Photograph copyrighted, 1907, by Kiser Photo Co., Portland, Oreg. Reproduced by permission.

structures of the broad valley in this section are favorable to the economical construction of canals necessary for such projects. Finally, the deep canyons cut into an impervious basalt in the vicinity of Mossy Rock and Mayfield afford opportunities for erecting dams and thereby concentrating the available head at two points.

Only one water power has been utilized within the Cowlitz basin at the present time. This development is on Rainy Creek, which enters the river from the right side near Kosmos. Fifty horsepower are developed over a head of 22 feet. The energy is used to operate a sawmill.

A number of water filings have been made in the Cowlitz basin from time to time for the purpose of power development. Most of them are located in the upper part of the basin on the principal tributaries of the river, where high-head projects are contemplated. It is believed that only four water filings have been made on the main stream. Two of these are located a short distance below the mouth of Cispus River and the other two in the Mossy Rock and Mayfield canyons.

The only construction work resulting from these filings is that of the Valley Development Co. Surveys were made in 1907 and 1908 and actual construction was begun in 1909 to utilize the large amount of head available from Lake and Johnson creeks near the town of Lewis. Lake Creek heads in a glacier in the Cascade Range, flows through Packwood Lake (Pl. II), of glacial origin, at an elevation of 3,020 feet, and enters Cowlitz River about 1½ miles above Lewis. In the first unit of the development it is proposed to equalize the flow of Lake Creek by building a dam 70 feet high and about 500 feet long on top at the outlet of Packwood Lake. This will provide 50,000 acre-feet of storage. The water from the lake will be carried by a canal 4.4 miles long and pressure pipes 6,010 feet long to a point near Lewis, where a head of 1,740 feet is available. The location of Packwood Lake with respect to the mouth of Lake Creek is shown in figure 1. Johnson Creek also heads in the mountains and enters the main stream 3 miles below Lewis. The second unit of the project will involve diverting the flow of Johnson Creek through 8.1 miles of flume to Snyder Lake (Pl. I) at an elevation of 2,200 feet, where 340 acre-feet of storage will be provided. A pressure pipe 4,630 feet long will connect the lake with the same power-house site used for unit No. 1, and 950 feet of head will be realized. If it be found that the demand for power warrants the expenditure necessary, the height of the Packwood Lake dam will be increased to 90 feet, thereby furnishing a total storage of 70,000 acre-feet, and the headwaters of Coal Creek, Clear Fork, and several minor streams will be diverted into the lake by canals, tunnels, and flumes.

POWER SITES.

Development units.—The determination of the available power in the Cowlitz basin makes necessary the assumption that certain stretches of river form logical development units. In some places the limits of a power development are unmistakably indicated by the natural conditions; in others, the decision can be reached only after mature study, and even then engineers working independently often differ as to limits and details. The units selected for this report are based on general considerations of water supply, stream gradient, topography, and other physical features that usually demand attention in such a study. It is not claimed that the units here selected are certainly the best. Others may be as good or better, but the selection now made is well adapted to show the relative limits of good, bad, and indifferent power sites. Final location and selection is the work of the engineer in private practice and beyond the province of a report of this kind. (See Pl. VIII, *A–G*, at end of volume.)

The following table includes the sections chosen on the basis indicated. The units have been numbered in order downstream and are fixed by landmarks and by a statement of the distance above an initial point of survey. The elevation of the water surface and the drainage area at the upper end of each unit together with the total fall and fall per mile between units has been listed. The average minimum discharge for the lowest week has been estimated from the data presented in the preceding pages and a comparison of records in near-by drainage basins. The horsepower statement represents 70 per cent of the theoretical horsepower and is derived from the known fall and the estimated minimum discharge.

Summary of available power in the Cowlitz River basin.

Stream and location.	Section No.	Distance above initial point of survey.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Minimum discharge for one week— Without storage. Total.	Minimum discharge for one week— Without storage. Per square mile.	Minimum discharge for one week— With storage (total).	Available horse-power, 70 per cent efficiency— Without storage.	Available horse-power, 70 per cent efficiency— With storage.
		Miles.	Feet.	Miles.	Feet.	Feet.	Sq. miles.	Sec.-ft.	Sec.-ft.	Sec.-ft.		
Ohanapecosh River at Mount Rainier National Park boundary		a 84.1	2,070				71	65	0.92			
Ohanapecosh River at mouth	1	77.6	1,347	a 6.5	a 723	111	178	143	.80		3,730	
Muddy Fork near Mount Rainier National Park boundary		a 5.8	a 2,310				a 25	50	a 2.00	b 69		
Muddy Fork at mouth	2	0	1,347	a 5.8	963	166	a 40	65	a 1.62	84	3,820	5,270
Cowlitz River below Muddy Fork		77.6	1,347				218	250	1.15	260		
Cowlitz River below Smith Creek	3	67.2	1,152	10.4	195	18.8	373	410	1.10	482	3,860	4,020
Cowlitz River, sec. 13, T. 12 N., R. 7 E	4	55.9	1,052	11.3	100	8.9	440				3,250	3,820
Cowlitz River below Cispus River		37.5	993				1,030	980	.95	1,290		
Cowlitz River below Big Bend	5	28.0	757	9.5	236	25	1,070	1,010	.94	1,320	18,300	24,100
Cowlitz River 2 miles above Riffe	6	17.0	600	11.0	157	14.3	1,140	1,050	.92	1,360	12,600	16,400
Cowlitz River below Mossy Rock Bridge	7	7.3	462	9.7	138	14.2	1,170	1,070	.91	1,380	11,700	15,100
Cowlitz River at Mayfield	8	0	354	7.3	108	14.8	1,320	1,170	.89	1,480	10,000	12,700
Summit Creek below Carlton Creek			a 2,250				a 34	20	a .59			
Summit Creek at mouth	9		1,520	a 2.0	730	a 365	a 36				1,160	
Clear Fork 8.4 miles above mouth			a 3,190				27	30	1.11			
Clear Fork at mouth	10		1,390	a 8.4	1,800	214	48	51	1.06		4,290	
Lake Creek below Packwood Lake			3,020				18	30	1.67	c 92		
Tailrace of proposed power plant near Lewis	11		1,247	5.5	1,773	322					4,220	12,900
Johnson, Glacier, and Hagar creeks above elevation of 2,200 feet			2,260					35		d 44		
Tailrace of proposed power plant near Lewis	12		1,247	8.9	1,013	114					2,820	3,540
Cispus River and small tributaries above elevation of 3,975 feet		a 46.5	3,975				19	19	1.00	e 76		
Cispus River 3 miles below Lake Creek	13	41.7	3,250	4.8	725	151	46	40	.87	97	1,090	4,370
Cispus River below Muddy Fork		38.2	3,155				92	90	.98	f 325		
Cispus River below Adams Creek	14	32.0	2,405	6.2	750	121	140	125	.89	360	5,360	19,300
Cispus River below Autus Creek	15	19.3	1,490	12.7	915	72	272	235	.86	470	9,080	26,100
Cispus River 1 mile above mouth	16	1.2	g 993	18.1	497	27	453	380	.84	615	9,270	18,500
Total											105,000	175,000

a These values are approximate.
b With 720 acre-feet storage in Backbone Lake.
c With 25,000 acre-feet storage in Packwood Lake.
g The actual elevation at the mouth of Cispus River is 958 feet. The elevation listed in the table represents an additional height of 35 feet which it is possible to obtain by a dam.
d With 340 acre-feet storage in Snyder Lake.
e With 16,000 acre-feet storage in Walupt Lake.
f With 50,000 acre-feet storage in reservoir above Muddy Fork.

NOTE.—The storage in Walupt Lake is considered only in section 13.

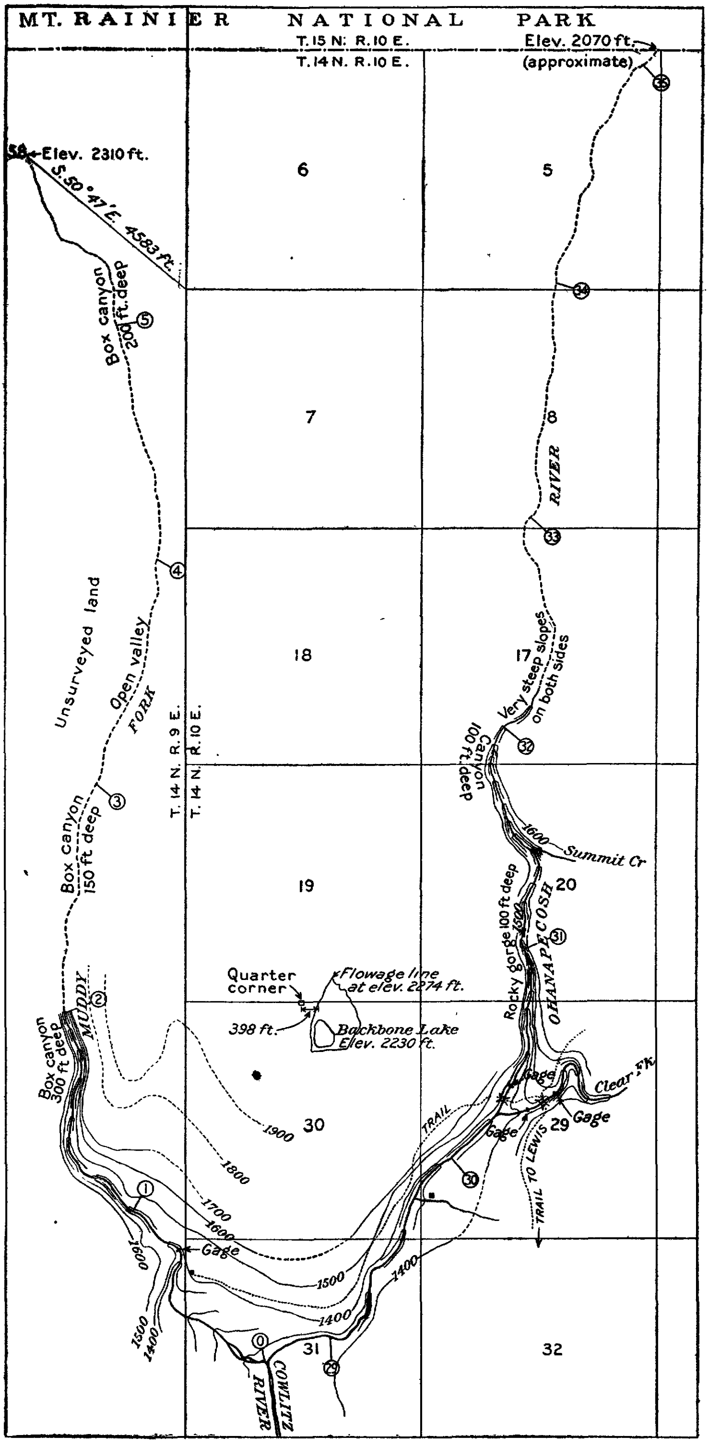


FIGURE 2.—Map of Backbone Lake and the confluence of Ohanapecosh River and Muddy Fork.

A brief description of the units included in the foregoing table follows:

Section 1, Ohanapecosh River between Mount Rainier National Park boundary and mouth.—Ohanapecosh River (Pl. I) is the larger of the two upper branches of the Cowlitz. It heads in a portion of the Cascade summit lying southeast of Mount Rainier and receives only a small portion of its water supply from the glaciers surrounding that mountain. The river has cut a steep passageway through the massive igneous country rock. Box canyons with vertical walls 50 to 250 feet high, together with numerous cascades and waterfalls, characterize portions of the stream course, and the valley is narrow and steep throughout its length. The highest and most picturesque waterfall is located about one-half mile above the Mount Rainier National Park boundary, where there is a sheer drop of 46 feet and a total fall of 74 feet in a distance of 250 feet.

The most feasible power development would be that of diverting the water from the river 2½ miles above the park boundary at an elevation of about 2,320 feet and carrying it past the waterfall mentioned to Backbone Lake (fig. 2), a distance of 7.5 miles, and leading it thence to a powerhouse located at the mouth of the stream. A dam across the outlet of the lake 44 feet high and 700 feet long on top would furnish 720 acre-feet of storage, which is ample to equalize the daily variation in demand and to supplement extreme low-water periods. It is reasonable to assume that right of way for diversion conduits will not be granted through Mount Rainier National Park, especially where the diversions would interfere with the scenic value of the park. Therefore, the upper limit of this section has been placed at the boundary line of the national park, and the capacity has been based on the minimum flow at that point.

The construction of conduits along either side of the valley would prove difficult and expensive on account of the heavy rockwork required in the canyons and along the steep slopes. Tunnels could be used to advantage in many places to assure permanency and to prevent damages from snowslides and falling timber. If the water were diverted along the right side of the valley, it would be advantageous to make use of a single power plant with separate units in conjunction with the Muddy Fork development, which will be described under section 2. It is possible that diversion along the left side might prove feasible on account of the additional water supply that would be gained by intercepting the flow of Clear Fork and Summit Creek. The chief difficulty with this plan of development, however, is that the hydraulic grade line of the conduit would cross Clear Fork in a deep box canyon, which is 800 to 900 feet deep in places. Summit Creek has a heavy gradient, and the conduit crossing of this stream would not be more than about 2 miles from

Ohanapecosh River. In the absence of more detailed information the relative merits of the two schemes outlined can not be determined. Consequently, the capacity of this unit has been computed without including the water supply of Clear Fork and Summit Creek.

The minimum weekly flow given in the table was estimated by determining the relation between the measurement of October 11, 1911, on Ohanapecosh River, 2 miles above Mount Rainier National Park boundary, and the discharge of the river above Clear Fork for that day. The factor derived in this manner was applied to the minimum discharge recorded above Clear Fork and the result is increased by 8 second-feet to allow 1 second-foot per square mile inflow between the point at which the measurement was made and the park boundary.

Section 2, Muddy Fork from national-park boundary to mouth.—Muddy Fork (Pl. I) is a glacial stream which receives its water supply from the Cowlitz and Little Cowlitz glaciers on the southeast side of Mount Rainier. The fact that the low-water flow of Ohanapecosh River and Muddy Fork occurs at different seasons renders the diversion of these two streams into one power plant especially advantageous. Muddy Fork has a steeper gradient and deeper canyons than Ohanapecosh River, but there are fewer falls and accordingly the gradient is more uniform. So far as could be learned, the elevation of Muddy Fork at the Mount Rainier National Park boundary has never been determined accurately, but surveys made by the Valley Development Co. indicate that the elevation is several hundred feet above that of Backbone Lake (fig. 2). Therefore it would not be necessary to secure right of way through the park for conduits leading to the lake. The water could be diverted at an elevation of about 2,300 feet and carried along the left side of the valley 4.7 miles to Backbone Lake. The storage of 720 acre-feet in that lake would more than equalize the flow during the lowest month. From the lake the water could be carried to a plant located at the junction of Ohanapecosh River and Muddy Fork by a penstock 1¼ miles long, or if 40 feet of fall were sacrificed only 0.6 mile of pressure pipe would be required. If the power were developed from the two rivers as above suggested, the stored water in the Backbone Lake reservoir would compensate all fluctuations in the daily load and the water from the Ohanapecosh could be delivered at a constant rate.

The most expensive part of this development would be the diversion dam on Muddy Fork and the upper 1½ miles of conduit. The river flows through a canyon with vertical walls about 100 feet high at the proposed headworks, so that difficulty would be experienced in transporting materials and in caring for the water while building the dam. The lower portion of the conduit traverses a gently sloping side hill which has an earth and gravel covering.

Muddy Fork is the only stream in the upper Cowlitz basin that receives an appreciable amount of water from melting glaciers. Therefore the behavior of the watercourses upon which gaging stations were maintained is not an index of the discharge of Muddy Fork. The measured discharge of this stream taken October 6, 1911, and the discharge for the low-water interval October 30 to November 3, 1911, as computed from the records on Ohanapecosh River, Cowlitz River at Lewis, and Clear Fork, provide a basis for a comparison with the records of Puyallup River at Electron. The Puyallup is also a glacial stream, the measurement station is located near the glaciers, and the records are fairly dependable. The factor derived by the comparison was applied to the minimum flow of Puyallup River at Electron for January 11 to 17, 1910, to obtain the minimum discharge of Muddy Fork at mouth for one week as shown in the table. The minimum at the national park boundary was estimated by deducting 1 second-foot per square mile for the lower drainage area.

The increased flow that can be realized by the storage available in Backbone Lake was estimated by studying the variation in flow of Puyallup River for the period February 2 to March 15, 1911.

Section 3, Cowlitz River between Muddy Fork and Smith Creek.—The Cowlitz Valley below the junction of Ohanapecosh River and Muddy Fork (Pl. VIII, *D*) is wide and filled with well-worn, water-sorted gravel. It flows over a rather broad flood plain and no evidence of bedrock outcrops were noted in the stream bed. Probably the most feasible method of utilizing the fall in section 3 would consist of building a low diversion dam at the upper end of the section with cut-off walls or sheet piling to prevent underflow through the loose gravel and of diverting the water by canal to a favorable power-house site. It is thought that no difficulty would be experienced in constructing a canal on either side of the valley because a large percentage of the excavated material would consist of gravel and alluvium. A canal on the left side would probably be longer than one on the right, but this would be offset by the fact that a larger flow from tributary streams would be intercepted on that side. The presence of glacial silt from the waters of Muddy Fork would cause considerable wear on turbines.

The minimum discharge for one week was computed on the basis of the records on Cowlitz River near Lewis and a deduction of 0.9 second-foot per square mile for the drainage area between the mouth of Muddy Fork and the gaging station.

Section 4, Cowlitz River between Smith Creek and a point in sec. 13, T. 12 N., R. 7 E.—Cowlitz River is wide in section 4 (Pl. VIII, *C* and *D*), but at several places it has cut a narrow passageway through the bench lands. The method of development outlined for unit No. 3 appears also to be well suited to conditions in this section, A canal located on either side would probably not be much longer than the distance by river. The lower limit of the unit is controlled by a marked decrease in the river gradient. The cost of development per horsepower would no doubt be greatly in excess of that warranted under existing market conditions.

Between the lower end of section 4 and the upper end of section 5, a distance of 15.3 miles by river, the total fall only amounts to 59 feet, equivalent to an average fall per mile less than 4 feet. As appropriate dam sites for utilizing the available head by backing the water upstream are lacking, this portion of the river has been neglected in the power schedule.

The minimum discharge for one week of Cowlitz River below Smith Creek was estimated on the basis of the records of the river near Lewis and at Randle. An allowance of 0.9 second-foot per square mile was made for drainage-area differences.

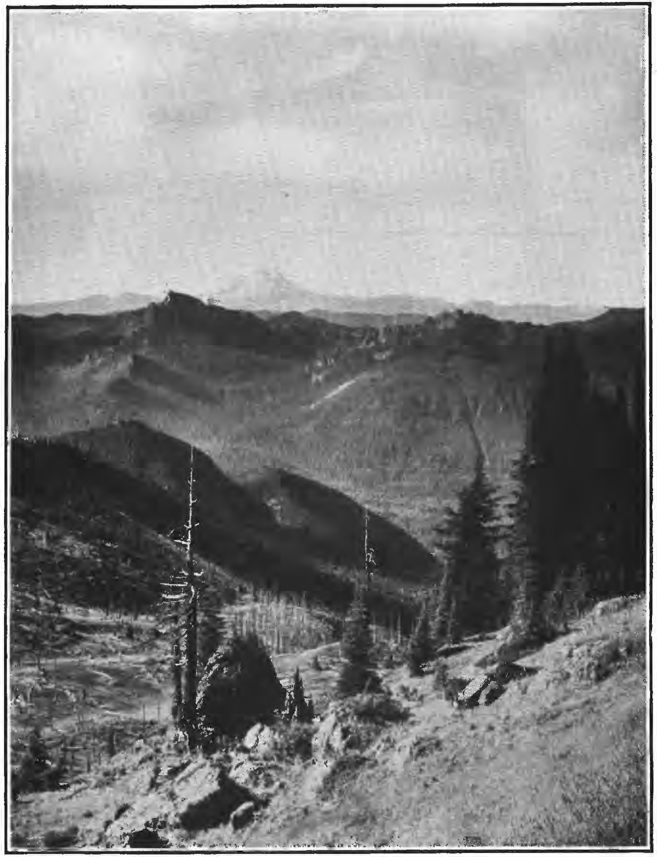
Section 5, Cowlitz River from mouth of the Cispus to a point below Big Bend.—One of the best power developments on Cowlitz River proper is found in section 5 (Pl. VIII, *B*). The confluence of Cispus River with the Cowlitz controls the upper limit and the approach of a steep ridge toward the river course on the left side below the Big Bend constitutes the lower limit. At a point about 500 feet below the mouth of Cispus River is an excellent dam site (Pl. III, *A*). At this point the bedrock is impervious and affords good foundation and abutments for a dam about 600 feet long and 35 feet high above low-water level. If such a dam were erected the water would be backed upstream 3 miles in the Cowlitz and 1 mile in the Cispus. A canal located on the left side of the valley between the dam site and the ridge mentioned above would make long detours from the river at two localities. It is thought, however, that it would be somewhat shorter than the distance between the two points by river. Considerable rock work would be necessary in the upper 2 miles of the canal, but the remainder of the excavation would be principally in gravel and alluvial material. Sufficient storage could be developed to provide for diurnal fluctuations in the demand for power by sacrificing about 5 feet of the head gained by the dam or building an artificial reservoir within the lower of the two detours mentioned.

The water could be diverted on the right side of the valley from the dam site to a point about 1 mile above Rainy Creek by about 4 miles of canal, at which point 190 feet gross head could be realized. It is reported that surveys were made and water-right filings posted three or four years ago with this end in view, but no action has been taken toward holding the rights.

The minimum discharge for one week of Cowlitz River below Cispus River was estimated on the basis of the records of Cowlitz River at Randle and of Cispus River below McCoy Creek. An

A. COWLITZ RIVER A SHORT DISTANCE BELOW THE MOUTH OF CISPUS RIVER.

Photograph by A. H. Barnes, Parkland, Wash.



B. MOUNT ST. HELENS FROM TAHOMA GLACIER.

Showing type of country drained by Nisqually River. Photograph by A. H. Barnes Parkland, Wash.

allowance of 0.8 second-foot per square mile and of 0.75 second-foot per square mile was made for the additional drainage area on Cowlitz and Cispus rivers respectively.

Section 6, Cowlitz River between Big Bend and a point 2 miles above Riffe.—The lower limit of section 6 (Pl. VIII, *B*) was selected to conform with the limitations of section 7 rather than to conform with the topographic features within section 6. Bedrock for a dam and headworks is apparently lacking and a canal located on either side of the valley would be longer than the river. At two points on the left side the river has encroached on the old terraces mentioned elsewhere with the result that the banks of the stream at these points are composed of cemented gravel and stand almost perpendicular for a height of 100 to 150 feet. These steep banks are so located that tunnels would be necessary in building a conduit. The right side of the valley appears to offer fewer difficulties in this respect and it is probable that the best location for a canal would be found there.

The minimum discharge for one week of Cowlitz River below Big Bend was derived by an adjustment, on the drainage-area basis, between the estimated minimum flow below Cispus River and that shown by the records at Mayfield.

Section 7, Cowlitz River from a point 2 miles above Riffe to Mossy Rock.—At a point on Cowlitz River about 400 feet below the head of Youngs Canyon there is favorable foundation and abutments for a dam 200 feet high and of about 600 feet top length (Pls. VIII, *A* and *B*). If erected to such a height, slack water would extend 13 miles upstream and a considerable area of good agricultural land would be flooded. Whether or not the power value will in the future be sufficient to warrant the purchase of this land can not now be determined. A dam 105 feet high and 300 feet long would create slack water upstream for 7 miles or 2 miles above Riffe, and very little agricultural land would be flooded. An ogee type of dam 300 feet long would discharge 68,000 second-feet with a head crest of 15 feet. It is believed that such a spillway capacity would be ample for flood discharge and that a head of 15 or 16 feet above spillway crest would not cause the overflow of any agricultural lands in section 6. Further study of this matter would be necessary for a final decision.

A practical difficulty to be met in the development of the plan above suggested is presented by the wide range of stage in Youngs Canyon. Driftwood left by floods at the head of the canyon indicates that high water rises at least 75 feet above low water. Therefore, the effective head during floods must be decreased by at least that amount. It would probably be well to conduct the head water by pressure pipes from the dam to a point below the Mossy Rock bridge, where an excellent power-house site is available and the channel is much wider, so that less head would be lost during floods.

The minimum discharge for one week of Cowlitz River 2 miles above Riffe was derived by an adjustment, on the drainage-area basis, between the estimated minimum flow below Cispus River and that shown by the records at Mayfield.

Section 8, Cowlitz River between Mossy Rock and Mayfield.—No difficulty would be experienced in finding a good dam site in the Mayfield Canyon, below Mayfield, for a dam high enough to back the water up to the Mossy Rock bridge (Pl. VIII, *A*). The land suitable for cultivation in the stretch of valley between the two canyons lies on benches 150 to 300 feet above the river grade, so that no damages would be incurred in that respect. The range in stage in the Mayfield Canyon is probably as great as in Youngs Canyon, so that head water would have to be conducted through pipes to the foot of the canyon in order to realize the total available head.

The minimum flow of Cowlitz River at Mayfield for September 12 to 18, 1910, is shown by the records to be 1,170 second-feet, which is somewhat lower than the minimum which occurred in 1911. It is thought, therefore, that the low-water records of 1910 form a conservative basis for estimating the available power in this section.

Section 9, Summit Creek.—Though rather small in point of water supply, Summit Creek has a heavy gradient near its mouth. The river surveys do not include this stream, but aneroid-barometer readings were taken to determine the approximate elevation of Summit Creek, at the mouth of Carlton Creek, a tributary from the right side entering the main stream about 2½ miles above the mouth. The aneroid-barometer readings, which were checked and referred to United States Geological Survey datum, indicate an elevation of 2,250 feet at the Hot Springs trail crossing, which is a short distance below Carlton Creek.

It is probable that a pressure pipe not more than 2 miles in length would make available the entire 730 feet of head listed in the table.

If the Ohanapecosh and Muddy Fork projects are developed, only a few miles of transmission line would be required to connect a small high head installation on Summit Creek with the transmission system of those plants. Hence the cost of construction and installation for power developed in this section would not be excessive, as the cost per horsepower installed would not be burdened with transmission line costs.

The minimum discharge for one week of Summit Creek at point of proposed diversion is assumed to be slightly less than the measurement which was secured October 11, 1911.

Section 10, Clear Fork, lower 8.4 miles.—Reference has been made to the proposed diversion of Clear Fork into Packwood Lake (Pl. II) as a future enlargement of the power plant in course of construction near Lewis. Surveys made by the Valley Development Co. indicate that a conduit 23 miles long would be required for this purpose. This distance could be reduced to about 8 miles if tunnels were used. In case investigation proved the cost of such conduits to be excessive, it is possible that the water from Clear Fork could be used to advantage through a separate plant located near its mouth. The conduit gradient between Packwood Lake and Clear Fork strikes the latter at an elevation of 3,190 feet 8.4 miles from the mouth and above the deep canyon referred to in section 1. A conduit 10 miles long and a penstock less than 1 mile long would be required to carry the water from the point of diversion along the left side of Clear Fork to a plant located near the mouth.

The minimum discharge of Clear Fork at mouth from 1907 to 1911 occurred September 13–19, 1909, and amounted to 51 second-feet. This represents 1.06 second-feet per square mile on the drainage area. It is conservative, therefore, to estimate that the minimum run-off for the higher area, above the proposed point of diversion, is 1.1 second-feet per square mile.

Section 11, Lake Creek.—Construction work on the development of the Lake Creek power project (fig. 1) is in progress. The project is briefly described on page 41.

A study of the records of Lake Creek, at mouth, indicates that during 1907 to 1911 the lowest minimum discharge for one week occurred in 1910 and 1911, and that there was not a great deal of difference between the two years. Therefore the minimum weekly discharge, as shown by the weir records below Packwood Lake, for 1911 has been assumed to represent the minimum available at the lake.

The ratio between the discharge at the lake and at the mouth for September 21 to December 31, 1911, averages 0.76. This factor was used to reduce the monthly run-off in acre-feet at the mouth to the probable run-off at the lake for the period covered by the records at the lower point. A mass diagram was constructed from the values derived in this manner, and the period of greatest deficiency from September, 1907, to December, 1911, was found to have occurred between March 1, 1908, and May 31, 1909. A storage of 21,000 acre-feet was shown to be required to equalize the average flow of 92 second-feet during this interval.

The actual storage required would be slightly greater than shown by a mass diagram constructed as outlined above, for the reason that monthly instead of daily values of run-off were used. It is thought, however, that 25,000 acre-feet would provide ample storage for utilizing the total run-off contributed to Packwood Lake.

Section 12, Johnson, Glacier, and Hagar creeks below elevation of 2,200 feet.—Section 12 (Pl. I) contains the second unit of the Valley Development Co.'s proposed plan. The scheme of development is described on page 41.

The minimum flow available for the Johnson Creek project was determined by weir measurements at points of proposed diversion in 1911 on Johnson Creek, Glacier Creek, and the two forks of Hagar Creek. The records on Johnson Creek at mouth show the minimum week of 1910 to have been slightly less than that of 1911. Accordingly the aggregate minimum for one week available for diversion as shown by the weir records was reduced to compare with the minimum week for 1910 at the lower station.

The period of greatest deficiency in the run-off of Johnson Creek at mouth is shown by the records to have occurred September 1 to 30, 1910. Hence the discharge available with storage in Snyder Lake was determined by studying the variation in flow of Johnson Creek at mouth during that month.

Section 13, Cispus River between elevation of 3,975 feet and a point 3 miles below the mouth of Lake Creek.—Section 13 (Pls. I and VIII, *G*) embraces the upper portion of the Cispus, which is very inaccessible with present transportation facilities. The lower end of the section is about 29 miles by wagon road and an additional 28 miles by trail from Morton, the nearest railroad terminal. The rugged character of the country would make construction work very expensive even under favorable conditions. It is evident, therefore, that the development of power in this part of the river will not prove practicable for a number of years.

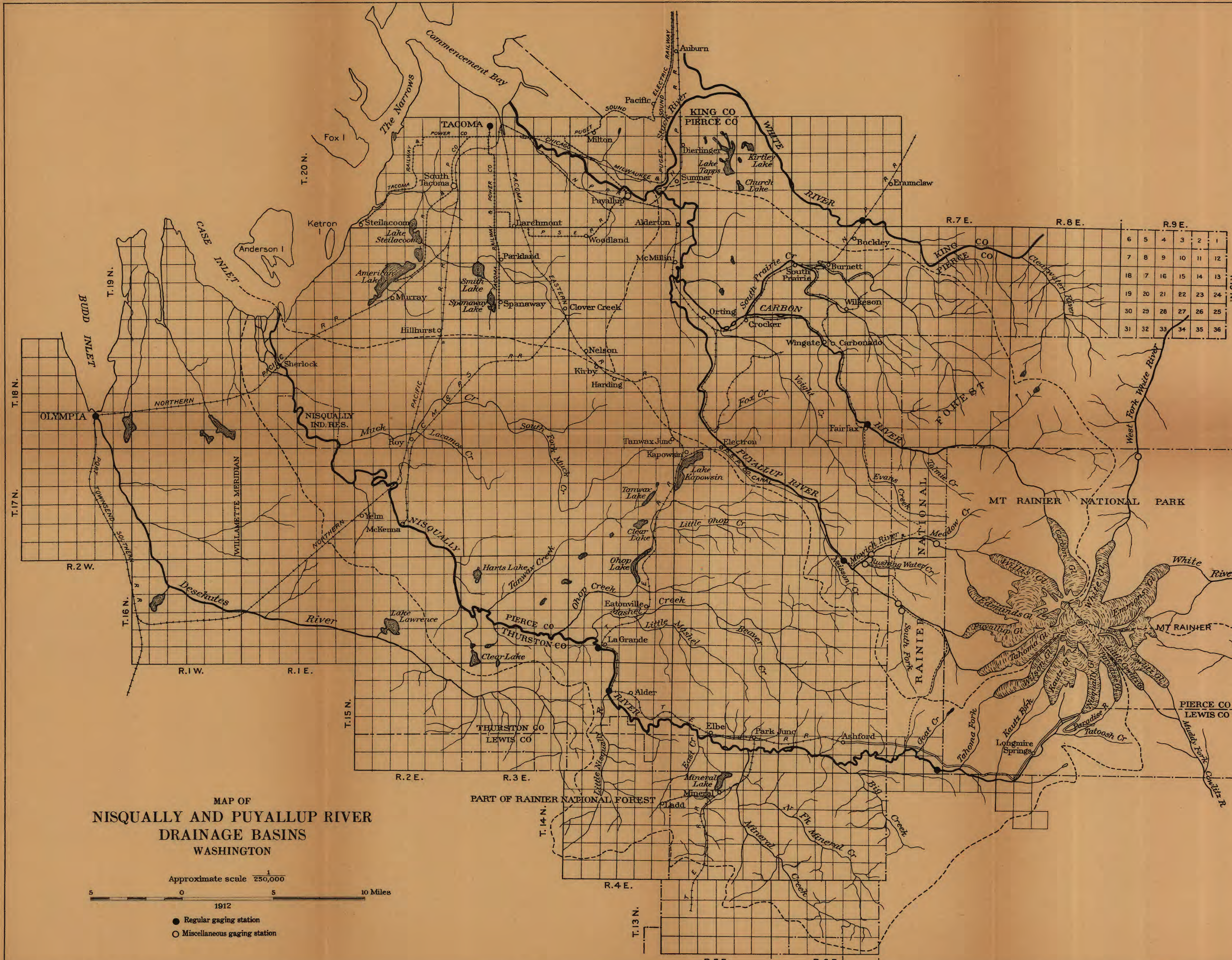
The water could be diverted from the river and small tributaries above an elevation of 3,975 feet and carried by a conduit on the left side of the valley to Walupt Lake (Pl. VIII, *G*) in a distance of 3 to 3½ miles. If the conduit were built with a capacity considerably greater than the minimum flow of the river at the point of diversion the additional supply gained thereby could be stored in Walupt Lake. A dam 50 feet high at the outlet of the lake would be about 700 feet long on top and would impound 22,700 acre-feet of water. It is estimated that 16,000 acre-feet would be sufficient to equalize the total flow of Lake Creek and the supply that would be delivered from the main stream by the conduit mentioned above. From the lake the water could be carried in a conduit and pressure pipe with an aggregate length of about 4 miles to a point on the river 3 miles below the mouth of Lake Creek where the 677 feet of head listed in the table could be realized.

Heavy rock work would be encountered in building both conduits and the sides of the valleys are so steep and rugged that it would be necessary to provide ample protection from snowslides and falling timber. Tunnels would, no doubt, prove the most satisfactory construction for the greater part of the length of the conduits if permanency were desired. Bedrock is thought to be available for the sides and foundation of the dam at the outlet of the lake. One of the difficulties to be met in building this dam is the lack of suitable material to render the structure impervious.

The minimum discharge for one week of Cispus River above Muddy Fork was estimated at 0.9 second-foot per square mile from the measurement obtained August 28, 1911, and from a comparison with the records on the river below McCoy Creek. On this basis it was assumed that the drainage area above an elevation of 3,975 feet would contribute 1 second-foot per square mile for the minimum weekly flow.

Section 14, Cispus River from Muddy Fork to Adams Creek.—Below an elevation of 3,250 feet the Cispus flattens into a broad marshy valley about 3 miles long and nearly a mile wide at the lower end (Pl. VIII, *F* and *G*.) Appearances indicate that the marsh was formerly a glacial lake and has been completely filled with glacial débris. The topography of the left side of the flat area was determined by a stadia traverse when the river survey was made. Time and funds would not permit a detailed survey of the right side, so that the topography shown by the dotted lines on that side was determined from sketches. It is thought, however, that the results obtained from measuring the areas under the contour lines shown on the river survey map will give conservative values for determining the storage made available by building a dam at a favorable site about 300 yards above the mouth of Muddy Fork. A dam 100 feet high would be about 1,400 feet long at the point indicated and would impound at least 50,000 acre-feet. If it were built 80 feet high about 28,000 acre-feet storage could be secured. The amount of storage required to equalize the total flow of Cispus River and Muddy Fork is estimated at 65,000 to 70,000 acre-feet. It is probable that a detailed survey of the reservoir site would indicate more storage than the figures given above. Natural conditions are favorable for building a hydraulic fill dam. An abundant water supply could be diverted for this purpose from Muddy Fork at low cost and it is not thought that it would prove difficult to procure sufficient suitable material for building the dam. It might be necessary, however, to provide cut-off walls to a considerable depth to intercept the underflow. The entire flow of Muddy Fork could be diverted into the reservoir by a conduit less than one-half mile long.

The dam site referred to and a water right have been filed upon, but no actual construction work has been begun. The plan of development consists of building a hydraulic fill dam about 60 feet high, which will provide approximately 14,000 acre-feet of storage. A conduit about 20 miles long is proposed on the right side of the valley to divert the water from the reservoir to the proposed power house, 3 miles above the mouth of Autus Creek. The rugged character of both sides of the valley makes it evident that a substantial and well-protected conduit on either side would be expensive and would require



Compiled from General Land Office map and U.S. Geological Survey topographic sheets

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considerable time to build. It seems doubtful whether the initial expenditure for the proposed undertaking would be warranted under present market conditions. Accordingly the lower limit of this section for the present report was placed at the mouth of Adams Creek.

Muddy Fork was surveyed for a distance of 1.8 miles to show that ample head could be secured from that stream for constructing the proposed hydraulic fill dam (Pl. VIII, *G*). The fact that the slope averages 330 feet to the mile in the distance surveyed indicates that a small high-head development could be successfully operated in conjunction with the larger unit within the section.

The minimum discharge for one week of Cispus River above Muddy Fork was estimated at 0.9 second-foot per square mile from the measurement obtained August 28, 1911, and from a comparison with the records on the river below McCoy Creek. Muddy Fork receives its water supply from the glaciers of Mount Adams and the low-water flow does not come at the same time as that contributed by the nonglacial drainage area of the upper Cispus. Therefore the minimum weekly flow below Muddy Fork was estimated at 1 second-foot per square mile.

Section 15, Cispus River between Adams Creek and Autus Creek.—It is probable that a portion of the available head listed in section 15 (Pl. VIII, *E* and *F*) would have to be sacrificed in order to secure a favorable site for a diversion dam. The construction of a conduit on either side of the valley would not be so expensive as in the foregoing section, although it is probable that the conduit would have to be somewhat longer than the distance by river.

The minimum discharge for one week of Cispus River below McCoy Creek yields 0.87 second-foot per square mile of drainage area. It was assumed that the drainage area of Cispus River below Adams Creek yields 0.9 second-foot per square mile.

Section 16, Cispus River between Autus Creek and a point 1 mile above the mouth.—The grade of Cispus River between the mouth of Autus Creek and backwater from the possible dam on Cowlitz River below the mouth of the Cispus (Pl. VIII, *E*), as described in section 5, averages 27 feet to the mile. It is probable that development of power in this section would not be feasible unless storage were provided above Muddy Fork. The left side of the valley would probably afford the best supporting ground for a conduit laid on a hydraulic gradient.

The minimum discharge for one week of Cispus River below North Fork was estimated from the records below McCoy Creek and an increase of 0.87 second-foot per square mile of additional drainage area.

NISQUALLY RIVER DRAINAGE BASIN.

GENERAL FEATURES.

The Nisqually River drainage basin embraces an area of the western slope of the Cascade Range lying about 30 miles southeast of the city of Tacoma, between the Puyallup basin to the north and the Cowlitz basin to the south (Pl. IV). It has a rather narrow drainage area of 675 square miles extending northwest and southeast. The river proper with its principal upper tributaries, Paradise and Kautz rivers, and Tahoma Fork, head at the foot of Paradise, Nisqually (Pl. V, *A*), Kautz and Tahoma glaciers (Pl. VI, *B*) lying on the south side of Mount Rainier. The river has a total length of 81 miles. It flows southward and westward from Nisqually Glacier for about 30 miles to a point near Alder, and from thence northwestward through a very tortuous channel, finally discharging into Case Inlet, the most southerly extension of Puget Sound, about 11 miles northeast of Olympia. In addition to the streams draining the glaciers, the principal tributaries are as follows: Mineral Creek and Little Nisqually River from the south and Mashel, Ohop, and Muck creeks from the north. None of these tributaries are of great economic importance on account of the very low minimum discharge which they contribute during the summer months. The approximate drainage area of the river at selected points is shown in the following table:

Drainage areas in Nisqually basin.

	Square miles.
Nisqually River at southwest corner of Mount Rainier National Park	73
Nisqually River below Mineral Creek	229
Nisqually River below Little Nisqually River	294
Nisqually River below Mashel Creek	383
Nisqually River below Muck Creek	691
Nisqually River at mouth	756
Mineral Creek at mouth	79
Mashel Creek at mouth	82
Muck Creek at mouth	107

The topography of the drainage area is varied and characteristic of glacial streams on the western side of the Cascades (Pl. III, *B*). Elevations range from 14,363 feet, the summit of Mount Rainier, to sea level. The fall of Nisqually River is practically all concentrated in a distance of 35 miles between the foot of the glaciers, 4,500 to 5,000 feet in elevation, and Lagrande, where the elevation of the river is 500 feet. This portion of the basin has been rendered very rugged and irregular by glacial and stream erosion, especially the area within and in the vicinity of Mount Rainier National Park. The main river in this section follows a high but rather uniform gradient to Alder, where it enters Lagrande Canyon (Pl. IX, *A*). Below this point a narrow channel has been cut through an andesite country rock, and the stream flows over numerous cascades to the mouth of the canyon 4 miles below, where the canyon walls rise vertically 400 feet above the water (Pl. V, *B*). Below Lagrande the grade decreases to the head of tidewater in a distance of about 35 miles. The steep valley slopes and irregular topography above the Lagrande Canyon are replaced by a flat undulating table-land characterized by shallow lakes and marshes in the lower portion of the basin.

The entire area, except the rolling lowlands extending from tidewater toward the higher plateaus, was originally covered with a dense growth of fir, hemlock, and cedar. Only a small percentage of this covering has been logged or burned off in the mountainous region, but the accessible portions of the lower areas have been almost entirely deforested during the past 40 years. In many localities where the logged-off land has not been cleared for cultivation the trees of the second growth are from 12 to 18 inches in diameter. The Mount Rainier National Park includes about 65 square miles and the Rainier National Forest 120 square miles of the upper portion of the drainage area.

The Nisqually River basin is favored with very good transportation facilities. The main lines of the Northern Pacific and the Oregon-Washington Railroad & Navigation Co. cross the lowlands and the Tacoma Eastern Railroad enters the basin at Kapowsin, follows the Ohop Creek valley to Lagrande, and from that point parallels the river to Ashford. A branch line connects Park Junction with Morton, which lies in the Cowlitz basin. Numerous roads connect the small rural towns with the railroad centers. A well-graded and well-maintained road is provided by the State and Pierce County from Tacoma to the southwest corner of Mount Rainier National Park and is joined at that point by the Government highway, which leads to Longmire Springs, and into Paradise valley. This road parallels the river from Lagrande to the foot of Nisqually Glacier.

Farming has been followed in the lower part of the basin for a number of years. Much of the lowland area is covered with a soil of sandy and gravelly texture, which is of little value for cultivation on account of its excessive drainage. Dry-farming methods could, no doubt, be used to advantage in this section, but much better results would be realized by making use of the large water supply of Nisqually River for irrigation. The diversion intakes for irrigation projects would be at such low elevations that feasible power development would not be sacrificed. It is understood that irrigation is contemplated in the region known as Yelm Prairie. No steps have been taken, however, to perfect the organization necessary for placing the scheme in operation. The bottom lands bordering the river and small creeks are very productive. Hay, oats, Canada field peas, hops, potatoes, berries, and fruits yield very good crops, and the proximity of good markets has resulted in a marked increase in land values.

A. NISQUALLY GLACIER.

Photograph copyrighted, 1909, by A. H. Baines, Parkland, Wash. Reproduced by permission.

B. NISQUALLY RIVER NEAR FOOT OF LAGRANDE CANYON.

Photograph by Kiser Photo Co., Portland, Oreg.

WATER SUPPLY.

RECORDS AVAILABLE.

The rainfall over the Nisqually River basin is a little higher and somewhat more uniform than that contributed to drainage areas lying east of the Olympic Range. This is due to the fact that the Olympic Range intercepts a portion of the moisture carried by the prevailing winds from the southwest, which otherwise would fall on these areas. The rainfall on the lower portion of the basin ranges between 50 and 60 inches. Records kept at Ashford near the park boundary, at an elevation of 1,780 feet, indicate an average annual precipitation of 70 inches. It seems probable that the mean annual precipitation is over 100 inches on Mount Rainier.

Nisqually River has long been recognized as a power stream. A reconnaissance was made and a report prepared by the Puget Sound Power Co. on the power possibilities as early as 1901, in connection with similar investigations on Puyallup River. The proximity of the Puyallup to the market center, however, led to the choice of the site of the Electron power plant instead of a development on the Nisqually.

The city of Tacoma began investigating the Lagrande project (pp. 61–62) in 1906 and began construction work on the municipal plant in 1909.

Engineers for the city established a gaging station on the river near the proposed intake in September, 1906, and later, when this gage was disturbed by backwater from construction work, installed another near the power-house site. Gage heights have been recorded, except for short intervals, to date and measurements were made by the engineers from 1906 to 1909. These data, together with measurements obtained by the United States Geological Survey in 1910 and 1911, form the basis for computing the daily discharge of the river.

A gaging station was established by the United States Geological Survey near the Mount Rainier National Park boundary in October, 1910, to determine the amount of water available for power development in the upper portion of the drainage.

Estimates of discharge resulting from observations at the stations mentioned in the foregoing paragraph are given below. For full descriptions of the stations and the results of daily observations, see Water-Supply Papers 292 and 312, Nisqually River near Ashford, Wash.

NISQUALLY RIVER NEAR ASHFORD, WASH.

Estimated monthly discharge of Nisqually River near Ashford, Wash., for 1910–11.

[Drainage area, 73 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1910.							
November	3,400	280	838	11.5	12.83	49,900	C.
December	430	152	253	3.47	4.00	15,600	B.
1911.							
January	245	152	178	2.44	2.81	10,900	B.
February	152	92	116	1.59	1.66	6,440	C.
March	280	92	145	1.99	2.29	8,920	B.
April	320	136	192	2.63	2.93	11,400	B.
May	640	245	335	4.59	5.29	20,600	B.
June	1,100	360	598	8.19	9.14	35,600	C.
July	750	260	508	6.96	8.02	31,200	C.
August	370	215	268	3.67	4.23	16,500	C.
September	800	215	336	4.60	5.13	20,000	C.
October	245	190	209	2.86	3.30	12,900	B.
November	1,800	190	473	6.48	7.23	28,100	C.
December	350	230	285	3.90	4.50	17,500	B.
The year	1,800	92	304	4.16	56.53	220,000	

NISQUALLY RIVER NEAR LAGRANDE, WASH.

Monthly discharge of Nisqually River below Little Nisqually River, near Lagrande, Wash., for 1906–1911.

[Drainage area, 294 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1906.							
September 5-30	930	320	573	1.95	1.89	29,500	B.
October	3,520	440	1,150	3.91	4.51	70,700	B.
November 1-12	4,150	730	2,230	7.59	3.39	53,200	B.
December	5,920	910	2,570	8.74	10.08	158,000	B.
1907.							
January	3,000	660	1,550	5.27	6.08	95,300	B.
February	7,020	1,690	2,880	9.80	10.20	160,000	C.
March	1,890	580	954	3.24	3.74	58,700	B.
April	4,060	960	1,810	6.16	6.87	108,000	B.
May	2,100	1,160	1,510	5.14	5.93	92,800	B.
June	1,750	660	1,080	3.67	4.10	64,300	B.
July	1,390	760	1,000	3.40	3.92	61,500	B.
August	1,330	470	718	2.44	2.81	44,100	B.
September	1,160	380	662	2.25	2.51	39,400	B.
October	620	410	520	1.77	2.04	32,000	B.
November	5,220	380	1,370	4.66	5.20	81,500	B.
The period	7,020	380	1,260	4.29	....	838,000	
1908.							
January	3,080	760	1,740	5.92	6.82	107,000	B.
February	2,170	620	1,230	4.18	4.51	70,800	B.
March	6,360	660	1,920	6.53	7.53	118,000	B.
April	7,020	810	1,990	6.77	7.55	118,000	B.
May	2,400	1,220	1,670	5.68	6.55	103,000	B.
June	2,550	1,220	1,750	5.95	6.64	104,000	B.
July	2,550	1,270	1,770	6.02	6.94	109,000	B.
August	1,480	770	967	3.29	3.79	59,500	B.
September	870	410	551	1.87	2.09	32,800	B.
October	1,320	350	568	1.93	2.22	34,900	B.
November	2,550	410	1,230	4.18	4.66	73,200	B.
December	4,060	410	1,210	4.12	4.75	74,400	B.
The year	7,020	350	1,380	4.70	64.05	1,000,000	

Monthly discharge of Nisqually River below Little Nisqually River, near Lagrande, Wash., for 1906-1911—Continued.

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1909.							
May 9-31	2,510	1,170	1,590	5.41	4.63	72,500	B.
June	3,660	1,220	1,940	6.60	7.36	115,000	B.
July	1,630	820	1,180	4.01	4.62	72,600	B.
August	945	530	738	2.51	2.89	45,400	B.
September	1,020	335	560	1.90	2.12	33,300	B.
October	570	305	386	1.31	1.51	23,700	B.
November	9,000	690	3,550	1.21	13.50	211,000	B.
December	4,420	820	1,920	6.53	7.53	118,000	B.
The period						692,000	
1910.							
January	4,330	550	1,530	5.20	6.00	94,100	B.
February	3,880	795	1,640	5.58	5.81	91,100	B.
March	10,600	1,370	3,210	10.9	12.57	197,000	B.
April	3,310	1,370	2,100	7.14	7.97	125,000	B.
May	2,710	1,170	1,660	5.65	6.51	102,000	B.
June	1,660	530	982	3.34	3.73	58,400	B.
July	1,120	610	761	2.59	2.99	46,700	B.
August	920	470	642	2.18	2.51	39,500	B.
September	606	380	483	1.64	1.83	28,700	B.
October	2,840	624	1,310	4.46	5.14	80,600	B.
November	10,500	642	2,870	9.76	10.89	171,000	B.
December	3,000	910	1,820	6.19	7.14	112,000	B.
The year	10,600	380	1,580	5.37	73.09	1,150,000	
1911.							
January	2,680	785	1,320	4.49	5.18	81,200	B
February	910	490	680	2.31	2.40	37,800	B.
March	2,070	502	1,020	3.47	4.00	62,700	B.
April	1,790	682	1,130	3.84	4.28	67,200	B.
May	4,280	1,930	2,690	9.15	10.55	165,000	B.
June 1-20	3,320	1,580	2,340	7.96	5.92	92,800	B.
September	1,650	402	751	2.55	2.84	44,700	B.
October	1,720	556	1,150	3.91	4.51	70,700	C.

MISCELLANEOUS MEASUREMENTS.

The following miscellaneous discharge measurements were made in the Nisqually River basin in 1901:

Miscellaneous discharge measurements made in Nisqually River basin in 1901.

[By J. H. Cunningham.]

Date.	Stream.	Tributary to—	Locality.	Discharge.
				Sec.-ft.
July 21	Nisqually River	Case Inlet	1 mile above Elbe	773
Oct. 4	do	do	do	352
Sept. 19	do	do	Highway bridge near Yelm Prairie.	565
Oct. 7	do	do	do	483

SUMMARY OF MINIMUM FLOW.

The discharge for the minimum day and minimum week of each year for which low-water records are available has been summarized to show the variation from year to year and the relation of the minimum values to the drainage areas. The column headed "Minimum week" is of especial importance, because it is this value that has been selected as a basis for primary power determinations.

Summary of minimum discharge by years at gaging stations in Nisqually River basin.

Stream and location.	Drainage area.	Year.	Minimum day.	Minimum week.		Discharge per square mile.	
				Date.	Discharge.	Minimum day.	Minimum week.
	Sq. miles.		Sec.-ft.		Sec.-ft.	Sec.-ft.	Sec.-ft.
Nisqually River below Mount Rainier National Park.	73	1911	92	Mar. 2-Feb. 24.	92	1.26	1.26
Nisqually River below Little Nisqually River.	294	1906	320	Sept. 9-15	477	1.09	1.62
		1907	380	Nov. 13-19	397	1.29	1.35
		1908	350	Oct. 21-27	361	1.19	1.23
		1909	305	Oct. 13-19	340	1.04	1.16
		1910	380	Sept. 7-13	400	1.29	1.36
		1911	402	Feb. 26-Mar. 4.	517	1.37	1.76

WATER POWERS.

GENERAL CONDITIONS.

The high gradient and well-sustained water supply of Nisqually River are very favorable to the development of power. The portion of the river most important for the development of power is about 35 miles from Tacoma and 60 miles from Seattle in an air line.

Below Nisqually Glacier the river flows southwesterly over a large amount of glacial detritus and crosses the southern boundary of Mount Rainier National Park in a distance of 5 miles. The course of the stream changes abruptly to westward at a point about half a mile below the boundary intersection and cuts through the southwest corner of the national park. From the glacier to the corner of the park the river falls 2,000 feet, or half of the elevation at its source, in a distance of 10.6 miles, and the gradient is over 450 feet to the mile in the upper mile of this stretch. Several reasons may be cited why it is not feasible to make use of this enormous fall in developing power: Right of way would be required through the only portion of the park that has been opened up by roads and trails. The water supply of the river and its principal confluents—Tahoma and Kautz forks—is subject to very great diurnal and seasonal fluctuation. Conduits over the rugged country would be very expensive to build and to maintain. Considerable difficulty would be experienced with ice in the conduits and pressure pipes at such a high elevation. Diversion dams would require sheet piling or cut-off walls extending to a great depth to intercept the flow of the streams. For these reasons it is not thought advisable to include the portion of the river above the southwest corner of Mount Rainier National Park in the power schedule.

TACOMA MUNICIPAL PLANT.

Aside from a small plant furnishing electric current for lighting purposes at Longmire Springs in the Mount Rainier National Park, there are no operating hydroelectric power plants in the basin. The city of Tacoma, however, is building a large power plant at Lagrande to utilize the fall in Nisqually Canyon, which will be in readiness for operation sometime during the fall of 1912. Permanency is being sought and good engineering practice is being attained in all the working parts of the system, and the project will be one of the most substantial developments in the Puget Sound region. (See Pl. VI, *A*.)

Surveys and water-supply determinations were begun in 1906 and were carried on during 1907 and 1908. Estimates and plans based upon the information obtained led to an adoption of the scheme to divert the water by means of a dam, located at a river elevation of 925 feet, 3.6 miles above Lagrande and to provide a tunnel and other conduits to a point near Lagrande, where a gross head of about 425 feet could be obtained. The construction of a temporary dam at an elevation of 931 feet was started in 1909. This dam, together with a diversion flume and temporary power house on the left side of the river, were completed in September, 1910. This temporary construction served two purposes: To divert the water past the permanent dam site and to provide power for operating the air drills to be used in the tunnel and for transporting the material from the tunnel.

The permanent dam will be of an ogee type with a batter on the upstream side of 1 to 12. The crest will be 260 feet long and will rise to 970 feet elevation, or 55 feet above bedrock. The structure will contain 8,000 cubic yards of concrete. A concrete intake provided with motor-regulated gates will divert the water into a concrete settling channel 40 feet wide, 22 feet deep, and 671 feet long, with a grade of 1.79 per cent. There will be a spillway 200 feet long at an elevation of 965 feet and two washout gates 8 feet wide by 22 feet high at the lower end of the settling channel. The floor of the concrete passageway to the tunnel entrance will be 6.5 feet higher than the settling channel floor. The tunnel was excavated through blue granite and is 1.9 miles long with a gradient of 10.6 feet to the mile. The sides and bottom of the tunnel will be lined with concrete and finished to an inside width of 8.5 feet and a height of 10 feet. The tunnel outlet will be connected to a steel pipe 10 feet in diameter, supported by a trussed steel bridge across Nisqually River. The steel pipe will deliver water to 943 feet of reenforced concrete tunnel, having a cross section 8.5 by 10 feet and a gradient of .212 per cent, leading to the artificial equalizing reservoir at Lagrande.

The reservoir will have an area of 247,000 square feet and a capacity of 69 acre-feet (3,020,000 cubic feet). It will be formed by reenforced concrete walls with an average height of 17 feet, and a maximum height of 22 feet surrounding a concrete floor provided with expansion joints and underlain with tiling for drainage purposes. A bypass will connect the supply conduit with the pressure pipes in order that sediment may be removed from the reservoir through washout gates, without shutting down the power plant. A concrete forebay, provided with motor-driven gates to be operated from the switchboard, will connect the reservoir to the pressure pipes leading to the power house, where an effective head of 420 feet will be realized. The pressure pipes will be 780 feet long and will range in size from 6 feet at the top to 4 feet at the gate valves in front of the turbines.

The primary power will be provided by four Francis inward-flow, single-discharge turbines operating on a horizontal shaft at 450 revolutions per minute. Each will have a normal capacity of 8,000 horsepower and a guaranteed efficiency of 84.5 per cent when developing 6,400 horsepower. The turbines will be regulated by oil-pressure governors and will be direct-connected to 5,000-kilovolt-ampere 3-phase 60-cycle alternating-current generators, furnishing current at 6,600 volts. The exciter equipment will consist of two 300-horsepower Allis-Chalmers impulse wheels, operating at 400 revolutions per minute. Each impulse wheel will be direct connected to 200-kilowatt 125-volt direct-current generators.

The voltage of the current generated will be stepped up to 55,000 by four bank transformers with three in a bank, delta-connected. The transformers will have a capacity of 1,667 kilovolt-amperes and will be water cooled and oil insulated. Two independent transmission lines of three wires each will transmit the energy from the plant to Tacoma, a distance of about 30 miles. Aluminum cable with 19 strands, having a conductivity equivalent to 00 copper wire, will be hung from cedar poles and cross arms by Thomas No. 4002 insulators.

POWER SITES.

Natural conditions are favorable for developing the high heads available on Nisqually River by diversion and conduits. There are several canyons along the river course that would permit realizing head by dams, but the relatively low-water supply would not warrant such a scheme of development. The topographic features, gradient, water supply, and the location of the Tacoma municipal plant have all been considered in selecting the sections of the river included in the table presented below. The summary of power shown in the table is a conservative estimate of the maximum

A. NISQUALLY RIVER AT HEAD OF LAGRANDE CANYON.

Photograph by A. H. Barnes, Parkland, Wash.

B. TAHOMA GLACIER.

Photograph by A. H. Barnes, Parkland, Wash.

amount available on the river. The actual horsepower realized in the future will, perhaps, be somewhat less than the amount shown on account of economic limitations based on detailed surveys and estimates. The sections have been numbered in order downstream and the distance above the initial point of the river surveys is given. The elevation of the water surface and the drainage area at the upper end of each section, together with the total fall and fall per mile between units, has been listed. The minimum discharge for one week has been estimated from the data presented in the preceding pages. The horsepower included represents 70 per cent of the theoretical horsepower and is derived from the known fall and estimated discharge with storage and without storage. (See Pl. IX, *A–E*, at end of volume.)

Summary of available power in the Nisqually River basin.

Stream and location.	Section No.	Distance above initial points of survey.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Minimum discharge for 1 week—Without storage. Total.	Minimum discharge for 1 week—Without storage. Per square mile.	Minimum discharge for 1 week—With storage (total).	Available horsepower, 70 per cent efficiency—Without storage.	Available horsepower, 70 per cent efficiency—With storage.
		Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Sq. miles.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*		
Nisqually River, southwest corner Mount Rainier National Park	....	70.6	1,995	.....	.....	.....	73	84	1.15	84	.....	.....
Nisqually River, 3 miles above Park Junction	1	60.1	1,445	10.5	550	52.3	139	160	1.15	160	3,670	3,670
Nisqually River, 1.5 miles below Elbe	2	52.3	1,150	7.8	295	37.8	250	290	1.16	*a* 420	3,750	3,750
Nisqually River, above Tacoma municipal dam	3	46.0	970	6.3	180	28.6	294	340	1.16	*a* 470	4,140	6,000
Nisqually River, at tailrace of Tacoma municipal plant	4	41.0	515	5.0	455	91.0	301	348	1.16	*a* 478	12,300	17,000
Nisqually River, above Tanwax Creek	5	32.0	375	9.0	140	15.5	.....	.....	.....	.....	3,860	5,310
Total	....	.....	.....	.....	.....	.....	.....	.....	.....	.....	27,700	35,700

a With 7,000 acre-feet of storage in Mineral Lake.

The physical conditions governing the development of power in the sections included in the foregoing table will be briefly described:

Section 1, Nisqually River between southwest corner of Mount Rainier National Park and a point 3 miles above Park Junction.—At the upper end of section 1 (Pl. IX, *D* and E) the river flows over a broad flood plain composed of glacial drift through which there is probably a considerable underflow. Therefore a diversion dam should be provided with sheet piling or cut-off walls extending down to the impervious stratum, in order to divert the total available water supply and to assure permanency. The information at hand concerning the topography in this section indicates that the right side of the valley would afford better supporting ground and permit the use of shorter conduit lines than the left side. In addition the Tacoma Eastern Railroad and the State and county highway on that side would facilitate construction. A more detailed examination of conditions might prove that the length of pressure pipes connecting at the lower end of the section would be longer than warranted. In that event the power listed in the table might be more economically attained by the development of smaller units with lower heads.

A gaging station is located on the river about one-half mile below the park boundary. The records at this point show a minimum for one week of 92 second-feet, February 29 to March 2, 1911. The regimen of the upper Nisqually is very similar to that of the Puyallup River at Electron. Therefore the probable minimum discharge for one week was computed by direct comparison with the records on Puyallup River, which cover a period of over three years.

Section 2, Nisqually River from a point 3 miles above Park Junction to a point 1.5 miles below Elbe.—If the available head along this section were to be recovered for power purposes by a single diversion the right side of the valley presents the more favorable location (Pl. IX, *C* and *D*). A diversion conduit on this side would be only a little longer than the river and would conveniently approach the river at the lower end of the section. The grade line of a conduit on the left side would make a long detour from the river in crossing Mineral Creek and would probably lie at a considerable distance from the river at the lower end of the section. If the left side were used, however, about 7,000 acre-feet of storage for supplementing the low-water flow could be had at Mineral Lake, which lies at an elevation of 1,411 feet. The storage could be secured by raising the surface of the lake 20 feet by a dam about 300 feet long and 30 feet high. The drainage area of the lake is small, but sufficient water for supplying the storage could be had from Mineral Creek by a diversion canal less than a mile long. If it should not prove feasible to make use of the Mineral Lake storage in this section it is possible that use might be made of the additional water supply in sections 3 and 4.

It is probable that the minimum discharge for one week would not occur at the gaging station near the park boundary at the same time that it would at the station below Little Nisqually River, on account of the high winter flow contributed by the lower drainage area. However, in order to be conservative it has been assumed that such a contingency might arise. The probable minimum flow for one week at the upper end of this section was computed by adjusting the difference in minimum weekly flow between the two gaging stations in direct ratio to the intervening drainage areas.

The increase in the flow that would result from the use of 7,000 acre-feet of storage in Mineral Lake was derived by considering the period of greatest deficiency as shown in the records below Little

Nisqually River. This occurred in September and October, 1909. The storage required to supply all deficiencies below 470 second-feet for the two months is 7,280 acre-feet. The inflow from Mineral Creek during the two months should provide the additional storage of 280 acre-feet.

Section 3, Nisqually River from a point 1.5 miles below Elbe to the Tacoma municipal dam.—A fall of 180 feet in section 3 (Pl. IX, *C*) could be utilized by constructing a dam at a point about 3½ miles below Elbe, where the Nisqually enters a narrow gorge (mile 50.3). At least 500 acre-feet of storage would be afforded by a dam raised to elevation 1,090 feet, or about 40 feet above low water. A dam of this height would be 700 feet long. A higher structure might easily be erected, but it is apparent that the right of way of the Tacoma Eastern Railroad would be submerged for a short distance. Possibly the additional head and storage thereby secured might be sufficiently valuable to warrant the expense of relocating this railroad. The determination of this point is, however, a matter of detail to be settled only after final survey and appraisal. With a 40-foot dam diurnal fluctuations in demand for power could be fairly well compensated and a draft of 500 acre-feet would lower the water in the reservoir only about 5 feet. From this dam a conduit line about 3 miles long would convey the water to a point near the upper slack-water limit of the Tacoma municipal dam.

The probable minimum flow for one week at the upper end of the section was computed by adjusting the difference in minimum weekly flow between the two gaging stations in direct ratio to the intervening drainage areas. The method of determining the increase in flow with storage in Mineral Lake is described in section 2.

Section 4.—The power in section 4 (Pl. IX, *C*) will be developed by the Tacoma municipal plant, which is in course of construction. A full description of the plant is given on pages 61–62.

The water supply available for power development is shown by the records at the gaging station below Little Nisqually River. The method of determining the increase in flow by providing storage in Mineral Lake is described in the discussion of section 2.

Section 5, Nisqually River below Tacoma municipal plant.—Within a short distance below the tailrace of the Tacoma municipal power house the grade is gradually reduced. The cost of developing power in section 5 would be excessive, and the section has been included in the table in order that the relative importance of this stretch of river may be noted.

The grade of the river averages less than 10 feet to the mile below section 5. It is evident, therefore, that the power could not be developed in competition with that available on other portions of the river. It is probable that the water supply of the river will be utilized eventually in irrigating the rolling lowlands in the lower portion of the drainage basin.

The discharge available in this section is practically the same as at the gaging station below the mouth of Little Nisqually River.

PUYALLUP RIVER DRAINAGE BASIN.

GENERAL FEATURES.

Puyallup River basin (Pl. IV) embraces an oval-shaped area of 470 square miles, extending northwest and southeast between the city of Tacoma and Mount Rainier. It lies between the basin of White River on the north and that of the Nisqually on the south, and is somewhat similar to those watersheds in general features. The Puyallup has its source at the foot of the North Tahoma and the Puyallup glaciers, which extend down the southwest slope of Mount Rainier, flows northwest for 50 miles, and empties into Commencement Bay at Tacoma.

The most important tributaries of the Puyallup are Mowich and Carbon rivers. The Mowich, which is larger than the main river above its mouth, heads in the north and south Mowich glaciers on the west side of Mount Rainier. Carbon River, which derives its name from the coal-bearing strata exposed along its course, has its headwaters in Carbon Glacier on the northwest slope of Mount Rainier and enters Puyallup River at a point 2½ miles below the town of Orting. The principal tributary of Carbon River is South Prairie Creek. This stream heads in Old Baldy Mountain near the northwest corner of Rainier National Park and enters the river from the north about 5 miles above its mouth. The following table indicates the approximate drainage area of Puyallup River and its tributaries at selected points:

Drainage areas in Puyallup River basin.

	Square miles.
Puyallup River below North Fork	23
Puyallup River below mouth of Mowich River	91
Puyallup River at Electron	125
Puyallup River below Carbon River	382
Puyallup River above Stuck River	410
Mowich River at mouth	47
Carbon River at Fairfax	79
Carbon River at mouth	224
South Prairie Creek at mouth	88

Elevations within the drainage area range from 14,363 feet at the summit of Mount Rainier to sea level at Tacoma. The feet of the glaciers lie at elevations of 4,300 to 4,700 feet. Glacial and stream erosion has rendered the upper portion of the basin very rugged and irregular. The broad gravel flood plains filled with glacial débris, noticeable on Puyallup and Mowich rivers, indicate that the glaciers have receded within recent times from a point a short distance below the junction of the two rivers to their present stand. About a mile below the mouth of Mowich River, at an elevation of 1,550 feet, the Puyallup enters a canyon which cuts through a hard, eruptive rock. This canyon is similar to but somewhat longer than the canyon on Nisqually River at Lagrande. Within it for a distance of 9 miles the river slope averages 100 feet to the mile. Between Melmont and a point 2 miles below Carbonado, a distance of 6 miles, Carbon River flows through a deep and precipitous canyon. The upper portion of the canyon has been cut through a basaltic formation, but the lower portion intercepts coal measures. The extremely rugged topography of the portion of the basin in the vicinity of Mount Rainier covers only a small percentage of the drainage area. Between the mouth of Mowich River and Electron, which is situated at the lower end of the Pullyup canyon, the ridges are high and steep but well covered with alluvial material and glacial drift. The lower portion of the basin comprises the rolling lowlands and flat areas that extend south from Puget Sound to Columbia River.

A branch line of the Northern Pacific Railway between Tacoma and Palmer Junction parallels Puyallup River from its mouth to Orting. From thence the line follows Carbon River for about 3 miles to Crocker, where it crosses that watercourse and follows South Prairie Creek; near Burnett it extends into the White River basin. The Tacoma Eastern Railroad skirts the southwestern boundary of the drainage area from Tacoma to Lake Kapowsin, near Electron. The lower portion of the basin is well provided with roads which connect the farms and logging camps with stations along the railroad.

Practically all the land free to entry has been patented, and a large proportion of it is suitable for farming when cleared. The soil covering of the lower portion of the basin, classified as "Orting loam" by A. W. Mangum, of the Department of Agriculture,[1] has a depth of 8 to 12 inches and is underlain by a mixture of alluvium and glacial deposits. Hay and grain yield large returns, and apples, pears, and cherries appear to be well adapted to the soil. Hops was the most profitable crop for a number of years, but on account of diminishing prices hay, oats, and potatoes have become the principal output of this region.

A bituminous coal of good quality[2] has been mined in the lower central portion of the Carbon River drainage area since 1881. The

[1] Mangum, A. W., Reconnaissance soil survey of the eastern part of the Puget Sound basin, Washington, 1909, p. 74.

[2] Landes, Henry, and Ruddy, C. A., Washington Geol. Survey, vol. 2, 1902, pp. 209-232.

mines are centered around the towns of Burnett, Wilkeson, Carbonado, Melmont, and Fairfax, which are all connected to the Northern Pacific by spur and branch lines of that system. All of the coal produced in this region is not suitable for coking purposes. However, the coal that contains a smaller percentage of fixed carbon is adaptable for generating steam, making gas, and for blacksmithing.

WATER SUPPLY.

RECORDS AVAILABLE.

The Puyallup River basin lies in a zone which marks the southern limit of the climatic influence of the Olympic Range. This influence operates by the intercepting of the moisture carried by the prevailing southwest winds. The mean annual precipitation at Tacoma is 43 inches, and at the mouth of the Mowich, at an elevation of 1,660 feet, it is probably about the same as at Ashford, in the Nisqually basin. Records kept at Ashford indicate a mean annual precipitation of 70 inches. The amount of rain and snow falling upon the high altitudes in the Mount Rainier National Park probably aggregates considerably over 100 inches.

Conditions on the Puyallup favor a well-maintained flow. Storage is provided by the glaciers, which melt during the summer when the run-off from the lower drainage has reached its minimum. The minimum flow of the upper portion of the river usually occurs during the cold periods, when the supply at the headwaters is frozen. The snowfall on the lower reaches of the basin is small and usually melts within a short time after falling, but depths of 6, 8, and even 10 feet are not uncommon at elevations above 1,600 feet.

A study of the water supply of Puyallup River was begun in 1901 by the Puget Sound Power Co. A gaging station was established in 1902, and records have been kept since that time. Arrangements were made with the power company in April, 1911, for engineers of the Geological Survey to obtain as frequent measurements at the station as possible and to analyze the records of back years.

A station was established on Carbon River November 23, 1910, to supplement the information obtained on Puyallup River and for use in connection with the river surveys in summarizing the available power in the basin.

PUYALLUP RIVER AT HEADWORKS NEAR ELECTRON, WASH.

This station is located about 200 yards above the intake of the Puget Sound Co.'s flume and one-fourth mile below the mouth of Mowich River. An automatic gage was installed at the gaging station, but the record is unsatisfactory because the glacial silt is rapidly deposited in the float well. The automatic records have been supplemented by three staff-gage readings a day and in the accepted records the mean of these has been used to compute the daily discharge. Though there is pronounced shifting in the channel, due to the disturbance of gravel deposits, sufficient meter measurements were made in 1911 to derive a fair degree of accuracy in the run-off records from November 11, 1910, to April 30, 1912. These measurements make possible a comparison with the daily measurements taken at the headgate of the power plant. The discharge records prior to 1911 are based on such a comparison. The measurements show some unaccountable inconsistency, especially at low-water periods, when there is no reason to believe that there occurs any marked change in channel conditions. The flow of the river during low-water periods is nearly all diverted through the power plant and an opportunity was thereby afforded to check the computed measurements at such periods with the equivalent flow indicated by the kilowatt-hour output record of the power plant. The courtesy of the Stone & Webster Management Association in furnishing this output record is gratefully acknowledged.

The daily flow record of Puyallup River at this point may be found in Water-Supply Paper 312. The following table contains the monthly estimates of flow from January, 1909, to April, 1912.

Monthly discharge of Puyallup River at headworks near Electron, Wash., for 1909–1912.

[Drainage area, 91 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1909.							
January	1,410	165	418	4.59	5.29	25,700	C.
February	495	173	273	3.00	3.12	15,200	C.
March	275	170	205	2.25	2.59	12,600	C.
April	365	166	217	2.38	2.66	12,900	C.
May	750	255	380	4.18	4.82	23,400	B.
June	1,390	495	724	7.96	8.88	43,100	B.
July	715	390	542	5.96	6.87	33,300	B.
August	820	318	451	4.96	5.72	27,700	B.
September	580	215	361	3.97	4.43	21,500	B.
October	365	136	224	2.46	2.84	13,800	C.
November	2,490	181	944	10.4	11.60	56,200	C.
December	1,190	178	368	4.04	4.66	22,600	C.
The year	2,490	136	425	4.67	63.48	308,000	
1910.							
January	860	120	264	2.90	3.34	16,200	C.
February	445	168	251	2.76	2.87	13,900	C.
March	1,830	290	671	7.37	8.50	41,300	B.
April	1,100	272	477	5.24	5.85	28,400	B.
May	940	330	533	5.86	6.76	32,800	B.
June	1,180	272	413	4.54	5.06	24,600	B.
July	800	290	554	6.09	7.02	34,100	C.
August	695	284	437	4.80	5.53	26,900	C.
September	570	154	296	3.25	3.63	17,600	C.
October	1,550	270	615	6.76	7.79	37,800	B.
November	3,200	290	873	9.59	10.70	51,900	C.
December	672	244	426	4.68	5.40	26,200	C.
The year	3,200	120	486	5.34	72.45	352,000	

Monthly discharge of Puyallup River at headworks near Electron, Wash., for 1909–1912—Continued.

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1911.							
January	580	180	319	3.51	4.05	19,600	B.
February	216	138	163	1.79	1.86	9,050	B.
March	495	130	230	2.53	2.92	14,100	B.
April	411	180	254	2.79	3.11	15,100	A.
May	1,000	251	448	4.92	5.67	27,500	A.
June	1,590	468	821	9.02	10.06	48,900	A.
July	1,410	551	766	8.42	9.71	47,100	B.
August	620	350	483	5.31	6.12	29,700	A.
September	715	205	390	4.29	4.79	23,200	A.
October	425	156	214	2.35	2.71	13,200	A.
November	2,960	150	660	7.25	8.09	39,300	C.
December	518	220	352	3.87	4.46	21,600	B.
The year	2,960	130	426	4.68	63.55	308,000	
1912.							
January	1,830	184	694	7.63	8.80	42,700	B.
February	920	262	515	5.66	6.10	29,600	A.
March	247	147	183	2.01	2.32	11,300	A.
April	338	219	264	2.90	3.24	15,700	A.
The period						99,300	

CARBON RIVER AT FAIRFAX, WASH.

The daily records at this station since November 23, 1910, may be found in Water-Supply Paper 312. The following table gives monthly estimates from November, 1910, to April, 1912:

Estimated monthly discharge of Carbon River at Fairfax, Wash.

[Drainage area, 79 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy
	Maximum.	Minimum.	Mean.	Mean per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1910.							
November 23-30	1,100	305	568	7.19	2.14	9,010	B.
December	650	255	392	4.96	5.72	24,100	B.
The period						33,100	
1911.							
January	460	155	260	3.29	3.79	16,000	A.
February	185	85	120	1.52	1.58	6,660	A.
March	405	98	191	2.42	2.79	11,700	A.
April	260	155	202	2.56	2.86	12,000	A.
May	755	220	356	4.51	5.20	21,900	A.
June	[a] 1,100	[a] 440	628	7.95	8.87	37,400	C.
July	820	405	567	7.18	8.28	34,900	B.
August	510	280	400	5.06	5.83	24,600	C.
September	[a] 460	155	287	3.63	4.05	17,100	C.
October	185	85	121	1.53	1.76	7,440	B.
November	2,840	74	668	8.46	9.44	39,700	C.
December	550	126	264	3.34	3.85	16,200	B.
The year	2,840	74	339	4.29	58.30	246,000	
1912.							
January	2,110	126	648	8.20	9.45	39,800	C.
February	962	[a] 276	599	7.58	8.18	34,500	B.
March	[a] 266	99	154	1.95	2.25	9,470	B.
April	456	122	262	3.32	3.70	15,600	B.

[a] Estimated by means of a hydrograph comparison with Puyallup River at headworks near Electron.

MISCELLANEOUS MEASUREMENTS.

The following miscellaneous discharge measurements were made in the Puyallup River basin in 1901, 1903, and 1911:

Miscellaneous discharge measurements in Puyallup River basin.

[By G. L. Parker and J. H. Cunningham.]

Date.	Stream.	Tributary to—	Locality.	Discharge.
				Sec.-ft.
Sept. 7, 1911	Puyallup River	Commencement Bay	Below South Fork	194
Sept. 15, 1901	do	do	Below Mowich River[a]	304
Jan. 18, 1903	do	do	do.[a]	250
Feb. 23, 1903	do	do	do.[a]	9,560
Sept. 7, 1911	South Fork	Puyallup River	Mouth	7.4
Sept. 6, 1911	Mowich River	do	Mount Rainier National Park boundary.	250
Do.	do	do	Above Rushing Water Creek, at elevation 1,800 feet.	285
Sept. 7, 1911	Rushing Water Creek.	Mowich River	2 miles above mouth, at elevation 2,450 feet.	2.7
Do.	do	do	Mouth	9.0

[a] The measurements were made at the Puget Sound Power Co.'s gaging station, above the proposed headworks.

SUMMARY OF MINIMUM FLOW.

The discharge for the minimum day and minimum week of each year for which low-water records are available has been summarized to show the variation from year to year and the relation of the minimum values to the drainage areas.

Summary of minimum discharge by years at gaging stations in Puyallup River basin.

Stream and location.	Drainage area.	Year.	Minimum day.	Minimum week.		Discharge per square mile.	
				Date.	Discharge.	Minimum day.	Minimum week.
	Sq. mi.		*Sec.-ft.*		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
Puyallup River at headworks	91	1909	136	Oct. 25–31	163	1.50	1.79
		1910	120	Jan. 11–17	125	1.32	1.37
		1911	130	Feb. 26–Mar. 4	137	1.43	1.51
		[a] 1912	147	Mar. 20–26	152	1.62	1.67
Carbon River at Fairfax	79	1911	74	Oct. 27–Nov. 2	87	.94	1.10

NOTE.—The minimum values are for the period Jan. 1 to Apr. 30.

WATER POWERS.

DEVELOPMENT.

The steep gradients of Puyallup and Carbon rivers, together with a fairly well maintained flow, make these streams important sources of water power. Moreover, the proximity of the drainage area to the rapidly growing market centers, Seattle and Tacoma, is conducive to an early development of the power possibilities.

The Electron power plant.—The engineers for the Puget Sound Power Co. were the first to realize the favorable conditions for generating electrical energy in the Puyallup basin. Surveys and water-supply determinations were made in 1902 and 1903. Actual construction work was begun on the Electron plant on March 1, 1903, and the first current was delivered on April 14, 1904. (See Pl. VII.)

The headworks of the Electron plant are located 0.6 mile below the mouth of Mowich River, at an elevation of 1,605 feet, and consist of a low timber diversion dam and concrete intake. The dam is 200 feet long, 12 feet high, and rests on an impervious clay and gravel formation. The crest is broad and projects only 2 or 3 feet above the natural stream bed, so that flashboards are required to regulate the volume of water entering the intake. Triple lap sheet piling, set into the hardpan and bedded in concrete, prevents an underflow through the loose gravelly stream bed. The water is led from the headworks to the equalizing reservoir along the left side of the valley by a timber flume 10.2 miles long, having a cross section 8 feet by 8 feet and a grade of 7 feet per mile. An approximate storage of 183 acre-feet is secured in the artificial equalizing reservoir by earth embankments 18 feet high. Small mud boxes with sluiceways are located a short distance below the intake to intercept the suspended material carried by the water. They have proved inadequate for that purpose, however, and it is necessary to dredge a large amount of glacial silt from the reservoir every year. The reservoir is provided with a concrete forebay, in which the upper ends of the pressure pipes are embedded in separate compartments. Four of the pressure pipes are 4 feet in diameter at the top, tapering to 3 feet at the bottom, and the exciter pipe is 12 inches in diameter throughout. The pipes are 1,700 feet in length with concrete anchorages on bedrock at 100-foot intervals and concrete supporting piers midway between the anchorages. Standpipes are located near the upper end of the steel conduits to provide for surge.

At the entrance to the power house each of the large pressure pipes branches into two smaller pipes which lead to 3,750 horsepower Pelton wheels, 10 feet 6 inches in diameter to center of cups, operating at 225 revolutions per minute under a static head of 880 feet and an effective head of 875 feet. Each of the four units consists of a revolving-field alternating-current generator placed between and directly connected with two impulse wheels, as indicated above. All four units are controlled by Lombard type L oil-operated governors. Three of the governors operate deflecting nozzles and one a deflecting hood. The nozzles are provided with needles automatically connected with the deflecting apparatus for regulating the discharge. Each generator has a rated capacity of 3,500 kilowatts and generates 60-cycle 3-phase current at a voltage of 2,300. The exciter equipment consists of two 150-kilowatt

HYDROELECTRIC PLANT ON PUYALLUP RIVER NEAR ELECTRON, WASH.

direct-current generators, generating current at 125 volts, direct-connected on one side to a 300-horsepower Pelton wheel and on the other to a 200-horsepower 3-phase induction motor. The motors serve the function of a governor, for they may operate either as motors or generators according to whether the revolutions per minute is less or greater than the synchronous speed. The voltage is stepped up for transmission in three banks of transformers, oil-insulated and water-cooled, each comprising three 2,333-kilowatt 2,300 to 55,000 volt transformers connected in delta on both sides.

Duplicate transmission lines, 22 miles long, connect the plant with a switching station at Bluffs on the Puget Sound Electric Railway line. From Bluffs single lines run 9 miles west to Tacoma and 25 miles north to Seattle. The lines are composed of three semihard-drawn 19-strand No. 0000 copper cables, spaced 6 feet and transposed one-third turn every 4 miles. Cedar poles with a minimum height of 45 feet are used. They are located 125 feet apart on tangents and 90 to 100 feet apart on curves. The transmission line of the Puget Sound Electric Railway, operating at present at 27,000 volts but designed for double that capacity, is available as a duplicate line from Bluffs to Seattle and Tacoma in case of emergency.

Difficulty has been experienced occasionally during the winter season with anchor ice in the flumes. Snowslides and falling timber have damaged the flume several times to such an extent that it was necessary to shut down the plant to make repairs. The large amount of glacial silt in the water occasions an excessive wear on the impulse wheels, but it has always been possible to make repairs and replacements during off-peak periods.

Other plants.—Investigations have been made by private parties to determine the feasibility of development below the Electron plant, but it was not learned what results were obtained.

A small hydroelectric plant located on Carbon River about one-fourth mile above Fairfax makes use of 35 feet of head and is capable of developing 300 horsepower. It formerly supplied energy for operating machinery in near-by coal mines and for lighting the town of Fairfax, but has been displaced by a steam-power plant, which is more convenient.

POWER SITES.

The high heads available, the character of the stream bed, and other physical conditions seem to favor the development of the power of Puyallup and Carbon rivers by diversion and conduit lines. The sections of the rivers adapted to the development of a maximum amount of power have been chosen and are listed below in tabular form. Topographic features, water supply, and the location of the Electron plant have been carefully considered in the selection of the respective units. The sections have been numbered consecutively in order downstream and the distance above the initial point of the river surveys is given. The elevation of the water surface and the drainage area at the upper end of each unit, together with the total fall and fall per mile between units, has been listed. The minimum discharge for one week has been estimated from the data presented in the preceding pages. The horsepower included represents 70 per cent of the theoretical horsepower and is derived from the known fall and the estimated minimum weekly discharge. (See Pl. X, *A–D*, at end of volume.)

Summary of available power in the Puyallup River basin.

Stream and location.	Section No.	Distance above initial point of survey.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Minimum discharge for one week— Without storage. Total.	Minimum discharge for one week— Without storage. Per square mile.	Minimum discharge for one week— With storage (total).	Available horsepower, 70 per cent efficiency— Without storage.	Available horsepower, 70 per cent efficiency— With storage.
		Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Sq. miles.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*		
Puyallup River below North Fork	....	30.7	a2,235	......	......	......	23	54	2.35	54	......	......
Puyallup River above mouth of Mowich River	1	26.0	1,660	4.7	575	122	44	......	......	......	2,460	2,460
Puyallup River at headworks of Electron plant	....	25.4	1,605	b.6	b55	92	91	125	1.37	125	......	......
Puyallup River at tailrace of Electron plant	2	16.0	640	9.4	965	103	125	160	1.28	240	9,580	9,580
Puyallup River at Orting	3	7.0	175	9.0	465	52	c382	390	1.02	470	5,900	8,860
Puyallup River at lower end of river survey	4	.0	74	7.0	101	14.4	......	......	......	......	3,130	3,770
Mowich River at Mount Rainier National Park boundary	....	6.5	a2,475	......	......	......	26	65	2.50	65	......	......
Mowich River at mouth	5	.0	1,660	6.5	815	125	47	......	......	......	4,200	4,200
Carbon River at Mount Rainier National Park boundary	....	25.5	2,015	......	......	......	52	59	1.13	59	......	......
Carbon River at Fairfax	6	17.0	1,310	8.5	705	83	79	86	1.09	86	3,300	3,300
Carbon River near Carbonado	7	11.8	750	5.2	560	108	89	96	1.08	96	3,820	3,820
Carbon River near Orting	8	3.0	175	8.8	575	65	224	210	.94	210	4,380	4,380
Total	....	......	......	......	......	......	......	......	......	......	36,800	40,400

a These elevations were taken from topographic maps.
b This section of the river is disregarded in the power summary.
c This area includes the Carbon River drainage area.

A brief description of the physical features and the minimum water supply of the projects outlined in the foregoing table will be given.

Section 1, Puyallup River between North Fork and Mowich River.—Puyallup River proper heads in the North Tahoma Glacier at an elevation of 4,700 feet (Pl. X, *C*). At a point about 3 miles below the Mount Rainier National Park boundary it is joined by North Fork, which has its source at the foot of Puyallup Glacier at an elevation of 4,500 feet. The elevation of the river at the park boundary is 2,775 feet and that of North Fork at the boundary intersection is 2,525 feet. Hence, in order to divert water from both streams without securing right of way in the National Park, it would be necessary to provide intakes at the elevation of 2,525 feet. It is probable, however, that the expense necessary to provide intakes on both forks would not be warranted. Therefore the upper limit of this section has been chosen below the mouth of North Fork.

The most practicable plan of development of this power privilege involves diversion along the right side of the valley to a power house located at the mouth of Mowich River. It will later be shown that the Mowich could be developed in a way that would utilize the same power house. Diversion could be made along the left bank of the Puyallup and an additional head of 55 feet could be utilized by locating the power plant down close to the headworks of the Electron development. The advantage thus gained is outweighed by certain obvious disadvantages. Left-bank diversion would involve a long detour around the mouth of South Fork, and the installation of the conduit would present certain structural difficulties and heavy costs. These features in connection with the advantage gained by using a common power house for both Puyallup and Mowich developments make the right-bank diversion plan the more feasible.

The flood plain of Puyallup River is not so wide as that of Mowich River, but the stream bed is composed of the same kind of glacial deposits. Hence, there is doubtless a considerable underflow which would necessitate cut-off walls or sheet piling below a diversion dam. The slopes on both sides of the valley are steep and heavily timbered. Probably it would be advantageous to provide a protected wood-stave pipe line to shield the conduit from snowslides and falling timber.

The minimum flow for one week was derived by comparing the measurement of September 7, 1911, with the records at the gaging station and assuming a minimum flow of 1.0 second-foot per square mile from the area between the forks and the point of measurement.

Section 2, Puyallup River from headworks to power house of the Electron plant.—The power through this section (Pl. X, *B*) has been developed by the Puget Sound Power Co. A description of the plant is given in the preceding pages.

The minimum discharge for one week is derived directly from the records at the gaging station above the headworks.

Section 3, Puyallup River from Electron power house to Orting.—The Electron power house is located at the lower end of the Puyallup Canyon. Below this point the valley broadens and the grade of the river decreases appreciably (Pls. X, *A* and *B*). The lower end of this section has been chosen at Orting rather than at the mouth of Carbon River, because supporting ground for conduits to divert water from Puyallup River below the Electron plant is lacking on both sides of the valley below Orting. There would be an advantage in diverting the water on the left side of the river, in that storage for supplementing the low-water flow of the river might be secured in Lake Kapowsin, which lies at an elevation of 570 feet, by a feed canal a little over a mile in length. The estimated area of Lake Kapowsin is 530 acres, and it is thought that the level of the lake could be raised 10 feet without damaging property rights excessively. The feasibility of this scheme could only be determined by careful surveys and estimates. It is quite probable that such detailed information would indicate that the lake level could be raised more than 10 feet. The length of conduit required between Lake Kapowsin and a plant located near Orting would be about 6½ miles. A diversion on the right side would require about 6 miles of conduit and make possible the use of the Carbon River water through the same power house.

The minimum flow for one week of Puyallup River at the headworks for January 11 to 17, 1910, represents a yield of 1.32 second-feet per square mile of drainage area. In the Nisqually basin the minimum flow for one week supplied by the drainage area between the gaging station near the park boundary and the station below Little Nisqually River is 1.16 second-feet per square mile. The minimum per square mile for the area between the headworks and Electron should be less than either of the values indicated above. Therefore it is conservative to increase the minimum flow for one week, as shown by the records at the headworks, by 1.00 second-foot per square mile to derive the probable minimum at Electron.

The flow available with 5,300 acre-feet of storage in Lake Kapowsin was obtained by a study of the low-water flow for February 2 to March 15, 1911, which is the period of greatest deficiency according to the records at the headworks. The necessary correction for the difference in drainage area between the station and the proposed point of diversion into the lake was applied, and it was found that the storage was sufficient to increase the average flow for the 42 days to 240 second-feet, which is 80 second-feet greater than the minimum flow for one week.

Section 4, Puyallup River to lower end of survey.—The grade of the river from Orting to the lower end of the survey is slightly more than 14 feet to the mile. Sites for dams to secure the available head by backing water over the flat gradient are lacking. It is evident, therefore, that it would not prove feasible to develop the power in this section with existing market limitations.

It was assumed that the water supply from both Carbon and Puyallup rivers could be realized in this section. The probable minimum flow for one week was estimated from the records at the gaging station on each river, and an allowance of 0.85 second-foot per square mile was made for the additional drainage area.

Section 5, Mowich River between Mount Rainier National Park boundary and mouth.—Mowich River is somewhat larger than Puyallup River above the junction of the two, and although river surveys were not secured it is thought best to include the possibilities of this stream in the power schedule. As right of way for conduit lines could not be readily obtained within Mount Rainier National Park, the upper limit of this section (Pl. IV) has been chosen at the park boundary line. Probably the best scheme of development would consist of diverting the water at the park boundary and carrying it on the left side of the valley to a point near the mouth, where the available head could be utilized through the same power plant in conjunction with the upper Puyallup development, described in section 2. An additional water supply could be obtained by intercepting the flow of Rushing Water Creek, a tributary of Mowich River. If the water were conducted along the right side of the valley, it would be possible to use 55 feet of head between the mouth of Mowich River and the headworks of the Electron power plant, which is not included in the table. However, detailed surveys might prove that such a plan would require an excessive length of pressure pipe.

The grade of Mowich River between the national-park boundary and the mouth, a distance of 6 miles, is uniform, and the stream flows over a broad flood plain filled with glacial débris. In several localities the flood plain is one-half mile wide and the river flows through three or four channels. The gravel is loose and no doubt permits considerable underflow, so that a diversion dam would require sheet piling or cut-off walls. The slopes on either side are very steep and densely covered with mountain hemlock and Douglas fir. Accordingly snowslides and falling timber should be anticipated. A wood-stave pipe line, laid to an hydraulic gradient and protected by an earth covering, would no doubt minimize difficulties from these sources. In addition, troubles arising from the presence of anchor ice would be less in a wood-stave pipe line than in a flume or canal. The wear on the hydraulic machinery caused by the glacial silt carried in the water from Mowich River would constitute an important item in the cost of maintenance.

The probable minimum flow for one week was derived by comparing the measurement of Mowich River at Mount Rainier National Park boundary on September 6, 1911, with the records at the gaging station on Puyallup River at the headworks.

Section 6, Carbon River between park boundary and Fairfax.—In view of the fact that the grade of Carbon River averages over 80 feet to the mile between Fairfax and Mount Rainier National Park boundary this portion of the stream has been included in the power schedule, even though the river plan and profile were only secured as far as Fairfax (Pl. X, *D*). Carbon River emerges from the national park 3 miles east of the west boundary and below this point follows the north boundary very closely to the northwest corner, which lies in the center of the river. Therefore if it were not possible to secure right of way through the park for a diversion below the boundary line it would be necessary to conduct the water on the right side of the valley. Detailed surveys and estimates would be required to determine the most feasible development in this section.

The probable minimum for one week was obtained by deducting from the minimum weekly flow, as determined by the records at Fairfax, 1.00 second-foot per square mile for the difference in drainage area between the park boundary and the gaging station.

Section 7, Carbon River between Fairfax and Carbonado.—The portion of Carbon River offering the most favorable conditions for the development of power lies within this section (Pl. X, *D*). As mentioned elsewhere, the river flows through a deep canyon for a distance of 6 miles between Melmont and a point 2 miles below Carbonado. As the intake should be located some distance above the canyon entrance in order that the diversion conduits may have good supporting ground, the upper end of the section is chosen at Fairfax. The lower limit is governed by topographic conditions which limit the distance that the water can be carried on a hydraulic gradient. The right side of the valley flattens above Carbonado, but the left side is sufficiently high to provide supporting ground to the point indicated in the table. It is probable, however, that heavy construction work would be necessary on this side for about a mile of the conduit, extending along the steep slopes between Wingate Hill and the river.

The minimum flow for one week, as shown by the records at Fairfax for 1911, occurred October 27 to November 2, and was 87 second-feet. The minimum weekly flow of Puyallup River for 1911 occurred February 26 to March 4. A comparison of the records at the two localities for this week, referred to the minimum week of January 11 to 17, 1910, on Puyallup River, indicates a probable minimum flow of 86 second-feet at the Carbon River station. The smaller value was used in the table.

Section 8, Carbon River from Carbonado to a point near Orting.—Although the upper end of this section (Pl. X, *D*) lies in the Carbonado Canyon it is thought that a diversion dam and conduit could be provided in the vicinity of Carbonado at reasonable cost. It will be noted on the river plan that a branch line of the Northern Pacific Railway parallels the river from Crocker to Wingate, which is less than a mile from the proposed diversion point. It would be necessary to carry the water on the left side of the valley to secure supporting ground and such diversion would make possible the use of water from Carbon and Puyallup rivers through separate units of the same power plant.

The estimated minimum flow for one week at the gaging station at Fairfax was increased by 1.00 second-foot per square mile for the difference in drainage area of the river between Fairfax and Carbonado to give the probable minimum flow available in this section.

WHITE RIVER DRAINAGE BASIN.

GENERAL FEATURES.

The White River drainage basin has a total area of 488 square miles and is triangular in shape. The apex of the triangle extends toward the southern portion of Puget Sound, and the base, 25 miles in length, faces the Cascade Range between Mount Rainier and Pyramid Peak, which is about 2 miles north of the Naches Pass. White River proper is formed by the junction of East Fork and West Fork at a point 20 miles north of Mount Rainier. East Fork, the larger of the two, heads at the foot of White River Glacier and flows north and then west, having a total length of about 22 miles. West Fork drains Winthrop Glacier and flows in a relatively straight line toward the junction of the two forks. Below the forks the river pursues a general westerly course for 35 miles, then makes a long detour to the south, passes through the old Stuck River channel, and empties into Puyallup River about a mile above the town of Puyallup. Originally the river divided, flowing through both Stuck and Duwamish rivers, but the latter channel has been dammed, throwing the total flow into Puyallup River. (See Pl. XI.)

Greenwater River is the largest tributary of White River. It drains the western slope of the Cascade Range and flows into the main stream 2½ miles below the forks. Clearwater Creek, which enters the main stream from the south about 10 miles below the mouth of Greenwater River, is a small stream heading in Bears Head Mountains. The approximate drainage area of the river and tributaries at selected points is as follows:

Drainage areas in White River basin.

	Square miles.
East Fork at "The Dalles"	101
White River below junction of East and West Forks	212
White River below Greenwater River	293
White River below Clearwater Creek	373
White River at Buckley	424
White River at mouth	468
Huckleberry Creek at mouth	35
West Fork at mouth	65
Greenwater River at mouth	76
Clearwater Creek at mouth	40

The topography of the basin is exceedingly diverse. The area extending toward the Cascade Range is characterized by precipitous serrated ridges intersected by numerous laterals of the larger tributaries of Greenwater River. The area adjoining the lower slopes of Mount Rainier is high and steep, but the drainage is not greatly subdivided and the ridges are not sharp or irregular. Small lakes and a number of high cirques at the headwaters of Greenwater River

Compiled from General Land Office map and U.S. Geological Survey topographic sheets owe their origin to the action of glaciers which have long since disappeared. The glacial erosion in this section, however, is small in magnitude when compared to that effected by the glaciers extending down the slopes of Mount Rainier. The valley of Greenwater River is narrow and steep with little or no detritus in the stream course, whereas the East Fork and West Fork valleys occupy broad flood plains composed of glacial drift and sand. These wide valley floors reach nearly to the mouth of Greenwater River, indicating that the glaciers extended down to that point before the period of recession began. There is a marked difference between the mountainous area and the rolling lowlands in the western portion of the basin. The dividing line crosses the watershed near the mouth of Greenwater River. Below this line the river meanders from side to side in a rather wide valley flanked by high bench lands, which slope gently upward toward the boundaries of the basin and downward toward Puget Sound. White River is unlike the other rivers heading in Mount Rainier in that there are no narrow box canyons along its course.

Elevations within the basin range from 14,363 feet at the summit of Mount Rainier to sea level. The feet of the glaciers which form the source of East and West forks lie at an elevation of about 4,700 feet and the vertical fall of those streams from the glaciers to their junction is 3,200 feet. This is equivalent to two-thirds of the elevation at the glaciers and represents an average gradient of nearly 120 feet to the mile. The gradient of the river proper averages about 44 feet to the mile from the mouth of Greenwater River to Buckley, a distance of 24 miles. Portions of the Cascade Range drained by Greenwater River reach elevations between 5,700 and 6,600 feet. A large proportion of the fall between the crest of the mountains and mouth of the river is concentrated in the small lateral tributaries within a few miles from the ridges.

Originally the entire basin, except some of the highest and most rugged peaks, was covered with heavy timber. The lowland area contained a heavy stand of Douglas fir and cedar and in the mountainous region hemlock and white fir predominated. The accessible portions of the basin have been logged off to a great extent and forest fires have greatly depleted the stand in other sections. The higher areas, however, which are the most important for regution of the water supply, have not been seriously affected by forest fires. The wooded areas below the Rainier National Forest are for the most part in private ownership and will no doubt be logged off eventually, but at present only a small proportion of the timber above Buckley has been cut. The Rainier National Forest includes 175 square miles and the Mount Rainier National Park 90 square miles of the drainage area. The area controlled in these reserves represents about 46 per cent of the total.

Agriculture is confined to the lowland areas, where a considerable portion of the logged-off land has been cleared and under cultivation for a number of years. A large area of rolling lands surrounding Buckley and Enumclaw has been classified by A. W. Mangum [1] as Buckley loam. This soil carries a large amount of organic matter, mingled with a small amount of gravel and underlain by an impervious subsoil. Oats, hay, hops, potatoes, and late fruits yield good returns when the soil is properly drained. Pasturage is good, and considerable success has been attained in dairying. The bottom lands bordering the lower sections of White River are the most productive lands in the basin, and owing to their proximity to Tacoma and Seattle improved farms are valued as high as $1,000 an acre. Intensive farming methods have been used successfully in this district for growing vegetables, blackberries, raspberries, and other small fruits.

The lower portion of the basin is well provided with railroads and highways, but the upper portion is quite inaccessible. The main lines between Seattle and Tacoma of the Northern Pacific, Oregon-Washington, and Chicago, Milwaukee & Puget Sound railways follow the Stuck and Duwamish River flats. A branch line of the Northern Pacific extends from Tacoma up Puyallup River to Orting and from thence crosses into the White River drainage. It passes through Buckley and Enumclaw and joins the main line at Palmer Junction in the Green River basin. Good wagon roads join all portions of the agricultural district with the railroad stations. A State road is being built up the White River valley from Enumclaw and about 12 miles of the construction has been completed. It is possible to reach a point about 5 miles below the mouth of Greenwater River with a team and wagon. From the end of the road a good horse trail leads up the valley and extends up East Fork into the national park and a branch trail follows Greenwater River to its headwaters.

Considerable prospecting has been done in the upper portion of the basin and especially on East Fork, where gold-bearing ledges have been located. Little development work has been done to determine the extent of the mineralization and the prospects are so inaccessible that only exceptionally rich ore could be mined profitably.

WATER SUPPLY.

RECORDS AVAILABLE.

The precipitation within the White River drainage basin varies from 35 to 40 inches on the lower course of the river to probably over 100 inches at the summit of Mount Rainier and about 70 inches

[1] Mangum, A. W., Reconnaissance soil survey of the eastern part of the Puget Sound basin, U. S. Dept. Agr., 1909.

on the crest of the Cascades. The small amount of snow that falls in the lowlands soon melts. In the higher altitudes above Greenwater River, however, about 75 per cent of the total precipitation consists of snow, which piles up to depths of 4 to 10 feet from November to April inclusive. Accordingly the minimum flow of the upper section of the river is liable to occur during the cold periods in the winter, when the snow and ice storage is at a maximum. The melting of snow by "chinook" winds occasionally causes severe floods during the fall.

White River has a distinct advantage over the other rivers heading in Mount Rainier in the fact that its glaciers have a northern exposure and that it receives the drainage from a large auxiliary basin along the Cascades which is nonglacial in character. As these glaciers are partly sheltered from the direct rays of the sun, the maximum water supply from the melting of the glacial ice occurs after the remainder of the basin has yielded practically all of its water from ice and snow storage.

The development of power in the White River basin was under consideration for a number of years before actual construction work was begun on the Lake Tapps project, the first development undertaken. The water supply for this project was investigated for some time before work was begun, but the records are not available for the public.

A gaging station was established by the United States Geological Survey at Buckley April 22, 1899, and flow measurements were made in 1899, 1900, and 1901. The station was reestablished October 1, 1910, in order that additional water-supply data might be available. Temporary gaging stations were established on Greenwater River at the mouth and White River below the forks during October, 1911, and were maintained until April, 1912.

Stream-flow determinations were begun June 8, 1910, under the direction of P. H. Hebb, to indicate the water supply of the Mud Mountain project, which Mr. Hebb controls. The observed gage heights were furnished to the United States Geological Survey, and they served as a valuable basis for determining the flow at the lower station after water was carried around the gage by the diversion flume of the Pacific Coast Power Co.

WHITE RIVER BELOW THE FORKS, NEAR ENUMCLAW, WASH.

This station was established September 6, 1911, for the purpose of determining the yield of the upper portion of the drainage area. It is located about three-eighths of a mile below the junction of East and West forks and about 10 miles below the Mount Rainier National Park boundary. The record is fragmentary but affords a fairly good measure of the low-water discharge at this point.

Discharge measurements of White River near Enumclaw, Wash., 1911–12.

Date.	Hydrographer.	Width.	Area of section.	Mean velocity.	Gage height.	Discharge.
		Feet.	*Sq. ft.*	*Feet per sec.*	*Feet.*	*Sec.-ft.*
1911.						
Sept. 6	R. C. Pierce	54	140	3.77	2.53	527
27[a]	G. L. Parker	90	443	0.72	1.98	321
27	do	Zero flow, 0.0± .2			2.	
1912.						
May 5	R. C. Pierce	55	162	4.10	2.93	664

[a] Wading measurement.

Daily gage height, in feet, and discharge, in second-feet, of White River below forks, near Enumclaw, Wash., for 1911–12.

Day.	1911		1912							
	December.		January.		February.		March.		April.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
1								500		
2					3.5	925	2.50	500		
3								490		
4								475		
5							2.40	465	2.6	540
6								450		
7								440		
8			2.6	540	3.3	835	2.30	430		
9								410		
10							2.20	395		
11							2.20	395		
12								395	3.0	700
13								395		
14			5.7	2,120			2.20	395		
15					3.4	880		395		
16	3.1	745					2.20	395		
17								380		
18								370		
19	2.6	540	3.0	700				355		
20					3.3	835	2.05	342		
21								351		
22							2.10	360		
23					3.0	700	2.15	378		
24								395		
25								410		
26	2.6	540			2.8	620	2.30	430		
27			3.7	1,020				450		
28								460		
29					2.5	500		460		
30	2.48	493	4.5	1,420			2.40	465		
31								500		
Total								13,031		
Mean								420		

NOTE.—These discharges are based on a rating curve which is well defined between 500 and 700 second-feet.

WHITE RIVER AT BUCKLEY, WASH.

This station was established April 22, 1899, at the new highway bridge, 500 feet above the Northern Pacific Railway bridge and one-half mile north of the town of Buckley, Wash., in connection with studies of power possibilities. A wire gage was installed on the guardrail of the bridge. The measurements were made from the bridge and are subject to slight irregularities on account of poor measuring conditions.

The channel shifted somewhat during the winter of 1899–1900, and again during the high-water stages in 1901–2, but evidently did not change much, if any, during 1900–1901. The extreme flood of January, 1903, shifted the channel materially, leaving it dry where the gage had been. Readings were made on temporary gages until August 31 of that year, when the station was discontinued, but they are of absolutely no value after the first week in January. Discharges can not be computed for 1902, but the gage heights give a general idea of the behavior of the stream and the length of the low-water period.

The station was reestablished October 1, 1910, at the Northern Pacific Railway bridge, where measuring conditions were better than at the highway bridge. An inclined staff gage was driftbolted to the concrete retaining wall on the left abutment of the channel span of the bridge. Measurements were made from the deck of the railroad bridge about 50 feet above the water. The channel shifted considerably at this location, but frequent measurements were made, so that good results were obtained until July 19, 1911. After this date water was diverted around the gage in the flume of the Pacific Coast Power Co., of which no record was kept until October 23. Practically the whole flow was diverted during the interval September 12 to October 29, when the inverted siphon of the new Green River water-supply system of the city of Tacoma was laid under the river channel and below the railroad bridge. The construction work altered the channel, but evidently did not affect the rating materially, as the gage readings during November 1 to 6, when all the natural flow of the river was again passing the gage, do not appear to be affected.

A gage was established June 8, 1910, by D. H. White, of Tacoma, for P. H. Hebb, in sec. 8, T. 19 N., R. 7 E., about 5 miles above the Buckley station near Mud Mountain. The gage heights and discharge values, as computed by Mr. White, were furnished to the Geological Survey and have been used to supplement the records at Buckley. A comparison of the records at the two stations during October and the fore part of November gives consistent results. It has been assumed, therefore, that the discharge as computed for the upper station is fairly accurate for the low-water period, June to September, prior to the beginning of records at Buckley.

A rating for the gage at the upper station was derived by referring to the observer's gage height for the day and the measurements of the river and determinations of the flow in the Pacific Coast Power Co.'s flume, which were made during the interval July 6 to October 28, 1911. Discharges for the period July 19 to October 31, 1911, when the water was diverted around the gage at Buckley, were computed by applying this rating to the record of gage heights at the upper station.

The following is a statement of monthly discharge estimates based on data obtained at the foregoing stations. Results in detail are published in Water-Supply Paper 312.

Monthly discharge of White River at Buckley, Wash.

[Drainage area, 424 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1899.							
April 22-30	1,680	1,470	1,540	3.63	1.22	27,500	A.
May	3,980	1,260	2,560	6.04	6.96	157,000	A.
June	6,880	2,830	4,080	9.62	10.73	243,000	A.
July	4,500	2,100	3,030	7.15	8.24	186,000	A.
August	3,040	1,310	1,650	3.89	4.48	101,000	A.
September	1,550	890	1,150	2.71	3.02	68,400	A.
October	3,490	650	1,360	3.21	3.70	83,600	A.
November	7,560	940	2,680	6.32	7.05	159,000	B.
December	14,200	1,750	4,400	10.4	11.99	271,000	C.
The period					57.44	1,300,000	
1900.							
January	13,100	1,380	3,020	7.12	8.21	186,000	C.
February	2,820	1,270	1,670	3.94	4.10	92,800	B.
March	5,280	1,490	2,240	5.28	6.09	138,000	B.
April	3,020	1,270	1,860	4.39	4.90	110,000	B.
May	3,220	1,620	2,240	5.28	6.09	138,000	A.
June	4,700	1,620	2,210	5.21	5.81	132,000	A.
July	2,120	1,170	1,510	3.56	4.10	92,800	A.
August	3,440	890	1,140	2.69	3.10	70,100	A.
September	1,270	680	836	1.97	2.20	49,700	B.
October	3,920	620	1,270	3.00	3.46	78,100	B.
November	2,820	780	1,510	3.56	3.97	89,800	B.
December	8,640	1,320	2,660	6.27	7.23	164,000	B.
The year	13,100	620	1,850	4.36	59.26	1,340,000	
1901.							
January	11,200	930	1,820	4.29	4.95	112,000	C.
February	10,400	780	1,950	4.60	4.79	108,000	C.
March	8,280	1,020	1,850	4.36	5.03	114,000	B.
April	1,900	930	1,270	3.00	3.35	75,600	B.
May	4,160	1,380	2,360	5.57	6.42	145,000	B.
June	3,440	1,490	2,140	5.05	5.63	127,000	B.
July	2,120	1,270	1,650	3.89	4.48	101,000	B.
August	1,320	780	1,060	2.50	2.88	65,200	B.
September	780	490	620	1.46	1.63	36,900	B.
October	1,620	490	584	1.38	1.59	35,900	A.
November	14,600	710	1,930	4.55	5.08	115,000	B.
December	5,900	930	1,850	4.36	5.03	114,000	C.
The year	14,600	490	1,590	3.75	50.86	1,150,000	
1910.							
June 8-30	2,910	1,340	1,700	4.01	3.43	77,600	C.
July	1,670	1,100	1,340	3.16	3.64	82,400	C.
August	1,180	732	949	2.24	2.58	58,400	C.
September	920	545	673	1.59	1.77	40,000	C.
October	3,700	870	1,580	3.73	4.30	97,200	B.
November	8,700	870	2,680	6.32	7.05	159,000	B.
December	2,500	1,090	1,710	4.03	4.65	105,000	A.
The period					27.42	620,000	
1911.							
January	2,500	850	1,380	3.25	3.75	84,800	A.
February	1,020	460	669	1.58	1.64	37,200	A.
March	2,260	460	1,060	2.50	2.88	65,200	A.
April	1,920	700	1,160	2.74	3.06	69,000	A.
May	2,630	1,330	1,840	4.34	5.00	113,000	A.
June	3,800	1,650	2,500	5.90	6.58	149,000	A.
July	2,320	963	1,550	3.66	4.22	95,300	A.
August	925	600	702	1.66	1.91	43,200	B.
September	1,210	425	634	1.50	1.67	37,700	B.
October	530	390	429	1.01	1.16	26,400	B.
November	11,100	530	2,010	4.74	5.29	120,000	B.
The period	11,100	390	1,300	3.08	41.81	946,000	

GREENWATER RIVER AT MOUTH, NEAR ENUMCLAW, WASH.

This station was established September 6, 1911, at the Christoff ranger station, a mile above the mouth of Greenwater River, in the NW. ½ sec. 11, T. 19 N., R. 9 E., Willamette meridian. As it lies below all tributaries, except a small creek that enters from the north, the records fairly well represent the entire yield of the basin. The conditions at the station are favorable for good results, but sufficient measurements have not yet been secured to produce a good rating. The records for high-water stages are approximate, but for low-water periods they are satisfactory. Monthly estimates of discharge are given below, and full data appear in Water-Supply Paper 312.

Estimated monthly discharge of Greenwater River near Enumclaw, Wash., for 1911–12.

[Drainage area, 76 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Mean per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1911.							
October	66	37	46.6	0.613	0.71	2,870	B.
November 1–14	270	37	125	1.64	.85	3,470	B.
December 12–31	245	66	163	2.14	1.59	6,470	B.
1912.							
January	1,540	56	372	4.89	5.64	22,900	C.
February	710	125	314	4.13	4.45	18,100	B.
March	[a]142	52	79.5	1.05	1.21	4,890	C.
April 1–14	265	141	185	2.43	1.26	5,140	B.

[a] Estimated by interpolation.

MISCELLANEOUS MEASUREMENTS.

The following miscellaneous discharge measurements have been made in the White River basin:

Miscellaneous discharge measurements in White River basin.

Date.	Stream.	Tributary to—	Locality.	Discharge.
				Sec.-ft.
Sept. 29, 1911	East Fork [a]	White River	¼ mile above Silver Creek	101
Sept. 28, 1911	do	do	At mouth	207
Do	West Fork	do	½ mile above Mount Rainier National Park boundary.	64
Do	do	do	½ mile above mouth	106
Oct. 6, 1901	White River	Stuck River	At Buckley	517

[a] The flow of Silver Creek was estimated at 7 second-feet and the flow of Coat Creek at 5 second-feet at the time the measurement was made. Hence the discharge of East Fork below Coat Creek was 113 second-feet.

SUMMARY OF MINIMUM FLOW.

The discharge for the minimum day and minimum week of each year for which low-water records are available has been summarized to show the variation from year to year and the relation of the minimum values to the drainage areas.

Summary of minimum discharge by years at gaging stations in White River basin.

Stream and location.	Drainage area.	Year.	Minimum day.	Minimum week.		Discharge per square mile.	
				Date.	Discharge.	Minimum day.	Minimum week.
	Sq. m.		*Sec.-ft.*		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
Greenwater River at mouth	76	1911	37	Oct. 26–Nov. 1	37	0.49	0.49
White River at Buckley	424	1899	650	Oct. 9–15	839	1.53	1.98
		1900	620	Oct. 3–9	637	1.46	1.50
		1901	490	Sept. 30–Oct. 6	501	1.16	1.18
		1910	545	Sept. 12–18	571	1.29	1.35
		1911	390	Oct. 19–25	390	.92	.92

WATER POWERS.

PROSPECT OF DEVELOPMENT.

The proximity of White River to Seattle and Tacoma, together with its fairly well sustained flow and steep gradient, constitute elements favorable to hydroelectric development. However, the lack of a large amount of concentrated fall within a small section of the river has so far rendered power development more feasible on rivers farther from the market centers. The power possibilities of the lower portion of the river have been considered by hydraulic engineers for the past ten years and several reports have been prepared which outlined favorable power projects.

DEVELOPED POWERS.

The only development which has resulted from the investigations is the installation, at Dieringer (Pl. XII, *B*), by the Pacific Coast Power Co., of a plant designed and constructed by the Stone & Webster Engineering Corporation, of Boston, Mass.[1] Construction was begun in March, 1908, and the first current was delivered in November, 1911. The water is diverted from White River at an elevation of 670 feet and is carried on the left side of the valley for 8 miles by flumes (Pl. XII, *A*) and a chain of small artificial lakes and open canals to a reservoir formed by raising the elevation of Lake Tapps

[1] The White River power development in Washington: Eng. News, Apr. 11, 1912; Eng. Record, Apr. 13, 1912

35 feet, thereby joining it with Kirtley, Church, and Crawford lakes. Below the reservoir the water is conducted by an open canal and a tunnel for a distance of a little over a mile; it is then delivered to separate pressure pipes leading to the turbines. The power plant is located at Dieringer (Pl. XII, *B*), 10 miles east of Tacoma, and the elevation of the tailrace is about 70 feet.

The diversion dam (Pl. XIII) only extends 1 foot above the natural bed of the stream and is 12 feet broad, so that heavy drift can pass over the crest without injuring the structure. Temporary flash-boards 7 feet high will be used to raise the water level during periods of low water. The dam has a rock-filled timber-crib cross section and is supported by a concrete foundation laid on an impervious hardpan and bowlder deposit 8 feet below the natural surface of the stream bed. It is 352 feet long and the ends are protected by concrete wing walls extending a considerable distance upstream.

The concrete intake is provided with suitable gates, rack bars, stop-log equipment, and sluiceways; it is joined to a wooden flume 8 feet deep, 28 feet wide, and 1.1 miles long. The flume is laid to a grade of 7 feet to the mile and has a safe capacity of 2,000 second-feet. From the flume outlet the water is carried through a series of settling basins 2 miles in length formed by constructing embankments along the river side of the flat bench lands. Washout gates have been built to care for the large amount of glacial silt which will be deposited by the water when the velocity is reduced and spillways are provided to protect the embankments. The settling basins are connected with an unlined canal 40 feet wide on the bottom and 1.3 miles long, excavated to a grade of 1 foot to the mile, below which a timber-lined conduit 2 miles long drops the water 111 feet in elevation. It is proposed to utilize 94 feet of this head in a future development. The water finally reaches the reservoir through a natural passageway 1 mile long and an excavated canal 0.6 mile long.

The Lake Tapps reservoir has a capacity of 51,000 acre-feet; it is formed by 13 embankments containing an aggregate of 600,000 cubic yards of clay and gravel, which was excavated from the outlet canal and tunnel. Puddled cores were provided wherever the foundations appeared unreliable and the material in the embankments was sprinkled and rolled to insure water-tightness. The embankments are 40 feet wide on top and are built to an inside slope of 2½ to 1 and an outside slope of 2 to 1. The dam at the outlet of Lake Tapps is 45 feet high, 600 feet long, and is the highest of the 13 embankments.

An outlet canal 45 feet wide on the bottom and 2,500 feet long, capable of carrying 3,000 second-feet, was excavated through a ridge 90 feet above the low-water flowage area of the reservoir and

A. DIVERSION FLUME OF WHITE RIVER POWER DEVELOPMENT.

Capacity, 2,000 second-feet.

B. PACIFIC COAST POWER CO.'S PLANT AT DIERINGER, WASH.

DIVERSION DAM OF WHITE RIVER POWER DEVELOPMENT DURING CONSTRUCTION.

is lined with 12-inch planking laid edgewise to prevent erosion. A forebay 125 feet wide and a concrete portal, provided with rack bars and regulating gate electrically operated from the switchboard, connect the lower end of the outlet canal to a tunnel lined with reenforced concrete and finished to an inside diameter of 12 feet. The tunnel is 2,850 feet long, is excavated to a slope of 0.004, and has a capacity of 1,500 second-feet. The regulation of the water delivered from the tunnel to the pressure pipes is effected from a gatehouse, built on a circular concrete forebay 30 feet in diameter, which is equipped with motors controlled at the switchboard.

The pressure pipes are 2,000 feet long and consist of two riveted steel pipes 8 feet in diameter at the top and 6 feet in diameter at the bottom. A single steel pipe 2 feet in diameter throughout leads to the exciter impulse wheels. Ample provision was made to reduce the surge in the pipes to a minimum. Each of the large pipes is connected to a standpipe 6 feet in diameter and 85 feet high a short distance below the tunnel forebay. In addition two air chambers 7 feet in diameter and 75 feet high, located just outside the power house, provide an air cushion for the water column and permit governing without waste. Bursting plates and 30-inch relief valves are also provided in case the valves in the air chambers fail to operate.

The primary power equipment consists of two Francis single-runner inward-flow double-discharging turbines, which have a normal rating of 18,000 horsepower at an effective head of 440 feet and are capable of developing 20,400 horsepower at the maximum head of 480 feet. They are designed for a speed of 360 revolutions per minute, are regulated by oil-pressure governors deflecting the guide vanes, and have a guaranteed efficiency of 84½ per cent at full gate opening. It is claimed that these are the largest turbines in the world.[1] Each turbine is direct-connected to 10,000-kilowatt 6,600-volt 3-phase alternating-current generators. The exciter installation consists of two 720-horsepower impulse wheels operating at 400 revolutions per minute and direct-connected to 225-kilowatt 240-volt direct-current generators.

The current from the generators is stepped up to 55,000 volts for transmission by 3,330-kilowatt oil-insulated and water-cooled transformers in two banks of three each.

Eight transmission lines lead from the power house and connect with other high tension lines of the Puget Sound Traction, Light & Power Co. Two sets of steel towers carry six of these lines for 3½ miles and in addition cedar poles are used for supporting an aggregate length of 28 miles of line. The towers are 52 feet high and are

[1] Pfau, Arnold, The largest hydraulic turbines in the world: Eng. News, Apr. 18, 1912; Eng. Record, Apr. 20, 1912.

spaced 450 feet. The minimum height of poles is 45 feet and the spacing is 120 feet.

Provision has been made in designing and constructing the power house to double the present capacity by installing two more units similar to those in use. This will require a duplicate tunnel extending from the outlet canal and a duplicate set of pressure pipes connecting the tunnel with the new turbines.

UNDEVELOPED POWERS.

The uniform gradient of White River and its broad, fairly level valley are favorable to the development of power by diversion through conduits laid to a hydraulic gradient and a realization of the available head by means of pressure pipes. In outlining the power possibilities of the river it is necessary to divide the stream into units or sections. The upper and lower limits of these sections have been chosen in accordance with topographic features, water supply, stream gradient, and the location of the Pacific Coast Power Co.'s project. The summary of power is shown in the table below and represents a conservative estimate of the maximum amount available on the river. It will be noted that the portions of East and West forks above the Mount Rainier National Park boundary are not included in the table. The isolation of the district and the difficulties to be met in construction and operation, together with the uncertainty as to whether right of way through the park could be obtained, have made it seem best to omit an estimate of the available power within the park limits. The sections chosen for the summary have been numbered in order downstream and the distance above the initial point of the river surveys is given. The elevation of the water surface and the drainage area at the upper end of each section, together with the total fall and fall per mile between units, has been listed. The minimum discharge for one week has been estimated from the data presented in the preceding pages. The estimated horsepower represents 70 per cent of the theoretical horsepower and is derived from the known fall and estimated minimum discharge for one week, with storage and without storage. (See Pl. XIV, at end of volume.)

Summary of the available power in White River basin.

Stream and location.	Section No.	Distance above initial point of survey.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Minimum discharge for one week— Without storage. Total.	Minimum discharge for one week— Without storage. Per square mile.	Minimum discharge for one week— With storage (total).	Available horsepower, 70 per cent efficiency— Without storage.	Available horsepower, 70 per cent efficiency— With storage.
		Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Sq. miles.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*		
East Fork opposite Mount Rainier National Park boundary [a]		39.2	2,575				78	96	1.23	96		
East Fork at "The Dalles"	1	34.0	2,215	5.2	360	69	101	122	1.21	122	2,740	2,740
East Fork at mouth	2	27.4	1,840	6.6	375	57	147	175	1.19	175	3,630	3,630
White River below East and West Forks and Greenwater River at elevation of 1,850 feet		27.4	1,840				282	300	1.06	300		
White River below Twin Creek	3	18.4	1,450	9.0	390	43	320	325	1.02	[b] 640	9,290	9,290
White River opposite Mud Mountain	4	4.7	800	13.7	650	47	402				16,800	33,000
White River at intake of Pacific Coast Power Co.'s flume		1.1	670				422	390	0.92	[c] 990		
Stuck River at Dieringer	5		70		600						18,600	47,100
West Fork at Mount Rainier National Park boundary		[d] 10.6	[d] 2,880				25	54	2.16	54		
West Fork at elevation of 2,400 feet	6	6.6	2,400	4.0	480	120	48	75	1.56	75	2,060	2,060
West Fork at mouth	7	0	1,840	6.6	560	85	65	90	1.38	90	3,330	3,330
Greenwater River at elevation of 2,400 feet		[d] 9.0	2,400				42	23	0.55	23		
Greenwater River at elevation of 1,850 feet	8	[d] 2.3	1,850	6.7	550	82	70	33	0.47	33	1,000	1,000
Total											57,400	102,000

[a] Below Silver Creek.
[b] With 30,000 acre-feet of storage in Scatter Creek reservoir.
[c] With 30,000 acre-feet of storage in Scatter Creek reservoir and 51,000 acre-feet of storage in Lake Tapps reservoir.
[d] These figures were taken from topographic maps.

A brief description of the salient physical features to be considered in developing power on White River as outlined in the foregoing table will be given.

Section 1, East Fork of White River, mile 39.2 to mile 34.—The upper end of this section (Pl. XIV, *A* and *B*) is placed below Silver Creek and opposite the northeast corner of Mount Rainier National Park for reasons mentioned elsewhere. The inaccessibility of the section is doubtless the greatest drawback to the development of the power listed in the table. The proposed point of diversion is 22 miles by road and an additional 17 miles by trail from Enumclaw, the nearest railroad station.

East Fork flows over a broad flood plain filled with glacial drift. It is probable that the gravel and other detritus extends to a considerable depth, so that a diversion dam anywhere along the stream course would be difficult and expensive to construct. Supporting ground for a conduit slightly longer than the distance by river could be had on either side of the valley and would approach very near to the river at the lower end of the section. The timber covering on either side is heavy, and several rugged ridges which extend toward the river would have to be tunneled or lined canals would have to be built around them.

The probable minimum flow for one week of White River below the forks was computed as outlined under section 3 and is 265 second-feet. In deriving the probable minimum flow of East Fork at Mount Rainier National Park boundary it was assumed that the flow of the two forks is proportionate to the measurements of each fork at the mouth obtained September 28, 1911, and further that the flow at the park boundary and at the mouth varies in accordance with the measurements made at those points.

Section 2, East Fork of White River, "The Dalles" to mouth.—The narrowest portion of the East Fork valley is located at "The Dalles," which form the upper limit of this section (Pl. XIV, *B*). At this point vertical rock walls 600 feet high and 1,000 feet apart rise above the valley floor. It appears likely that bedrock lies nearer the stream surface at "The Dalles" than in any other locality along the river, and therefore this should be the best location for a diversion dam. The hydraulic grade line leading from the proposed point of diversion on the left side of the river would be somewhat longer than on the right side, as it would make a long detour from the river around Huckleberry Creek. It is probable that the additional water supply gained by intercepting the flow of Huckleberry Creek would not warrant the extra length of conduit required. If the water were carried on the right side of the valley it could be used in conjunction with that from Greenwater River, as indicated under section 8. This plan of development would be advantageous from the fact that the low-water period of the two streams comes at different times. East Fork would probably contribute its minimum flow during the winter, when the flow of Greenwater River is well sustained. On the other hand, the low-water flow of Greenwater River comes in August or September, when the yield of the East Fork is high on account of the melting of the glacier.

The probable minimum flow for one week of East Fork at "The Dalles" was determined by adjusting the probable minimum weekly flow at the park boundary and at the mouth in accordance with drainage-area differences.

Section 3, White and Greenwater rivers, mile 27.4 to mile 18.4.—Greenwater River is less than three-fourths of a mile from the junction of the two forks of White River. The divide between the two streams at this point is low, and the ground is composed of gravel and loam, so that a canal could be easily and cheaply constructed to divert the water from Greenwater River at an elevation of 1,850 feet into White River proper. Good foundations for a diversion dam would probably be available on Greenwater River at the necessary elevation. Therefore it appears entirely feasible to place the upper limit of this section (Pl. XIV, *B* and *C*) at the junction of East and West forks. If it were placed below the mouth of Greenwater River it would be necessary to sacrifice 175 feet of fall, which could not be utilized economically in any other manner. A diversion dam on the main river, either below the junction of the forks or below Greenwater River, would probably require sheet piling or cut-off walls to intercept the underflow and to render the structure permanent. Supporting ground is available on either side for a conduit line, but it is thought that the alignment on the left side would be shorter.

The probable minimum flow for one week of White River below the forks was derived by a comparison of the measurement at that point made September 27, 1911, with the discharge of the river at Buckley for September 28, 1911, the difference in flow at Buckley for September 28 and during the minimum week on record, which was October 19 to 25, 1911, being also considered. The minimum flow of Greenwater River probably never occurs at the same time as that of White River. There are no records to prove this condition, however, and no available data for estimating the minimum aggregate flow of the two streams accurately. Hence the minimum flow available for this section was estimated by combining the minima as recorded and computed for the two rivers.

Section 4, White River, mile 18.4 to mile 4.7.—The power possibilities within this section (Pl. XIV, *C* and *D*) have attracted considerable attention from engineers, and the land controlling the project is owned by private parties.

The proposed diversion is located a short distance below Twin Creek at an elevation of about 1,450 feet. The water can be carried along the right side of the valley about 5 miles to a reservoir site, including a flat swamp in the drainage area of Scatter Creek. A dam about 1 mile in length would furnish approximately 30,000 acre-feet of storage. The greatest height of the dam would be about 65 feet, but for a large portion of the length the embankment would only have to be from 10 to 15 feet high. A short tunnel through a ridge extending toward the river would be necessary to connect the reservoir to pressure pipes leading to the power-plant site opposite Mud Mountain. These pipes would be about 5 miles long, but the head under which they would operate for 4 miles of the distance would be less than 75 feet. Hence it would be feasible to prevent excessive impact by providing surge tanks.

A diversion conduit on the left side of the valley would require a siphon across Clearwater Creek or would make a long detour from the river at that locality.

The minimum flow for one week recorded for White River at Buckley occurred October 19 to 25, 1911, and was 390 second-feet. The probable minimum flow for one week of White River below East and West forks and Greenwater River at an elevation of 1,850 feet was computed as outlined under section 3 and is 300 second-feet. A consideration of the minima and drainage areas at the two localities indicates a minimum discharge for one week of 0.63 second-foot per square mile of intervening drainage area. This value was used to determine the probable minimum flow for one week of White River below Twin Creek.

The flow that can be had by manipulating 30,000 acre-feet of storage in the Scatter Creek reservoir was derived by a study of the daily discharges of White River at Buckley between August 11 and November 5, 1911, making allowance for the difference in flow at the two localities. The time required to fill the reservoir, prior to the low-water period chosen, was determined by assuming that the capacity of the diversion conduit would be 1,000 second-feet. As the filling interval was found to extend only from June 20 to August 10, it is evident that the reservoir would always be full before periods of deficiency occur.

Section 5, Pacific Coast Power Co.'s plant.—The available power in this section is developed by the Pacific Coast Power Co. A description of the project is given in the preceding pages.

The minimum flow for one week was derived directly from the records at Buckley.

The continuous flow available with a storage of 30,000 acre-feet in the Scatter Creek reservoir and 51,000 acre-feet in the Lake Tapps reservoir was determined by a study of the discharge at Buckley from July 21 to November 5, 1911, which is the period of greatest deficiency on record. The flow at Buckley as affected by the Scatter Creek reservoir during both drawing and releasing periods was tabulated and used in obtaining the increase in flow with storage in Lake Tapps. The time required to fill the Lake Tapps reservoir, prior to the period of deficiency chosen, was found to extend from June 11 to July 20, 1911. Due allowance was made for the filling of the upper reservoir as indicated under section 4. The capacity of the conduit leading to Lake Tapps is 2,000 second-feet, and accordingly this value was used in computing the filling period.

The period from January 25 to March 15, 1911, also marks a period of deficiency in flow for both projects discussed under sections 4 and 5. The storage required to maintain a continuous flow of 990 second-feet for this interval was found to be 48,000 acre-feet. Both reservoirs would be full at the beginning of the interval, and it would be necessary to draw storage from each to supply the respective continuous flow values chosen. Therefore no difficulty would be experienced from this period of deficiency.

Sections 6 and 7, West Fork from Mount Rainier National Park boundary to mouth.—West Fork shows the same glacial characteristics that have been described for East Fork. The stream winds from one side to the other of a broad gravelly flood plain ranging from one-fourth to half a mile in width. The water supply is considerably smaller than that of East Fork, but the gradient is steeper. The river surveys were not extended up the smaller fork, as it is very doubtful whether it may prove economical to develop the power available along its course. It has been included in the table for comparative purposes and to indicate a possible use in conjunction with the water from East Fork through a single power plant. The gravel and other glacial material in the stream bed is coarse and the channel is subject to marked shifting, so that difficulty would be encountered in providing a suitable diversion dam. Supporting ground could be had on either side for conduits to secure the head indicated in the table for each section.

The minimum flow for one week of West Fork at Mount Rainier National Park boundary and at an elevation of 2,400 feet was derived in a manner similar to that used for the East Fork computations. The process is described under sections 1 and 2.

Section 8, Greenwater River.—Greenwater River was not included in the river surveys, but it is thought that its lower portion is of sufficient importance to warrant placing it in the summary of power. The gradient averages over 80 feet to the mile and reference has already been made under section 2 to the advantage of water supply that might be gained through a joint development of this stream with East Fork. Little difficulty should be encountered in locating a diversion dam on impervious bedrock sides and bottom. The valley is very much narrower than that of East Fork, and the slopes are steeper and more rugged. Hence the cost of a conduit line would probably be greater than along the glacial stream.

The minimum flow for one week of Greenwater River at mouth, for 1911, occurred September 26 to November 1, and was 37 second-feet. This value represents 0.49 second-foot per square mile of drainage area. Hence the minimum flow for one week at an elevation of 2,400 feet was computed by deducting from the weekly minimum at the mouth a flow of 0.49 second-foot per square mile for intervening drainage area.

GREEN RIVER DRAINAGE BASIN.

GENERAL FEATURES.

The Green River drainage basin comprises an area of 376 square miles lying in a long, narrow strip that extends east and west between Auburn and the crest of the Cascade Mountains. It is contiguous to the basin of Cedar River on the north and to that of White River on the south. The river rises in Green Pass opposite the head of

Naches River and flows westward throughout its length of 55 miles to Auburn, where it empties into Duwamish River, which in turn flows into Elliott Bay. (See Pl. XI.)

The eastern limit of the basin is marked by the peaks of the Cascade Range, which reach elevations between 5,500 and 6,000 feet. The topography is quite irregular, but the gradient of the stream is uniform and the valley rather wide, except at the headwaters. In the vicinity of Kanaskat the river has cut through a broad plateau to the level of the Duwamish Flats. At this point the fall is somewhat more concentrated than farther upstream. The upper portion of the basin is characterized by sharply incised valleys and knifelike ridges. The drainage is extensively subdivided and does not show as great evidences of former glacial action as the adjoining basin of Cedar and Greenwater rivers. The only important tributaries entering Green River are Sunday Creek and East Fork of Green River. The former really constitutes the headwaters of the river and the latter joins the main stream from the north at Eagle Gorge.

Approximate drainage areas in Green River basin.

	Square miles.
Green River below Sunday Creek	60. 1
Green River below Smay Creek	139
Green River below North Fork	217
Green River at Kanaskat	235
Green River below Newauken Creek	303
Green River at mouth	385
Sunday Creek at mouth	22. 9
North Fork at mouth	22. 5

The Green River basin was among the first drainage areas west of the Cascade Range to suffer from deforestation. The operation of the Northern Pacific Railway, the first transcontinental line to the Pacific Northwest, made practically all parts of the basin accessible to the lumbermen, and subsequent logging operations, supplemented by frequent forest fires, have greatly depleted the original forest covering. There remains, however, a stand that might be considered heavy in less densely wooded districts. Douglas fir and cedar may be found in the remote places of the lower portion of the basin and mountain hemlock is the principal stand in the mountainous section. The Rainier National Forest includes 90 square miles and the Snoqualmie National Forest 70 square miles of the drainage area. The area controlled by these reserves represents over 40 per cent of the total.

HYDRAULIC DEVELOPMENT.

The small low-water flow, lack of storage, and slight gradient render Green River relatively unimportant for power development. There are several places along the river where a moderate amount of storage could be secured by a moderately high dam. If such a dam were provided, however, the right of way of the Northern Pacific Railway would be flooded. (See Pl. XV.)

Surveys and investigations of water supply have been made by engineers to deterimne the feasibility of developing power below Kanaskat, but it is not known whether favorable reports were made. The grade of the river below Kanaskat averages over 50 feet to the mile for 10 miles. Supporting ground for conduits laid to a hydraulic gradient is not available for realizing more than about 500 feet of this fall. The discharge for the lowest week on Green River at Kanaskat, for 1911, was 130 second-feet, which is believed to have been an average minimum. Hence the project would yield 5,170 horsepower at 70 per cent efficiency.

The intake of the Tacoma gravity water-supply system is located 2 miles above Palmer Junction at a river elevation of 880 feet. An ogee type concrete dam, with a crest 150 feet long and a center height of 16 feet, intercepts the flow of the river. The water enters a concrete intake provided with hand-operated gates and is carried by tunnel through a ledge around the right end of the dam to a small settling basin provided with washout gates. Below the settling basin the water is carried by reenforced-concrete pressure pipes 7 feet in diameter and two tunnels 9 feet wide and 6½ feet high for an aggregate distance of one-half mile to a point where a reenforced concrete siphon 327 feet long is laid under the stream bed. The capacity of this section of the system is 130 second-feet. On the left side of the river a Y branch connects the siphon to two wood-stave pipe lines 5 and 6 feet in diameter. The 5-foot line will carry 65 second-feet, which is sufficient for the present needs of the city. The conduit follows the left side of Green River to the Northern Pacific Railway, where it turns southwest and parallels the railroad as far as Buckley, crossing White River through an inverted steel siphon. From Buckley the water is conducted in a westerly direction, siphoned across Puyallup River, and discharged into McMillin reservoir 1 mile west of the town of McMillin. The total length of wood-stave pipe line between the headworks and the reservoir is 24 miles. For the greater part of this distance the hydraulic gradient chosen permits the use of pipe 4 feet in diameter. The reservoir covers an area of 18.5 acres and has a capacity of 336 acre-feet (110,000,000 gallons). Another wood-stave pipe line, 4.5 feet in diameter, and 17 miles long, having a capacity of 65 second-feet, connects McMillin reservoir to the city mains.

Aside from the one possible development outlined above Green River has no valuable power sites, especially as in this region an enormous amount of power can be had cheaply. In view of the fact that the Tacoma water-supply system is designed to divert the entire low-water flow of the river, and as the feasibility of power development above the point of diversion is doubtful, it is thought that a power schedule for Green River is not warranted.

The plan and profile included in Plate XV were prepared from field data secured for the Cedar Lake quadrangle and from information obtained from a profile of the Northern Pacific Railway.

Flow records of Green River appear in Water-Supply Paper 312.

CEDAR RIVER DRAINAGE BASIN.

GENERAL FEATURES.

The Cedar River basin (Pl. XI) consists of a long, narrow area of 204 square miles, extending northeast and southwest from the southern end of Lake Washington, near Seattle, to the Cascade Range. The river heads in Yakima Pass at an elevation of 3,500 feet and flows west and a little north 45 miles to its junction with Lake Washington. Cedar Lake, which has an area of 1,200 acres, lies at an elevation of 1,555 feet and is 12 miles from the source of the river. Rex River is the only important tributary. It enters Cedar Lake from the southeast and has a total length of 8 miles.

Evidences of glaciation are very marked in the upper portion of the basin. Cedar Lake was formed through glacial agencies and the remains of terminal moraines are still noticeable below the outlet. The elevations of the peaks along the main ridge of the Cascades are from 5,300 to 5,400 feet. The mountain sides are very steep and several of the small feeders at the headwaters rise in glacial cirques.

At a point about 2 miles below Cedar Lake the river takes a very steep gradient over a number of cascades and through a narrow V-shaped valley. Within 3 miles in this section the fall averages nearly 200 feet to the mile. The topography in the vicinity of Moncton, below the steep portion of the river referred to above, indicates the likelihood that Cedar River was tributary to the South Fork of Snoqualmie River at one time. The stream bed is only a few feet lower than the divide separating the two basins.

The Cedar River basin, though close to the lumbering centers, has not suffered severely from deforestation except in the lower portion of the basin. The proportion of logged-off land to the total area is small and the section which contributes the largest water supply is still in forest. Douglas fir and cedar are particularly well adapted to the low and medium elevations within the basin, and mountain hemlock abounds over the upper and rugged slopes. The city of Seattle has acquired 117 square miles of the drainage area by condemnation, purchase, and from the Forest Service for the purpose of insuring the continued purity of water for domestic use through the gravity water-supply system. This area represents 57 per cent of the total drainage area.

Approximate drainage areas in Cedar River basin.

	Square miles.
Cedar River at outlet Cedar Lake	73.9
Cedar River at tailrace of Seattle municipal plant	82.0
Cedar River below Taylor Creek	119
Cedar River at Landsburg	149
Cedar River at Maple Valley	172
Cedar River at mouth	204
Rex River at mouth	21.9

WATER SUPPLY.

RECORDS AVAILABLE.

The first discharge data on Cedar River were those obtained by T. A. Noble for the Seattle Power Co. in 1895 to 1899. Two gaging stations were maintained, one at Clifford Bridge, near the present intake of the Seattle water-supply system, and the other at Vaughn Bridge, near Cedar Lake.

Early in 1901 the Seattle water-supply pipe line was completed and put in operation, and on March 24 of that year gage readings were begun in the pool back of the dam.

These readings have been continued and regularly reported to the Geological Survey since September, 1902. A station was also maintained at Cedar Lake for about 10 months in 1902–3. Records have also been kept by the United States Engineer Corps at Renton, near the mouth of the river.

Data for the following stations are presented in Water Supply Paper 312:

Cedar River at Vaughn bridge, near North Bend	1898–99
Cedar River at Cedar Lake, near North Bend	1902–3
Cedar River near Ravensdale	1901–2
Cedar River at Renton	1901–1903, 1906–1908

Monthly estimates of discharge at the several stations are as follows:

CEDAR RIVER AT VAUGHN BRIDGE, NEAR NORTH BEND, WASH.

This station was established June 26, 1898, by T. A. Noble, engineer for the Seattle Power Co., to replace the station at Clifford Bridge, 15 miles below. The stations were maintained simultaneously for a sufficiently long period to determine a relation between the low-water discharge at these two points. The records show the run-off from the Cedar River basin above the outlet of Cedar Lake and are directly comparable with the records obtained at Cedar Lake during 1902-3.

The gage readings for July 1 to December 31, 1898, and results of four discharge measurements have been published.[1] Additional

[1] Water-Supply Paper U. S. Geol. Survey No. 38, pp. 382-383.

gage heights were furnished to the Geological Survey by Mr. Noble for the present report. Two low-water float measurements were also made by B. E. Grant, of the Snoqualmie Falls Power Co., the notes of which have been furnished by the Seattle-Tacoma Power Co. Computations of daily and monthly discharges are presented here for the first time.

Several factors have served to introduce uncertainties into the record. There are no measurements of over 400 second-feet discharge and those at low water are somewhat erratic, owing, no doubt, to the extremely low velocities at the bridge.

The channel is said to have shifted during the high water in the winter of 1898–99, but no measurements were made to determine the extent of such shift, and therefore the relatively low discharges in March and April, 1899, are especially liable to error. On the whole, however, the record probably gives a fairly close approximation of the total run-off of the Cedar Lake basin for practically a year.

Monthly discharge of Cedar River at Vaughn Bridge, near North Bend, Wash., for 1898–99.

[Drainage area, 74 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1898.							
June 26–30	505	375	443	5.99	1.11	4,390	B.
July	355	89	203	2.74	3.16	12,500	B.
August	89	57	68.0	.919	1.06	4,180	B.
September	220	44	73.1	.988	1.10	4,350	B.
October	285	106	168	2.27	2.62	10,300	B.
November	1,180	267	610	8.24	9.19	36,300	C.
December	3,580	135	684	9.24	10.65	42,100	C.
The period						114,000	
1899.							
January	5,080	110	1,290	17.4	20.06	79,300	C.
February	3,280	350	1,110	15.0	15.62	61,600	C.
March	570	165	321	4.34	5.00	19,700	C.
April	1,760	165	590	7.97	8.89	35,100	C.
May 1–28	2,030	544	1,280	17.3	18.01	71,100	C.
The period						267,000	

CEDAR RIVER AT CEDAR LAKE, NEAR NORTH BEND, WASH.

This station was established October 17, 1902, to secure data in regard to the run-off of the upper portion of the Cedar River basin and to determine the amount of power available below Cedar Lake. It was located 800 feet below the outlet of Cedar Lake, 9 miles southeast of North Bend, Wash., and the results are directly comparable with those obtained at Vaughn Bridge in 1898–99.

Measurements were made from a cable and car. The datum of the gage was 1,542.07 feet above sea level (city of Seattle datum). Records were suspended when work was begun on the new dam of the Seattle municipal power plant.

The records at this station are excellent and much more reliable than those at Vaughn Bridge on account of more favorable conditions.

Monthly discharge of Cedar River at Cedar Lake, Wash., for 1902–3.

[Drainage area, 74 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1902.							
October 17–31	288	84	173	2.34	1.31	5,150	A.
November	1,170	198	668	9.03	10.08	39,700	A.
December	2,650	274	797	10.8	12.45	49,000	A.
1903.							
January	4,310	402	1,260	17.0	19.60	77,500	A.
February	450	198	289	3.91	4.07	16,000	A.
March	546	175	243	3.28	3.78	14,900	A.
April	718	247	414	5.59	6.24	24,600	A.
May	1,470	514	894	12.1	13.95	55,000	A.
June	1,550	466	931	12.6	14.06	55,400	A.
July	596	142	340	4.60	5.30	20,900	A.
August 1–8	132	102	116	1.57	.47	1,840	A.
The period						360,000	

CEDAR RIVER AT CLIFFORD BRIDGE, NEAR RAVENSDALE, WASH.

This station was established by T. A. Noble, for the Seattle Power Co., in connection with investigations of the power possibilities of Cedar River. It is located about one-fourth mile below the present station at the intake dam of the Seattle water-supply pipe line, and the records are therefore directly comparable with those obtained since 1901 at the latter point.

A discussion of the methods of measurement and the results obtained, together with a list of meter and float measurements and a hydrograph of discharge, have been published by Mr. Noble,[1] and a table of daily and monthly discharge has appeared in the publications of the United States Geological Survey.[2] The original notebooks and computations, which were obtained by the Geological Survey through the kindness of Mr. Noble, have been studied and revised to make them consistent with the present practice of the Survey. The gage heights are published in Water-Supply Paper 312 for the first time.

Records were suspended August 12, 1898, when three years' records had been obtained, but were resumed in September for about three weeks on account of the extreme low water. The daily discharge during the interval has been estimated by comparison with the record at Vaughn Bridge, 15 miles above Clifford Bridge, near the outlet of

[1] Trans. Am. Soc. Civil Eng., vol. 41, June, 1899, pp. 1–15.

[2] Water-Supply Paper 28, 1899, pp. 172–173, Nineteenth Ann. Rept., pt. 4, 1898, p. 502; Twentieth Ann. Rept., pt. 4, 1900, p. 517.

Cedar Lake. On the whole, this record is excellent and is probably fully as reliable as any on Cedar River.

Monthly discharge of Cedar River at Clifford Bridge, near Ravensdale, Wash., for 1895–1898.

[Drainage area, 149 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1895.							
July 25–31	193	[a] 186	190	1.28	0.33	2,640	B.
August	[a] 184	151	163	1.09	1.26	10,000	B.
September	375	151	210	1.41	1.57	12,500	A.
October	224	128	166	1.11	1.28	10,200	A.
November	213	96	141	.946	1.06	8,390	A.
December [b]	1,990	550	1,060	7.11	8.20	65,200	A.
The period						109,000	
1896.							
January	2,900	517	1,170	7.85	9.05	71,900	A.
February	2,340	635	1,210	8.12	8.76	69,600	A.
March	1,780	501	910	6.11	7.04	56,000	A.
April	1,160	517	774	5.19	5.79	46,100	A.
May	1,780	825	1,100	7.38	8.51	67,600	A.
June	2,200	1,220	1,540	10.3	11.49	91,600	B.
July	1,650	292	688	4.62	5.33	42,300	A.
August	318	182	236	1.58	1.82	14,500	A.
September	184	144	165	1.11	1.24	9,820	A.
October	203	137	159	1.07	1.23	9,780	A.
November	5,310	604	1,540	10.3	11.49	91,600	B.
December	4,680	680	2,200	14.8	17.06	135,000	B.
The year	5,310	137	975	6.55	88.81	706,000	
1897.							
January	2,860	825	1,330	8.93	10.30	81,800	A.
February	2,270	825	1,170	7.85	8.17	65,000	A.
March	1,220	608	814	5.46	6.30	50,100	A.
April	2,790	775	1,500	10.1	11.27	89,300	B.
May	1,920	875	1,410	9.46	10.91	86,700	B.
June	1,340	725	977	6.56	7.32	58,100	A.
July	2,130	473	1,010	6.78	7.82	62,100	A.
August	465	315	373	2.50	2.88	22,900	A.
September	360	282	318	2.13	2.38	18,900	A.
October	375	266	308	2.07	2.39	18,900	A.
November	4,330	295	1,270	8.52	9.51	75,600	A.
December	3,910	554	1,530	10.3	11.87	94,100	B.
The year	4,330	266	1,000	6.71	91.12	724,000	
1898.							
January	1,990	369	754	5.06	5.83	46,400	A.
February	3,560	354	1,300	8.72	9.08	72,200	A.
March	680	360	508	3.41	3.93	31,200	A.
April	1,220	354	618	4.15	4.63	36,800	A.
May	1,220	775	921	6.18	7.12	56,600	A.
June	1,040	408	724	4.86	5.42	43,100	A.
July	425	153	262	1.76	2.03	16,100	A.
August	156	108	124	.832	.96	7,620	B.
September	250	83	127	.852	.95	7,560	B.
The period						318,000	

[a] Interpolated.

[b] Maximum and minimum for Dec. 13–29. Mean for this period taken as mean for month.

NOTE.—Water was shut off at Cedar Lake, while building a temporary dam, from Nov. 4 to 26, 1895, and the observed discharges for this period as given are less than the natural. The effect of the storage on the monthly mean as given in Mr. Noble's notes was 246 second-feet, which gives 387 second-feet as the natural monthly mean, and this figure has been used in all studies of run-off conditions.

CEDAR RIVER NEAR RAVENSDALE, WASH.

This station was established by the city engineer of Seattle on March 24, 1901, the dam and pipe line having been completed and put in operation on January 10, 1901. It is located at the timber and concrete diversion dam at Landsburg station, on the Chicago, Milwaukee & Puget Sound Railway, about 3 miles north of Ravensdale on the Northern Pacific and 15 miles below Cedar Lake.

The data obtained at this station are of great value not only because of the importance of Cedar River for power and municipal supply, but because they are continuous and reliable and contribute the only long-time record on the western slope of the Cascade Mountains in Washington.

The records at the dam are directly comparable with those obtained at Clifford bridge, a short distance below, from 1895 to 1898, and together they form a 14-year record.

Monthly discharge of Cedar River near Ravensdale, Wash., for 1901–1912.

[Drainage area, 149 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1901.							
March 24-31	702	680	691	4.64	1.38	11,000	A.
April	1,010	623	759	5.09	5.68	45,200	A.
May	1,310	680	973	6.53	7.53	59,800	A.
June	1,050	680	824	5.53	6.17	49,000	A.
July	702	265	439	2.95	3.40	27,000	A.
August	260	185	207	1.39	1.60	12,700	B.
September	271	175	205	1.38	1.54	12,200	B.
October	232	175	197	1.32	1.52	12,100	B.
November	2,250	595	1,040	6.98	7.79	61,900	A.
December	2,600	532	1,120	7.52	8.67	68,900	A.
The period						360,000	
1902.							
January	2,250	455	947	6.36	7.33	58,200	A.
February	1,180	455	676	4.54	4.73	37,500	A.
March	1,050	560	745	5.00	5.76	45,800	A.
April	930	518	705	4.73	5.28	45,000	A.
May	1,310	755	1,140	7.65	8.82	70,100	A.
June	930	560	710	4.77	5.32	42,200	A.
July	1,050	325	604	4.05	4.67	37,100	A.
August	313	195	245	1.64	1.89	15,100	A.
September	525	110	211	1.42	1.58	12,600	B.
October	325	139	209	1.40	1.61	12,900	A.
November	1,220	283	837	5.62	6.27	49,800	A.
December	2,720	630	1,150	7.72	8.90	70,700	A.
The year	2,720	110	682	4.58	62.16	494,000	
1903.							
January	6,020	740	1,790	12.0	13.83	110,000	A.
February	815	448	572	3.84	4.00	31,800	A.
March	778	396	480	3.22	3.71	29,500	A.
April	890	483	653	4.38	4.89	38,900	A.
May	1,400	718	1,020	6.85	7.90	62,700	A.
June	1,310	688	980	6.58	7.34	58,300	A.
July	852	283	533	3.58	4.13	32,800	A.
August	277	130	179	1.20	1.38	11,000	A.
September	702	156	440	2.95	3.29	26,200	A.
October	1,500	205	657	4.41	5.08	40,400	A.
November	1,400	377	780	5.23	5.84	46,400	A.
December	1,400	906	1,070	7.18	8.28	65,800	A.
The year	6,020	130	764	5.13	69.67	554,000	

Monthly discharge of Cedar River near Ravensdale, Wash., for 1901–1912—Continued.

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1904.							
January	1,910	429	1,110	7.45	8.59	68,200	A.
February	1,010	436	744	4.99	5.38	42,800	A.
March	970	422	712	4.78	5.51	43,800	A.
April	1,500	623	1,030	6.91	7.71	61,300	A.
May	1,180	845	942	6.32	7.29	57,900	A.
June	1,090	736	856	5.74	6.40	50,900	A.
July	740	248	502	3.37	3.88	30,900	A.
August	295	156	183	1.23	1.42	11,300	A.
September	243	143	175	1.17	1.30	10,400	A.
October	160	126	141	.946	1.09	8,670	A.
November	970	130	359	2.41	2.69	21,400	A.
December	1,500	416	831	5.58	6.43	51,100	A.
The year	1,910	126	632	4.24	57.69	459,000	
1905.							
January	1,010	396	647	4.34	5.00	39,800	B.
February	1,010	289	557	3.74	3.90	30,900	B.
March	1,090	442	766	5.14	5.93	47,100	B.
April	890	511	644	4.32	4.82	38,300	B.
May	2,020	429	829	5.56	6.41	51,000	B.
June	1,220	416	679	4.56	5.09	40,400	B.
July	497	283	352	2.36	2.72	21,600	B.
August	277	185	243	1.63	1.88	14,900	B.
September	254	200	221	1.48	1.65	13,200	B.
October	1,260	185	734	4.93	5.68	45,100	B.
November	970	301	499	3.35	3.74	29,700	B.
December	1,090	560	756	5.07	5.84	46,500	B.
The year	2,020	185	578	3.88	52.66	418,000	
1906.							
January	1,910	595	968	6.50	7.49	59,500	A.
February	1,400	616	992	6.66	6.94	55,100	A.
March	890	497	635	4.26	4.91	39,000	B.
April	852	616	704	4.72	5.27	41,900	B.
May	702	504	566	3.80	4.38	34,800	B.
June	630	497	567	3.81	4.25	33,700	B.
July	560	254	349	2.34	2.70	21,500	B.
August	265	216	238	1.60	1.84	14,600	B.
September	307	210	230	1.54	1.72	13,700	B.
October	1,500	226	712	4.78	5.51	43,800	B.
November	11,400	546	1,930	13.0	14.50	115,000	A.
December	2,360	539	1,040	6.98	8.05	64,000	A.
The year	11,400	210	741	4.97	67.56	537,000	
1907.							
January	1,050	462	675	4.53	5.22	41,500	B.
February	3,920	830	1,470	9.87	10.28	81,600	A.
March	1,050	455	625	4.19	4.83	38,400	B.
April	1,310	553	828	5.56	6.20	49,300	B.
May	1,050	623	826	5.54	6.39	50,800	B.
June	778	344	486	3.26	3.64	28,900	B.
July	469	243	312	2.09	2.41	19,200	B.
August	313	216	246	1.65	1.90	15,100	B.
September	313	232	258	1.73	1.93	15,400	B.
October	243	210	224	1.50	1.73	13,800	B.
November	2,480	216	637	4.28	4.78	37,900	B.
December	1,600	469	868	5.83	6.72	53,400	A.
The year	3,920	210	615	4.13	56.03	445,000	
1908.							
January	970	422	680	4.56	5.26	41,800	B.
February	815	371	563	3.78	4.08	32,400	B.
March	4,500	462	1,190	7.99	9.21	73,200	A.
April	1,800	602	979	6.57	7.33	58,300	B.
May	1,090	914	1,010	6.78	7.82	62,100	B.
June	1,260	838	1,020	6.85	7.64	60,700	B.
July	970	295	553	3.71	4.28	34,000	B.
August	384	254	288	1.93	2.22	17,700	B.
September	301	248	269	1.81	2.02	16,000	B.
October	525	238	297	1.99	2.29	18,300	B.
November	890	289	548	3.68	4.11	32,600	B.
December	1,400	410	634	4.26	4.91	39,000	B.
The year	4,500	238	670	4.50	61.17	486,000	

Monthly discharge of Cedar River near Ravensdale, Wash., for 1901–1912—Continued.

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1909.							
January	1,800	504	870	5.84	6.73	53,500	B.
February	1,220	483	705	4.73	4.92	39,200	B.
March	778	497	612	4.11	4.74	37,600	B.
April	1,140	511	692	4.64	5.18	41,200	B.
May	1,260	672	933	6.26	7.22	57,400	B.
June	1,600	546	985	6.61	7.38	58,600	B.
July	525	307	429	2.88	3.32	26,400	B.
August	325	271	305	2.05	2.36	18,700	B.
September	338	265	298	2.00	2.23	17,700	B.
October	340	275	303	2.03	2.34	18,600	B.
November	6,360	575	2,060	13.8	15.40	123,000	B.
December	2,970	575	1,120	7.52	8.67	68,900	B.
The year	6,360	265	774	5.19	70.49	561,000	
1910.							
January	905	451	579	3.89	4.48	35,600	B.
February	1,160	519	695	4.66	4.85	38,600	B.
March	3,110	890	1,550	10.4	11.99	95,300	A.
April	1,620	882	1,090	7.32	8.17	64,900	A.
May	1,420	680	867	5.83	6.72	53,400	B.
June	680	405	501	3.36	3.75	29,800	B.
July	477	247	316	2.12	2.44	19,400	B.
August	263	200	226	1.52	1.75	13,900	B.
September	347	215	265	1.78	1.99	15,800	B.
October	755	334	468	3.14	3.62	28,800	B.
November	3,380	457	1,280	8.59	9.58	76,200	A.
December	1,060	512	792	5.32	6.13	48,700	B.
The year	3,380	200	719	4.83	65.47	520,000	
1911.							
January	1,240	505	724	4.86	5.60	44,500	B.
February	610	444	527	3.54	3.69	29,300	B.
March	526	405	490	3.29	3.79	30,100	B.
April	717	347	454	3.05	3.40	27,000	B.
May	1,720	717	995	6.68	7.70	61,200	A.
June	1,100	386	689	4.62	5.16	41,000	B.
July	418	253	343	2.30	2.65	21,100	B.
August	347	215	254	1.70	1.96	15,600	B.
September	411	241	293	1.97	2.20	17,400	B.
October	316	215	267	1.79	2.06	16,400	B.
November	13,600	253	1,760	11.8	13.17	105,000	A.
December	1,060	610	800	5.37	6.19	49,200	B.
The year	13,600	215	632	4.24	57.57	458,000	
1912.							
January	2,380	498	1,090	7.32	8.44	67,000	A.
February	1,720	755	1,100	7.38	7.96	63,300	A.
March	830	373	514	3.45	3.98	31,600	B.
April	645	431	542	3.64	4.06	32,300	B.

CEDAR RIVER AT RENTON, WASH.

This station was established by the United States Engineer Department in February, 1901, and maintained by it in connection with studies of the proposed Lake Washington canal. The measurements and gage readings have been furnished by the United States Engineer Office, Seattle, but the computation of daily and monthly discharge has been made by the United States Geological Survey. The records at this point show the total run-off from the Cedar River drainage basin. There is a tributary area of 55 square miles below the Ravensdale station, practically all being of low relief.

The channel evidently shifts materially during floods, but a large number of measurements have been made, which define the ratings for about three years altogether. No discharges have been computed for periods when there is any uncertainty, as better estimates can be made by comparison with the Ravensdale record. The daily discharges as published are believed to be fully reliable.

Monthly discharge of Cedar River at Renton, Wash., for 1901–1907.

[Drainage area, 204 square miles.]

Month.	Discharge in second-feet.				Run-off.		Accuracy.
	Maximum.	Minimum.	Mean.	Per square mile.	Depth in inches on drainage area.	Total in acre-feet.	
1901.							
March 1-31	1,400	890	1,050	5.15	4.21	45,800	A.
April	1,260	636	944	4.63	5.17	56,200	A.
May	1,480	714	1,010	4.95	5.71	62,100	A.
June	1,100	773	900	4.41	4.92	53,600	A.
July	760	295	504	2.47	2.85	31,000	A.
August	286	158	205	1.00	1.15	12,600	A.
September	276	121	173	.848	.95	10,300	A.
October	535	115	161	.789	.91	9,900	A.
November	2,770	572	1,170	5.74	6.40	69,600	A.
December	2,940	676	1,280	6.27	7.23	78,700	A.
The period					39.50	430,000	
1902.							
January	2,770	792	1,320	6.47	7.46	81,200	A.
February	1,480	494	942	4.62	4.81	52,300	A.
March	1,180	773	948	4.65	5.36	58,300	A.
April	1,030	734	845	4.14	4.62	50,300	A.
September	395	114	179	.877	.98	10,700	A.
October	275	134	195	.956	1.10	12,000	A.
November	810	280	567	2.78	3.10	33,700	A.
The period					27.43	298,000	
1903.							
May 14-31	1,530	990	1,190	5.83	3.90	42,500	A.
June	1,460	870	1,100	5.39	6.01	65,500	A.
July 1-15	990	708	849	4.16	2.32	25,300	A.
The period					12.23	133,000	
1906.							
September	370	213	250	1.23	1.37	14,900	A.
October	1,380	165	608	2.98	3.44	37,400	A.
November	5,650	675	1,740	8.53	9.52	104,000	B.
December	2,840	635	1,130	5.54	6.39	69,500	A.
The period					20.72	226,000	
1907.							
January	1,610	655	1,080	5.29	6.10	66,400	A.
February	4,890	1,450	2,250	11.0	11.45	125,000	A.
March	1,690	860	1,100	5.39	6.21	67,600	A.
April	1,930	860	1,280	6.27	7.00	76,200	A.
May	1,380	1,000	1,160	5.69	6.56	71,300	A.
June	1,080	465	705	3.46	3.86	42,000	A.
July	525	300	369	1.81	2.09	22,700	A.
August	355	205	256	1.25	1.44	15,700	A.
September	355	250	281	1.38	1.54	16,700	A.
October	300	205	234	1.15	1.33	14,400	A.
November	3,010	250	771	3.78	4.22	45,900	A.
December	2,840	1,150	1,620	7.94	9.15	99,600	B.
The year	3,010	205	916	4.49	60.95	664,000	

SUMMARY.

From the foregoing data tables have been compiled showing the mean monthly discharge from 1895 to 1912, and the average for the lowest week for 1895 to 1898 and 1901 to 1904, for Cedar River at Ravensdale.

No records of Cedar River are available from June, 1899, to March, 1901, but this gap has been filled by comparison with the station on White River at Buckley, from which approximate estimates can be made. Simultaneous records were kept on the two stations from April to December, 1901, and from June, 1910, to November, 1911, and the comparison of the mean monthly discharge is given below.

Comparison of monthly discharge, in second-feet, of White River at Buckley and Cedar River at Ravensdale, Wash.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901.												
Cedar River	......	......	......	759	973	824	439	207	205	197	1,040	1,120
White River	......	......	......	1,270	2,360	2,140	1,650	1,060	620	584	1,930	1,850
Per cent	......	......	......	60	41	39	27	20	30	30	54	61
1910-11.												
Cedar River	724	527	490	454	995	689	......	......	......	468	1,280	792
White River	1,380	669	1,060	1,160	1,840	2,500	......	......	......	1,580	2,680	1,710
Per cent	52	79	46	39	54	28	......	......	......	30	48	46

The comparisons for July to September, 1910, and July to November, 1911, are vitiated by the influence of storage on Cedar Lake on the flow at Ravensdale and can not be used.

The average of the ratios for November to May, inclusive, is 53 per cent; the individual months show some variation from this, but for a series of three or four consecutive months the use of this ratio to reduce the White River discharge should give a fairly close approximation to the probable flow of the Cedar.

The mean of the ratios for June, July, September, and October is 30 per cent, and this has been used for these four months, but for August, 20 per cent. The monthly mean discharges from October, 1898, to May, 1899, were estimated from the Vaughn bridge records by reversing the process used for computing the discharge at Cedar Lake from that at the Ravensdale station as outlined on page 111.

Beginning with 1905 the flow of Cedar River has been controlled by the dam of the Seattle municipal power plant at the outlet of Cedar Lake, and as no record of storage on the lake is available the reduction to natural flow can not be made and the minimum day or week of natural flow can not be computed. The minimum varies greatly from year to year, the lowest weekly average recorded for 1898 having been only 31 per cent of the highest corresponding value which occurred during the preceding year.

The variation in yearly means is much smaller; the lowest year on record, 1905, has an average discharge of 578 second-feet, or 58 per cent of that observed in 1897, 1,000 second-feet, and 52 per cent of the estimated mean for 1899.

Monthly discharge, in second-feet, of Cedar River near Ravensdale, Wash.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1895	......	......	......	......	......	......	......	163	210	166	387	1,060	....
1896	1,170	1,210	910	774	1,100	1,540	688	236	165	159	1,540	2,200	975
1897	1,330	1,170	814	1,500	1,410	977	1,010	373	318	308	1,270	1,530	1,000
1898	754	1,300	508	618	921	724	262	124	127	306	762	1,000	617
1899	1,840	1,590	566	888	1,510	1,220	909	330	345	408	1,420	2,330	1,110
1900	1,600	885	1,190	986	1,190	663	453	228	251	381	800	1,410	836
1901	964	1,030	980	759	973	824	439	207	205	197	1,040	1,120	728
1902	947	676	745	705	1,140	710	604	245	211	209	837	1,150	682
1903	1,790	572	480	653	1,020	980	533	179	440	657	780	1,070	764
1904	1,110	744	712	1,030	942	856	502	183	175	141	359	831	632
1905	647	557	766	644	829	679	352	243	221	734	499	756	578
1906	968	992	635	704	566	567	349	238	230	712	1,930	1,040	741
1907	675	1,470	625	828	826	486	312	246	258	224	637	868	615
1908	680	563	1,190	979	1,010	1,020	553	288	269	297	548	634	670
1909	870	705	612	692	933	985	429	305	298	303	2,060	1,120	774
1910	579	695	1,550	1,090	867	501	316	226	265	468	1,280	792	719
1911	724	527	490	454	995	689	343	254	293	267	1,760	800	632
1912	1,090	1,100	514	542	......	......	......	......	......	......	......	......	....

Summary of minimum discharge by years at gaging stations on Cedar River.

Location.	Drainage area.	Year.	Minimum day.	Minimum week.		Discharge per square mile.	
				Date.	Discharge.	Minimum day.	Minimum week.
	Sq. miles.		*Sec.-ft.*		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
Vaughn bridge	74	1898	44	Sept. 9–15	44.9	0.595	0.607
Clifford bridge	149	1895	128	Oct. 26–Nov. 1	135	.859	.906
		1896	137	Oct. 22–28	145	.920	.973
		1897	266	Oct. 5–11	275	1.79	1.85
		1898	83	Sept. 13–19	86.9	.557	.583
		1901	175	Sept. 30–Oct. 6	175	1.17	1.17
		1902	110	Sept. 20–26	126	.738	.846
		1903	130	Aug. 17–23	133	.872	.893
		1904	126	Oct. 23–29	131	.846	.879

WATER POWERS.

DEVELOPMENT.

The availability of a large amount of storage on Cedar Lake and a very steep gradient for a few miles below the lake are elements which brought about an early investigation of the water-power possibilities of Cedar River. Stream-flow investigations were begun in 1895 by engineers for the city of Seattle and for private interests at the same time the Snoqualmie Falls project was under consideration, but construction work was not started until nearly two years after that on Snoqualmie River. (See Pl. XVI.)

Work was begun on the Seattle municipal plant in April, 1902, and the first current was delivered January 10, 1905. The development utilizes 610 feet gross head in a distance of about 3 miles by river and a storage of 23,000 acre-feet on Cedar Lake to supplement the low-water flow of the river. The headworks consist of a rock-filled timber-crib dam, located one-half mile below the original outlet of the lake, which raises the water surface of the lake 18 feet, or 21 feet including the height of flashboards. The foundations of the structure are laid 15 feet below the original stream bed and rest on a clay and gravel formation. Two wood-stave pipe lines 4 feet and 5.7 feet in diameter, laid to a uniform hydraulic gradient, lead from the dam along the right side of the river for a distance of 3.1 miles to the top of the hill above the power plant. They were placed in trenches and backfilled with earth to protect them from falling timber, snowslides, etc. Steel pressure pipes 4 feet in diameter and 951 feet long join each of the conduits to the impulse wheels and turbines in the power house. Standpipes 2 feet in diameter and 60 feet high are connected to each pressure pipe near the upper end and release valves are also provided to relieve excessive pressure due to surge.

The smaller pipe delivers water to the initial installation, which consists of two Pelton water wheels with a rated capacity of 2,400 horsepower direct-connected to 1,200-kilowatt 2,300-volt 60-cycle 3-phase alternating-current generators operating at 400 revolutions per minute. Replogle governors regulate the speed by deflecting the wheel nozzles and by operating a needle valve. Two 150-horsepower Pelton wheels, direct-connected to 75-kilowatt 125-volt direct-current generators, furnish the excitation. In 1908 the large pipe line was built and two more units were installed. Inward-discharge Francis turbines operate at a speed of 600 revolutions per minute and are direct-connected to Westinghouse alternating-current generators. Each turbine has a rated capacity of 8,000 horsepower and is regulated by Lombard governors, which deflect the angle of the vanes. The generators furnish 4,000 kilowatts of 3-phase 60-cycle 2,300-volt current at full normal load. The exciter equipment consists of one 300-horsepower and one 50-horsepower impulse wheel, direct-connected to a 150-kilowatt and a 25-kilowatt direct-current generator, respectively.

Fort Wayne transformers arranged in three banks of three each step the current up from 2,300 volts to 60,000 for transmission. Each bank of three has a normal capacity of 4,500 kilowatts. Two separate high-tension lines 38.7 miles long transmit the energy to the distribution system. One of the lines is composed of three No. 2 solid copper wires spaced 6 feet apart, and the other line consists of three No. 0000 7-strand hard-drawn copper cables spaced 7 feet apart. Both lines are supported by cedar poles 35 feet and 55 feet high, respectively. The spacing of the shorter poles is 100 to 150 feet and that of the larger poles 150 to 750 feet.

It is proposed to build a masonry dam 202 feet high above bedrock at a narrow place in the valley about 2 miles below the lake outlet. Such a dam would raise the water to an elevation of 1,607 feet, or 70 feet above the original elevation of the lake and 52 feet above the crest of the present dam. This will provide 125,000 acre-feet of storage. The flowage area of the Cedar Lake reservoir at an elevation of 1,612 feet is shown in Plate XVI. A dam raising the water to this height would provide 140,000 acre-feet of storage. Investigations are being made to determine whether safe foundations for a dam of this height are available.

The water supply of the city of Seattle is taken from Cedar River at the Landsburg dam, 15 miles below Cedar Lake, at an elevation of 536 feet. The dam and gravity diversion works were built in 1900 and the first water was delivered to the distribution system in January, 1901. The diversion dam consists of a rock-filled timber-crib structure 120 feet long, anchored to four concrete cut-off walls. Two of these walls extend 4 feet into the impervious stream bed and the other two about 2 feet. A timber apron 34 feet long, supported by two additional cut-off walls, protects the toe of the dam from undermining. Masonry wing walls flank the ends of the dam and shield the river banks from lateral erosion. The intake is located on the left side of the river and is connected with a settling basin by two wood-stave pipe lines 4.5 feet in diameter and one-half mile long. The settling basin is housed in and contains suitable gates for regulating the flow in the pipes. The original conduit is composed of 22 miles of wood-stave pipe ranging in diameter from 3.7 feet to 3.5 feet and 6.1 miles of riveted steel pipe 4 feet in diameter. The original conduit has a capacity of 34.8 second-feet and the other 69.2 second-feet.

If it proves feasible to build a high dam below Cedar Lake, sufficient storage will be available to regulate practically the entire flow of the river, and in that event Cedar River will assume importance as a power stream from the lake to Maple Valley, although the diversion of the Seattle water-supply system would materially reduce the flow below the Landsburg dam.

The possibilities of power development by diverting water over the divide to the South Fork of Snoqualmie River are discussed on page 120.

CEDAR LAKE STORAGE.

The possibilitities of further power development in the section of Cedar River just below Cedar Lake are of special importance on account of the plans of the city of Seattle for enlarging their present plant. Records have been kept for less than two years at the point of intake at Cedar Lake, and it is therefore desirable to compute the probable discharge by comparison with the long-time Ravensdale record.

There are available ten whole and two partial months of records at Cedar Lake, which can be compared with simultaneous records at the Ravensdale station including July to September, 1898, at Vaughn bridge, and October 17, 1902, to August 8, 1903, at the Cedar Lake Station. The comparisons of these discharges are given below:

Comparisons of mean monthly discharge, in second-feet, of Cedar River, Wash.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1898.												
Vaughn bridge	......	......	......	......	......	......	203	68	73	......	......	......
Clifford bridge	......	......	......	......	......	......	262	124	127	......	......	......
Ratio	......	......	......	......	......	......	0.77	0.55	0.57	......	......	......
1902-3.												
Cedar Lake	1,260	289	243	414	894	931	340	[a] 116	......	[b] 173	668	797
Ravensdale dam	1,790	572	480	653	1,020	980	533	[a] 251	......	[b] 180	837	1,150
Ratio	0.70	0.51	0.51	0.63	0.88	0.95	0.64	0.46	......	0.96	0.80	0.69

[a] Aug. 1-8. [b] Oct. 17-31.

The records for Cedar Lake for the end of October, 1902, were probably affected by storage and can not be used. The ratios for May and June, 1903, 0.88 and 0.95, seem too high; they give an inflow of only 124 and 49 second-feet, respectively, between the two stations. This relatively low run-off from the low area in the early summer is to be expected, but not to such a marked extent. Factors of 0.85 and 0.90 have been taken as more probable ratios for May and June. The mean of the two ratios for July is 0.70. The mean of the ratios for August and September (weighting that for August, 1903, in proportion to the length of time covered) is 0.55, and this is assumed to hold also for October. For November to April the ratios show considerable divergence. The run-off during this period is caused partly by rains, but more largely by the melting of snows, the rate of which depends on temperature changes fully as much as precipitation. A cool dry winter month will cause a more marked decrease in outflow from the higher area above Cedar Lake than from the lower portion of the drainage basin.

The monthly means for the two stations for these months have been plotted as cordinates, and for December to April they fall on a well-defined curve of relations. November gives a relatively higher discharge for Cedar Lake, which is to be expected, as chinook winds almost always occur during this month, causing rapid melting of snow in the headwaters. The effect of wet and dry weather on the relation of the run-off at the two stations during November would be similar to what seems to occur in the following months; therefore a curve of relations for November has been drawn parallel to that for December to April.

In computing the most economical storage capacity the mass-curve method has been employed. This method has been used by Barrows [1] in studying the effect of storage on Kennebec River, and by Barrows and Babb [2] in similar studies on Penobscot River, and has been fully

[1] Barrows, H. K., Water resources of the Kennebec River basin, Maine: Water-Supply Paper U. S. Geol. Survey No. 198, 1907, pp. 150-162.

[2] Barrows, H. K., and Babb, C. C., Water resources of the Penobscot River basin, Maine: Water-Supply Paper U. S. Geol. Survey No. 279, 1912, pp. 194-202.

described in the reports on these two drainage basins. The base data for the mass curve are embodied in the following table.

Column 1 shows the mean monthly discharge in second-feet of Cedar River at Cedar Lake as observed or as derived from the values at Ravensdale by comparisons.

Column 2 indicates the surplus (+) or deficit (−) of the discharge figures in column 1 relative to an assumed constant discharge of 400 second-feet through a power plant having its intake at Cedar Lake, like that of the Seattle municipal plant.

Column 3 is the equivalent of column 2 expressed in acre-feet, and column 4 shows the total surplus of water in acre-feet available for storage at the end of any given month, beginning with August, 1895, and assuming 400 second-feet minimum flow. The values in this column are used in plotting the mass curve (fig. 3). There is a break in the records on Cedar River from May, 1899, to April, 1901, but in order to give as long a period as possible for this study, June, 1901, is taken as following May, 1899. A comparison of records on Cedar and White rivers indicates that the intervening period was one of well sustained discharge and would not contain a critical period in the mass curve if the records were available.

The discharges at Cedar Lake have been estimated to the end of 1907, using the same reduction factors during the summer months as for the earlier years and neglecting storage actually used, except during 1907, when a small allowance was made for storage. The load carried on the municipal power plant during the summer of 1905 and 1906 is not believed to have been large enough to have necessitated any considerable draft on the lake.

Water available for storage on Cedar Lake.

	Mean monthly discharge (second-feet).	Surplus (+) or deficit (−) for a discharge of 400 second-feet.		Water available for storage (acre-feet).
		Second-feet.	Acre-feet.	
	1	2	3	4
1895.				
August	90	− 310	−19,100	− 19,100
September	116	− 284	−16,900	− 36,000
October	91	− 309	−19,000	− 55,000
November	267	− 133	− 7,900	− 62,900
December	728	+ 328	+20,200	− 42,700
1896.				
January	816	+ 416	+25,600	− 17,100
February	847	+ 447	+25,700	+ 8,600
March	608	+ 208	+12,800	21,400
April	499	+ 99	+ 5,900	27,300
May	935	+ 535	+32,900	60,200
June	1,390	+ 990	+58,900	119,100
July	481	+ 81	+ 5,000	124,100
August	130	− 270	−16,600	107,500
September	91	− 309	−18,400	89,100
October	87	− 313	−19,200	69,900
November	1,180	+ 780	+46,400	116,300
December	1,540	+1,140	+70,100	186,400

Water available for storage on Cedar Lake—Continued.

	Mean monthly discharge (second-feet).	Surplus (+) or deficit (−) for a discharge of 400 second-feet. Second-feet.	Acre-feet.	Water available for storage (acre-feet).
	1	2	3	4
1897.				
January	931	+ 531	+32,600	219,000
February	816	+ 416	+23,100	242,100
March	531	+ 131	+ 8,100	250,200
April	1,050	+ 650	+38,700	288,900
May	1,200	+ 800	+49,200	338,100
June	879	+ 479	+28,500	366,600
July	707	+ 307	+18,900	385,500
August	205	− 195	−12,000	373,500
September	175	− 225	−13,400	360,100
October	169	− 231	−14,200	345,900
November	989	+ 589	+35,000	380,900
December	1,070	+ 670	+41,200	422,100
1898.				
January	483	+ 83	+ 5,100	427,200
February	910	+ 510	+28,300	455,500
March	272	− 128	− 7,900	447,600
April	366	− 34	− 2,000	445,600
May	783	+ 383	+23,600	469,200
June	652	+ 252	+15,000	484,200
July	203	− 197	−12,100	472,100
August	68	− 332	−20,400	451,700
September	73	− 327	−19,500	432,200
October	168	− 232	−14,300	417,900
November	610	+ 210	+12,500	430,400
December	684	+ 284	+17,500	447,900
1899–1901.				
January	1,290	+ 890	+54,700	502,600
February	1,110	+ 710	+39,400	542,000
March	321	− 79	− 4,900	537,100
April	590	+ 190	+11,300	548,400
May	1,280	+ 880	+54,100	602,500
June	742	+ 342	+20,400	622,900
July	307	− 93	− 5,700	617,200
August	114	− 286	−17,600	599,600
September	113	− 287	−17,100	582,500
October	108	− 292	−18,000	564,500
November	828	+ 428	+25,500	590,000
December	776	+ 376	+23,100	613,100
1902.				
January	638	+ 238	+14,600	627,700
February	418	+ 18	+ 1,000	628,700
March	476	+ 76	+ 4,700	633,400
April	444	+ 44	+ 2,600	636,000
May	970	+ 570	+35,000	671,000
June	639	+ 239	+14,200	685,200
July	423	+ 23	+ 1,400	686,200
August	135	− 265	−16,300	670,300
September	116	− 284	−16,900	653,400
October	115	− 285	−17,500	635,900
November	668	+ 268	+15,900	651,800
December	797	+ 397	+24,400	676,200
1903.				
January	1,260	+ 860	+52,900	729,100
February	289	− 111	− 6,200	722,900
March	243	− 157	− 9,700	713,200
April	414	+ 14	+ 800	714,000
May	894	+ 494	+30,400	744,400
June	931	+ 531	+31,600	776,000
July	340	− 60	− 3,700	772,300
August	99	− 301	−18,500	753,800
September	242	− 158	− 9,400	744,400
October	361	− 39	− 2,400	742,000
November	624	+ 224	+13,300	755,300
December	736	+ 336	+20,700	776,000

Water available for storage on Cedar Lake—Continued.

	Mean monthly discharge (second-feet).	Surplus (+) or deficit (−) for a discharge of 400 second-feet.		Water available for storage (acre-feet).
		Second-feet.	Acre-feet.	
	1	2	3	4
1904.				
January	768	+ 368	+22,600	798,600
February	475	+ 75	+ 4,300	802,900
March	450	+ 50	+ 3,100	806,000
April	704	+ 304	+18,100	824,100
May	800	+ 400	+24,600	848,700
June	770	+ 370	+22,000	870,700
July	351	+ 49	− 3,000	867,700
August	101	− 299	−18,400	849,300
September	96	− 304	−18,100	831,200
October	78	− 322	−19,800	811,400
November	239	− 161	− 9,600	801,800
December	545	+ 145	+ 8,900	810,700
1905.				
January	392	− 8	− 500	810,200
February	313	− 87	− 4,800	805,400
March	493	+ 93	+ 5,700	811,100
April	390	− 10	− 600	810,500
May	704	+ 304	+18,700	829,200
June	611	+ 211	+12,600	841,800
July	246	− 154	− 9,500	832,300
August	134	− 266	−16,400	815,900
September	122	− 278	−16,500	799,400
October	404	+ 4	+ 200	799,600
November	374	− 26	− 1,500	798,100
December	485	+ 85	+ 5,200	803,300
1906.				
January	654	+ 254	+15,600	818,900
February	674	+ 274	+15,200	834,100
March	382	− 18	− 1,100	833,000
April	443	+ 43	+ 2,600	835,600
May	481	+ 81	+ 5,000	840,600
June	510	+ 110	+ 6,500	847,100
July	244	− 156	− 9,600	837,500
August	131	− 269	−16,500	821,000
September	126	− 274	−16,300	804,700
October	392	− 8	− 500	804,200
November	1,450	+1,050	+62,500	866,700
December	1,040	+ 640	+39,400	906,100
1907.				
January	418	+ 18	+ 1,100	907,200
February	1,030	+ 630	+35,000	942,200
March	372	− 28	− 1,700	940,500
April	542	+ 142	+ 8,400	948,900
May	702	+ 302	+18,600	967,500
June	437	+ 37	+ 2,200	969,700
July	218	− 182	−11,200	958,500
August	105	− 295	−18,100	940,400
September	112	− 288	−17,100	923,300
October	93	− 307	−18,900	904,400
November	593	+ 193	+11,500	915,900
December	574	+ 174	+10,700	926,600

NOTE.—30 second-feet deducted from computed values for August, September, and October, 1907, to allow for storage, and 90 second-feet added to November, when the reservoir would have filled again.

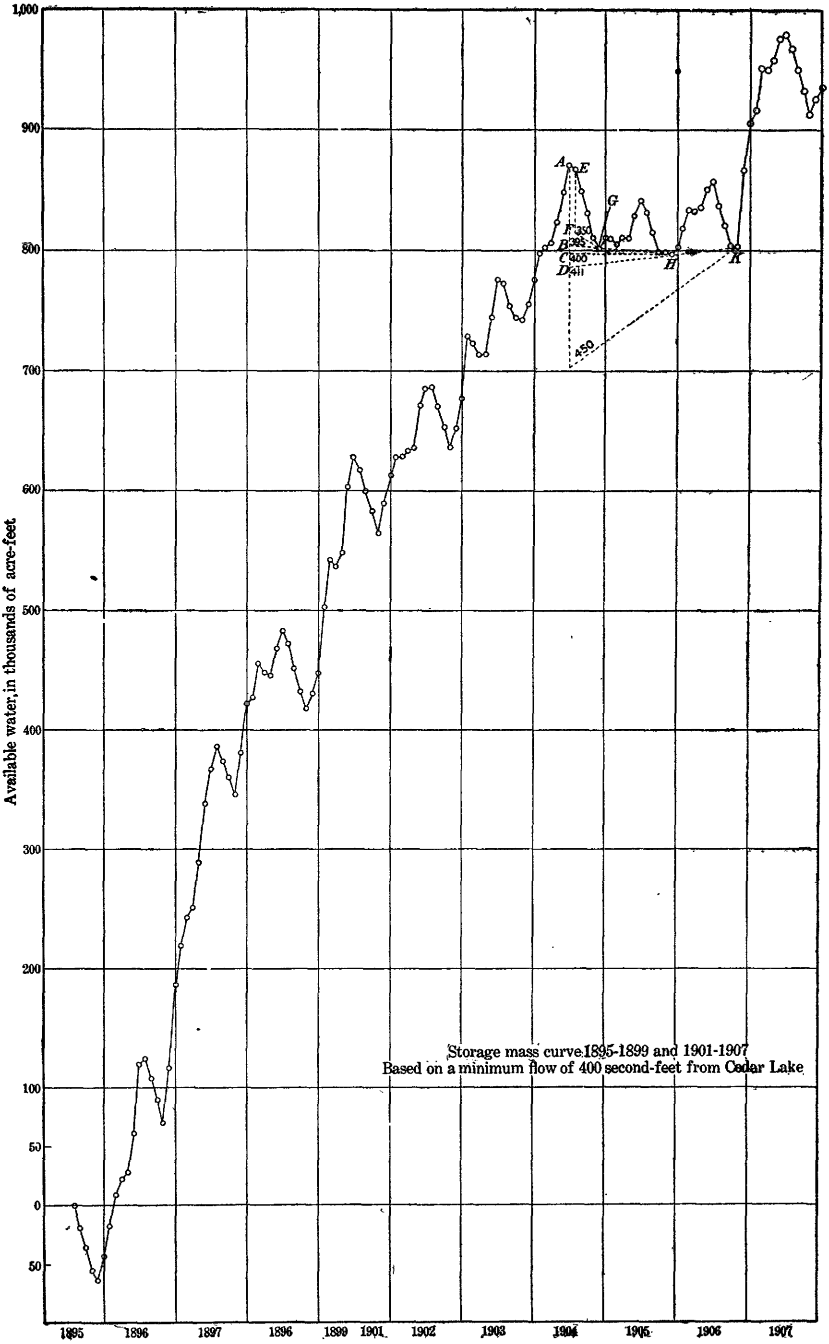

FIGURE 3.—Mass diagram of Cedar Lake discharge.

Figure 3 is a mass diagram for the period covered by the table, obtained by platting the amounts in column 5 as ordinates and time in months as abscissas. The features of this diagram and the information that can be gleaned from it are as follows:

1. For the interval of time between any two dates represented on the axis of abscissas the surplus or deficiency is obtained by subtracting the ordinate corresponding to the earlier date from the ordinate corresponding to the later date; if this difference is positive it represents a surplus; if it is negative it represents a deficiency. An ascending part of the curve, therefore, shows a period during which the quantity of available water is increasing, and a descending part of the curve indicates a period in which the quantity of available water is decreasing.

2. The crests and hollows of the curve indicate those instants of time when supply and demand are equal.

3. If a horizontal line is drawn from any of the low points of the curve back to a rising line the maximum ordinate scaled from the horizontal line to the curve will show the amount in acre-feet that would have to be stored to provide the assumed flow during the period of drought covered by the horizontal line.

4. The period during which this greatest ordinate occurs is therefore the critical one, and all the surplus of supply over demand during parts of this period must be stored to meet the deficiency during the remainder of it.

The period which includes the maximum ordinate extends from December, 1902, to November, 1905, and the maximum ordinate falls in June, 1904. The maximum ordinate corresponds to 68,900 acre-feet, which is the amount of storage required to provide at all times from August, 1895, to December, 1906, a minimum outflow of 400 second-feet at Cedar Lake.

The amounts of storage required to maintain this minimum for all years of record are as follows:

	Storage required (acre-feet).
1895 (August to November)	62, 900
1896	54, 200
1897	39, 600
1898	65, 300
1901	58, 400
1902	50, 700
1903	34, 000
1904	68, 900
1905	43, 700
1906	42, 900

The study of storage requirements by monthly means fails to take into account the variations in discharge during the month, and for this reason the values of storage required are slightly too low. Thus the estimated monthly mean for July, 1904, was 351 second-feet, a deficiency of 49 below the assumed minimum, but the discharge for the first 11 days was greater than 400, the excess amounting to 1,700 acre-feet. The deficiency for the last 20 days amounted to 4,700 acre-feet, the net deficiency being 3,000 acre-feet, as tabulated.

In November the deficiency for the first 20 days is 11,400 acre-feet, the excess for the last 10 days is 1,800 acre-feet.

If we take the deficiencies for July and November as 4,700 and 11,400 acre-feet, instead of 300 and 9,600 acre-feet, the total deficiency to be supplied by storage becomes 72,400 acre-feet, which is 3,500 acre-feet or 5 per cent greater than the results obtained by using monthly means. The difference is probably about the same in total amount for other years.

The effect of modifying the assumed conditions of minimum flow is obtained by means of the intercepts of the dotted lines radiating from the various low points in the mass curve (G, H, and K, fig. 3), measured upon the vertical ordinate A–D with regard to the point A.

Thus for an assumed flow of 395 second-feet the line H–B is drawn on a slope with the horizontal corresponding to a continuous discharge of 5 second-feet, so that A–B represents 4,500 acre-feet (the equivalent of 5 second-feet for the period June to November, 1904). The storage required to produce a minimum flow of 395 second-feet will therefore be 4,500 acre-feet less than the 68,900 acre-feet required for a minimum flow of 400 second-feet, or 64,400 acre-feet, or the distance A–B. This line passes through the point G for the month of November, 1904, as the average for the 12 months from November, 1904, to November, 1905, equals 395 second-feet.

The dotted line marked 411 passes through points H and K, and for amounts of minimum flow greater than 411 second-feet the sloping lines start from K; the period during which storage is being utilized is the 28 months from June, 1904, to October, 1906. For discharges of less than 395 second-feet the dotted lines radiate from G, and the ordinates are measured from A until a discharge of 350 second-feet is reached, when the dotted line is parallel to A–E, as the discharge is practically equal to the monthly mean for June, 1904. The period during which storage is used for discharges of less than this minimum is the four months from July to October, 1904, and a mass curve taking into account daily instead of monthly discharge should be used strictly in order to eliminate the error caused by taking only monthly means.

The summer of 1898 is the critical period in the mass curve for discharges of less than about 200 second-feet, as the months of August and September of that year gave the lowest recorded discharge on Cedar River. The average for the lowest three or four months was not quite as low as in 1904.

The probable maximum limit of storage lies somewhere between the conditions represented by the dotted lines F–G and the line K–D (411 second-feet), which represents a draft on the reservoir for an aggregate period of 28 months.

Any increase in draft over this amount would necessitate carrying approximately 1,690 acre-feet storage for each second-foot increase, or about 30 acre-feet for each additional horsepower developed at the Seattle municipal plant.

The high masonry dam required would cost probably too much per acre-foot developed to warrant utilization of the storage possibilities of Cedar River to quite as full an extent as this.

In the following table are given in condensed form the results from the mass curve showing the amount of storage required to give various minimum discharges from Cedar Lake.

Storage required for different minimum discharges from Cedar Lake.

[Drainage area, 74 square miles.]

Discharge from Cedar Lake.	Storage required.	Period of draft on storage.
Sec.-ft.	*Acre-feet.*	*Months.*
350	53,800	4
395	68,100	17
400	72,600	17
411	83,900	28
450	168,500	28

This is also shown more completely in graphic form in figure 4, where values of necessary storage in acre-feet are plotted as abscissas

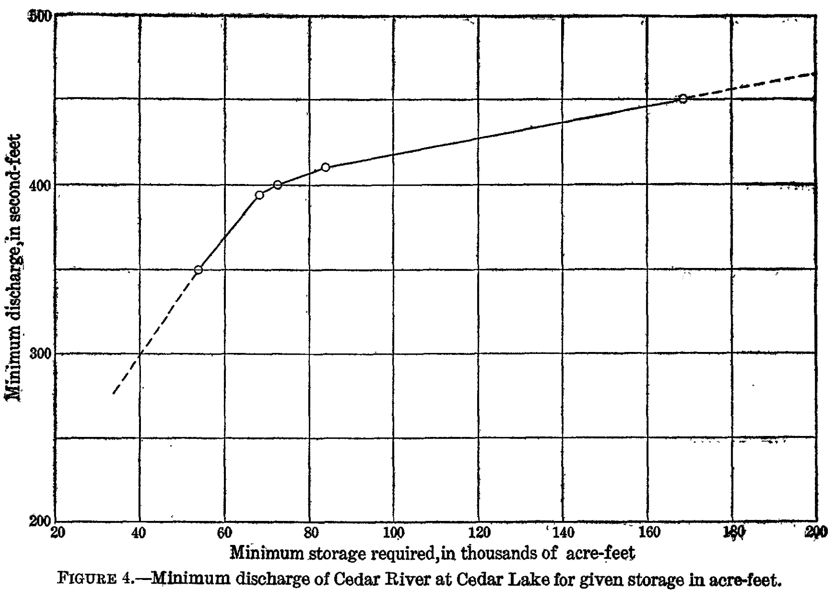

FIGURE 4.—Minimum discharge of Cedar River at Cedar Lake for given storage in acre-feet.

and values of minimum discharge from Cedar Lake as ordinates. The length of time that storage must be drawn is a measure of the slope which the line makes with the vertical axis. In this manner the curve has been extended approximately as a dotted line beyond the computed values. The sharp break in the curve at a point corresponding to about 400 second-feet and 75,000 acre-feet indicates that the maximum feasible storage development is somewhere near this value.

POWER SITES.

The following table has been prepared to show the power possibilities of the river in sections chosen in accordance with natural features and the present hydraulic developments. The horsepower included represents 70 per cent of the theoretical horsepower and is derived from the known fall and estimated discharge.

The plans and profiles shown in Plate XVI were prepared from field data secured for the topographic map of the Cedar Lake quadrangle of the United States Geological Survey, from maps prepared under the direction of the city engineer of Seattle, and from a profile of the Chicago, Milwaukee & Puget Sound Railway.

Summary of the available power in Cedar River basin.

Stream and location.	Section No.	Distance above initial point of survey.	Elevation.	Distance between points.	Fall between points.	Fall per mile.	Drainage area.	Minimum discharge for one week— Without storage. Total.	Minimum discharge for one week— Without storage. Per square mile.	Minimum discharge for one week— With storage (total).	Available horsepower 70 per cent efficiency— Without storage.	Available horsepower 70 per cent efficiency— With storage.
		Miles.	*Feet.*	*Miles.*	*Feet.*	*Feet.*	*Sq. miles.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*		
Cedar River below Cedar Lake		20.7	1,555				74	45	0.61	400		
Cedar River at tailrace of Seattle municipal power plant	1	17.3	945	3.4	610	179	82	49	.60	404	2,180	19,400
Cedar River at intake of Seattle water-supply system	2	5.7	536	11.6	409	35	149	87	.58	[a] 292	1,600	13,100
Cedar River at Maple Valley	3	0	305	5.7	281	41	172				1,600	5,370
Total											5,380	37,870

[a] This value derived by deducting 150 second-feet from the total regulated flow.

A brief description of the physical conditions and limitations to be considered in developing the units included in the foregoing table are given below. (See Pl. XVI, at end of volume.)

Section 1.—The total fall in this section has been fully developed by the Seattle municipal plant, as previously described (pp. 108–110). Further development will be made by increasing the storage capacity with a new dam at Cedar Lake and enlarging the power house. The minimum discharge used in computing power available without storage is that observed in 1899; the minimum discharge with storage has been taken as 400 second-feet, as determined by a study of the mass diagram for Cedar Lake.

Section 2.—This section has a relatively low fall per mile and the whole amount of fall is probably not feasible of development under present conditions. It would probably be necessary to make the development in at least two units. The minimum discharge has been found by adding to the minimum weekly discharge at Cedar Lake the proportional increase between Cedar Lake and Clifford bridge.

Section 3.—Below the Landsburg dam Cedar River has cut a narrow valley into the low piedmont plateau, much as White and Green rivers have done. The Seattle water-supply pipe line follows this plateau through what is known as the Wilderness from a short distance below the intake to a point near Renton. The surplus discharge over what is required for the city supply would be available for power development, and could be diverted along the plateau and dropped back into the river at some point between Maple Valley and Renton. Storage could probably be obtained in some of the lakes which abound in the Wilderness. The extent of economical development and the distance the water should be carried could be determined only by careful surveys. In this schedule the lower limit of the section is taken as Maple Valley. The low-water discharge without storage has been taken as that of the lowest week at the Clifford bridge station in 1898. The discharge with storage has been reduced 150 second-feet from the regulated flow above the Landsburg dam. This would furnish a water supply to meet the requirements of a city of 900,000 population, assuming a daily per capita consumption of 100 gallons.

As regards engineering advantages, the most feasible plan of utilzing the undeveloped power resources of Cedar River would involve diverting its flow at the tailrace of the Seattle municipal plant over the divide to the north into the Snoqualmie River basin. South Fork of Snoqualmie River lies about 4 miles in a direct line from the tailrace and the line that would be followed by a conduit would be hardly a mile longer. The canal would be built across the flat divide, and its construction should not prove expensive. About a mile of pressure pipe would be required to reach the power house, which would probably be located in the NE. ¼ sec. 22, T. 23 N., R. 8 E., about a mile by river below Tanner. The elevation of the South Fork at this point is approximately 470 feet, and the gross head available is 475 feet. A discharge of 300 second-feet on the basis of 70 per cent efficiency would render available 11,300 continuous horsepower. This water would then be available for further power development at Snoqualmie Falls, where with a head of 268 feet, the height of the falls, it would generate 6,400 horsepower continuously. This is practically 60 per cent of what would have been available at the lowest water ever recorded at that point (490 second-feet in 1898). The total available power would thus be 37,100 horsepower, compared with 37,870 that could be developed along the natural channel of Cedar River.

The discharge available for diversion into the Snoqualmie basin has been taken as 300 second-feet, assuming that 100 second-feet of the amount released from Cedar Lake at low water would have to be allowed to pursue its natural course down Cedar River to supply the Seattle municipal pipe line. The inflow to Cedar River between the lake and the Landsburg dam would probably furnish 50 second-feet, except for short periods during the summer, when a small amount of stored water might have to be released from Cedar Lake to supply the deficiency. Thus there would be no danger of jeopardizing the city's public water supply.

MARKET CONDITIONS IN PUGET SOUND REGION.

GROWTH OF CENTRAL ELECTRIC STATIONS IN THE UNITED STATES AND PACIFIC COAST STATES.

Water power has become a dominant factor in the industrial development of the country, largely if not entirely by reason of the fact that so great an advancement has been made in the long-distance transmission of electric power. During the past 20 years the practically possible transmission radius has been increased from a merely nominal distance to about 200 miles, and even greater distances are being reached, though with somewhat severe current losses. It is the general consensus of opinion among those conversant with the situation that improvements in equipment and experience will make possible a very much larger radius of transmission than that now practicable.

The importance of electrical energy to industrial progress had become so well recognized by 1902 that Congress passed an act authorizing the Bureau of the Census to gather statistics concerning street railways and central electric light and power stations. In 1906 the act was amended to provide for a similar census every five years. The reports on the use of electric power, together with statistical tables relating thereto, may be found among the special reports of the Bureau of the Census. The following tables have been compiled from the data published in these reports:

TABLE 1.—*Primary power utilized in generating electricity in the United States for 1907 and 1902.*

Kind of power.	Central stations.		Electric railways.		Per cent of increase.	
	1907	1902	1907	1902	Central stations.	Electric railways.
Steam engines:						
Number	7,206	5,930	2,511	2,336	21.5	7.5
Horsepower	2,627,450	1,379,941	2,368,183	1,298,133	90.4	82.4
Water wheels:						
Number	2,481	1,390	228	159	78.5	43.4
Horsepower	1,349,087	438,472	91,961	49,153	207.7	87.1
Gas engines:						
Number	463	165	41	15	180.6	173.3
Horsepower	55,828	12,181	16,335	1,925	358.3	748.3
Total:						
Number	10,998	7,850	3,637	2,811	40.1	29.4
Horsepower	4,098,188	1,845,048	2,519,823	1,359,285	122.1	85.4

Kind of power.	Total.		
	1907	1902	Per cent of increase.
Steam engines:			
Number	9,717	8,266	17.6
Horsepower	4,995,633	2,678,074	86.5
Water wheels:			
Number	2,709	1,549	74.9
Horsepower	1,441,048	437,625	195.5
Gas engines:			
Number	504	180	180.0
Horsepower	72,163	14,106	411.6
Total:			
Number	14,635	10,661	37.3
Horsepower	6,618,011	3,204,333	106.5

TABLE 2.—*Commercial and municipal central electric stations in the United States and geographic subdivisions for 1907 and 1902.*

	Year.	Population.	Total number of stations.	Horsepower installation—		Water wheels.	
				Total.	Per 1,000 inhabitants.	Number.	Rated horsepower.
United States	1907 1902	85,532,761 78,576,436	4,714 3,620	4,098,188 1,845,048	48 23	2,481 1,390	1,349,087 438,472
Per cent of increase		8.9		122.1			207.7
Western division of United States.[a]	1907 1902	4,783,457 4,289,085	480 346	803,999 280,818	168 65	508 361	503,632 168,045
Per cent of increase		11.5		186.3			199.7
Washington	1907 1902	965,615 649,724	71 40	67,224 22,894	70 35	48 41	56,118 17,238
Per cent of increase		48.6		193.6			225.5
California	1907 1902	2,125,238 1,673,343	129 115	384,673 134,788	181 81	172 133	208,444 78,933
Per cent of increase		27.0		185.4			164.1
Oregon	1907 1902	599,480 468,225	61 39	126,815 17,798	212 38	72 46	102,052 11,195
Per cent of increase		28.0		612.5			811.6

[a] The western division comprises Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

TABLE 3.—*Cost of construction, income, and expenses of commercial and municipal central electric stations in the United States and geographic subdivisions for 1907 and 1902.*

	Year.	Cost of construction and equipment to date.	Cost of construction and equipment per horsepower installed.	Total expenses for year.	Gross income for year.	Undivided returns.[a]	Undivided returns [a] per horsepower installed per year.
United States	1907	$1,096,913,622	$268	$106,205,149	$175,642,338	$69,437,189	$16.90
	1902	504,740,352	274	55,457,830	85,700,605	30,242,775	16.40
Western division [b]	1907	204,354,453	254	16,246,637	28,608,543	12,361,906	15.40
	1902	68,905,056	245	6,988,447	10,758,823	3,770,376	13.40
Washington	1907	20,789,849	309	1,911,691	3,410,542	1,498,851	22.30
	1902	3,537,022	154	566,667	783,651	216,984	9.50
California	1907	111,780,551	291	8,357,184	14,416,529	6,059,345	15.80
	1902	36,547,474	271	3,219,422	5,066,417	1,846,995	13.70
Oregon	1907	14,403,278	114	918,760	1,965,245	1,046,485	8.30
	1902	5,157,651	290	338,142	691,582	353,440	19.90

[a] Undivided returns represent the earning capacity of the cost of construction and equipment to date.
[b] Western division comprises Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

Table 1 shows the horsepower installation of electric systems in the United States and the derivation from different kinds of primary power for the years 1902 and 1907. The percentage increase for each item is given. This summary shows that the use of power more than doubled between 1902 and 1907. The increase in the use of steam, gas, and water power amounted to 86.5, 411.6, and 195.5 per cent respectively. The increase in the number of steam and gas engines and water wheels is by no means as large as that of horsepower installed, indicating that the size of power units increased considerably. It is noteworthy that the distribution of power from central stations increased more rapidly than that from electric railway power stations. This may be accounted for by a greater demand for light and commercial power, but is probably in a greater measure due to a tendency toward centralization of distribution for all purposes, including electric railway energy, from central electric stations. On account of the efficiency obtained and the greater demand for uniform and uninterrupted service, centralization of electric distribution is more marked now than in 1907. It also seems reasonable to expect that the census of 1912 will show fully as great increase in the total use of electrically transmitted energy, both from steam engines and water wheels.

General statistics of commercial and municipal central stations in the United States and geographic subdivisions, together with percentages of increase during the five-year interval between 1902 and 1907 and the total population of the areas indicated, are shown in Table 2. It will be noted that the use of electric power grew much more rapidly than the population and the percentage increase in horsepower installed was appreciably greater in the Western States than for all the United States. One of the elements that should be considered in studying market conditions is the relation between population and the amount of power generated. As the plant capacity is in a measure indicative of the power generated the horsepower installation per 1,000 inhabitants is given in the table. It is surprising to find that this value is so much greater for the western territory than for the country as a whole.

Table 3 summarizes the total cost, total yearly expenses, gross income, and undivided returns of commercial and municipal central electric stations in the United States. The latter item is the difference between the total expenses and gross income and represents the earning capacity of the money invested. The cost of construction and equipment and the undivided returns per horsepower installed are listed to show in a general way the capital necessary for building and placing in operation electric power plants and the returns that may be expected from such an investment. A better system for analyzing these items would be on a kilowatt-hour basis, but greater inconsistencies were found in comparisons of this nature than in those on the basis chosen, probably because it was more difficult for the Bureau of the Census to secure reliable data as to output.

A striking feature to be noted in studying the data presented is that the cost per horsepower installed is somewhat greater than is deemed good practice by engineers. An economical steam plant generating electricity should cost from $60 to $80 per horsepower. Physical conditions and natural limitations are so varied in developing water power that the cost is not so uniform as for steam plants. In the western section of the United States, where water-power possibilities have scarcely been touched, installations costing more than $150 per horsepower at the rated capacity are considered high, and those costing $60 per horsepower are considered low. These figures include the cost and installation of electrical machinery, including step-up and step-down transformers, but not of transmission lines or distribution systems. Several reasons may be given for the high cost per installed horsepower shown in the table. The changes in plant equipment and machinery have been so radical that the greater efficiencies to be obtained by newer devices have caused wholesale "scrapping" of machinery long before it has served its normal period. Thus the cost per horsepower of the new installations is burdened with the cost of the older equipment. As mentioned elsewhere, the tendency has been to centralize stations and to merge a number of smaller plants into one system. Often the smaller plants are bought on the basis of capitalization, and a bonus paid for good will, etc. Probably the greatest factors in producing the high cost per horsepower installed are the items of transmission and distribution. The latter is so dependent on the local market features and is so closely related to economy in line losses, transformer and converter capacities, etc., that it is almost impossible to give a general figure covering the cost per horsepower installed. The cost figures are slightly larger for the western division of the United States than for the whole country and appear to lack uniformity in California, Washington, and Oregon. The same statement applies to the undivided returns per horsepower.

The information obtained in the tables was not secured for the purpose of close analysis. It only indicates general features and tendencies of the development of electric power and serves merely as an index in the study of local conditions.

NATURAL RESOURCES AND HARBOR FACILITIES OF THE PACIFIC COAST STATES.

During the past 20 years Pacific coast developments have had a vigorous growth. Favorable natural conditions and almost unlimited latent resources assure continued prosperity and advancement. The harbors along the coast, although few in number, rank among the best in the world. The Pacific coast is nearly 5,000 miles nearer Hongkong and other oriental ports than is Liverpool via the Suez Canal. Australia and Oceania are nearer to any of the west coast harbors than to London. The opening of the Panama Canal will increase the commercial activities of this section manyfold and will greatly promote the financial relations of its cities with all the large world centers.

The State of Washington is well provided with natural resources. The timber over a large area of the State ranks among the finest in the world, and the policy of the Federal and State Governments in regulating the cutting and preventing forest fires insures a continued and well-proportioned lumber industry. In all parts of the State agriculture has yielded greater returns than was anticipated 10 years ago, and the resulting increase in land values makes possible further extension of irrigation development in the arid areas. Washington is the only State west of the Rocky Mountains that is important as a coal producer, and the iron, silver, lead, and copper deposits of the Cascade Range, at present unexploited, will contribute an appreciable amount to the wealth of the State in the future. Marble and sandstone quarries are also capable of furnishing a greater supply than is needed for local use. The successful manufacture of Portland cement by water power in the northwestern part of the State is evidence that this method would prove profitable in many other localities where the necessary materials are available.

Puget Sound offers about 1,000 miles of steep shore line, which can be approached at almost any point by the largest ocean-going vessels, and in addition is well protected from the storms of the Pacific Ocean. With such an extensive water front, provided with almost unlimited harbor possibilities, it is evident that export and import trading will thrive. A large part of the Alaska supplies and products will pass through the Puget Sound ports, and an increasing trade with the Orient will be fostered. Five transcontinental railroads have their terminals at Seattle and Tacoma. The development of the country tributary to these railroads has scarcely passed from the pioneer stage, and the value of its resources is just beginning to be realized.

INDUSTRIAL DEVELOPMENT IN WASHINGTON.

Economical transportation facilities and abundance of cheap water power combine to make conditions favorable for manufacturing industries. It seems probable, therefore, that a great amount of this power will be utilized for manufacturing. Aside from the manufacture of lumber and timber products the industries of Washington have not yet assumed great importance. Like all new and growing Commonwealths abounding in natural resources, close economies have not been attained, and the employment of capital has not been directed toward industrial competition with the older and better-organized communities of the East. Consequently, manufactured products, with few exceptions, have not been adequate for the local demand. This is true in great measure of all the Western States. It will be seen from the following table, which is prepared from data incorporated in reports issued by the Bureau of the Census, that Washington compares favorably with other States on the Pacific coast in the preparation of raw materials for the market:

TABLE 4.—*Statistics of manufacturing in Pacific coast States and selected cities in 1904 and 1909.*

State or city.	Year.	Value of products.	Cost of materials.	Value added by manufactures.[a]	Primary horsepower.
California[b]	1909	$529,761,000	$325,288,000	$204,323,000	329,100
	1904	367,218,000	215,726,000	151,492,000	210,359
Per cent increase		44	51	35	56
Oregon	1909	93,032,000	49,576,000	43,456,000	175,069
	1904	55,525,000	30,597,000	24,928,000	81,348
Per cent increase		68	62	74	115
Portland	1909	46,861,000	25,076,000	21,785,000	....
	1904	28,651,000	17,024,000	11,627,000	....
Per cent increase		64	47	87	....
Washington	1909	220,746,000	117,888,000	102,858,000	297,897
	1904	128,822,000	66,166,000	62,656,000	168,342
Per cent increase		71	78	64	77
Seattle	1909	50,569,000	28,019,000	22,550,000	....
	1904	25,407,000	14,358,000	11,049,000	....
Per cent increase		99	95	104	....
Tacoma	1909	22,450,000	13,716,000	8,734,000	....
	1904	14,264,000	8,158,000	6,106,000	....
Per cent increase		57	68	43	....
Everett	1909	7,423,000	3,859,000	3,564,000	....

[a] This item represents the increase in value of materials brought about by manufacturing—that is, value of products less cost of materials.

[b] San Francisco showed a decrease in all items except capital. This was occasioned by the earthquake and fire, which occurred during the interval between 1904 and 1909.

The value added to materials through the agency of manufacturing is the best basis of making comparisons of the growth and development of industries. The increase in value during the census period is shown to be 29 per cent greater in Washington than in California and 10 per cent less than in Oregon. The industries of Seattle more than doubled from 1904 to 1909 and show a greater increase than any other city or State listed in the table. Portland holds second place in this respect and is credited with an increase of 87 per cent during the same period. California ranks first in the total value added by manufacturing for 1909. It exceeds Washington in this item 100 per cent and Oregon 370 per cent.

Tables 5, 6, and 7, presented below, indicate the growth and magnitude of principal industries in the State of Washington, in Seattle, and in Tacoma. They have been compiled from data published in the special reports of the Bureau of the Census. The value of products, cost of materials, value added by manufacturing and percentages of increase for intercensal periods are given in each table in order that the data may be comparable with that given in Table 4.

TABLE 5.—*Statistics of manufactures of principal industries in Washington for 1900, 1904, and 1909.*

Products.	Year.	Value of products.	Cost of materials.	Value added by manufactures.[a]	Per cent increase of value added by manufactures.
Lumber and timber	1909	$89,154,820	$36,878,866	$52,275,954	52
	1904	49,572,512	16,325,954	33,246,558	93
	1900	30,286,280	13,043,512	17,242,768	....
Flour and grist mill	1909	17,852,944	15,474,096	2,378,848	26
	1904	14,663,612	12,771,390	1,892,222	68
	1900	6,773,574	5,649,327	1,124,247	....
Slaughtering and meat packing	1909	15,653,998	13,759,982	1,894,016	129
	1904	6,251,705	5,423,134	828,571	49
	1900	4,293,953	3,736,658	557,295	....
Foundry and machine shop	1909	7,987,931	3,724,022	4,263,909	103
	1904	3,862,279	1,762,995	2,099,284	63
	1900	2,257,643	970,092	1,287,551	....
Butter, cheese, and condensed milk	1909	7,271,047	5,676,191	1,594,856	165
	1904	2,992,576	2,391,877	600,699	133
	1900	1,190,239	932,190	258,049	....
Cars and general shop construction and repairs by steam railroads.	1909	4,666,469	2,484,023	2,182,446	126
	1904	2,768,726	1,804,516	964,210	31
	1900	1,497,680	760,858	736,822	....

[a] This item represents the increase in value of materials brought about by manufacturing—that is, value of products less cost of materials.

TABLE 6.—*Statistics of manufactures of principal industries in Seattle for 1904 and 1909.*

Products.	Year.	Value of products.	Cost of materials.	Value added by manufactures.[a]
Lumber and timber	1909 1904	$7,739,199 1,519,247	$3,676,366 500,957	$4,062,833 1,018,290
Per cent increase		410	634	299
Slaughtering and meat packing	1909 1904	$7,170,724 3,419,085	$6,409,544 3,028,998	$761,180 390,087
Per cent increase		110	112	95
Flour and grist mill	1909 1904	$4,430,408 4,593,566	$3,872,155 4,158,330	$558,253 435,236
Per cent increase or decrease		−4	−7	+28
Foundry and machine shop	1909 1904	$4,289,630 1,771,571	$2,041,612 855,655	$2,248,018 915,916
Per cent increase		142	139	145
Butter, cheese, and condensed milk	1909	$513,923	$438,849	$75,074
Cars and general shop construction and repairs by steam railroads	1909	283,295	129,503	153,792

[a] This item represents the increase in value of materials brought about by manufacturing; that is, value of products less cost of materials.

TABLE 7.—*Statistics of manufactures of principal industries in Tacoma for 1904 and 1909.*

Products.	Year.	Value of products.	Cost of materials.	Vaue added by manufactures.[a]
Lumber and timber	1909 1904	$6,040,235 2,404,917	$2,889,255 733,459	$3,150,980 1,671,458
Per cent increase		151	294	89
Slaughtering and meat packing	1909	$4,371,152	$3,762,709	$608,443
Flour and grist mill	1909 1904	$3,844,348 2,293,587	$3,429,768 2,068,775	$414,580 224,812
Per cent increase		68	66	84
Foundry and machine shop	1909 1904	$1,367,629 897,986	$696,942 439,122	$670,687 458,864
Per cent increase		52	59	46
Butter, cheese, and condensed milk	1909	$28,175	$13,134	$15,041
Cars and general shop construction and repairs by steam railroads	1909	241,804	104,758	137,046

[a] This item represents the increase in value of materials brought about by manufacturing—that is, value of products less cost of materials.

Table 5 summarizes the data relative to the more important industries in Washington for the three years 1900, 1904, and 1909. It will be noted that lumber and timber products predominate. Taking the value added by manufactures as a basis of comparison for the census of 1909, lumber and timber products represent 51 per cent; foundry and machine-shop products, 4.1 per cent; and flour and grist mill products, 2.3 per cent of the total for all manufacturing indicated in Table 4. The growth of the newer industries, such as slaughtering and meat packing, foundry and machine shops, butter, cheese, and condensed milk, and cars and general shop construction and repairs by steam railroads has shown a decidedly greater increase for the period from 1904 to 1909 than that for 1900 to 1904. On the other hand, the rate of increase of lumber and timber products and flour and grist mill products, representing older and better established industries, has been smaller for the later period.

The data relating to the principal industries of Seattle are shown in Table 6 for 1904 and 1909. In 1909 the value added by manufacturing to lumber and timber products is 18 per cent of the total for all industries in the city, which is shown in Table 4. Similar percentages for foundry and machine-shop products, slaughtering and meat packing products, and flour and grist mill products are, respectively, 10, 3.4, and 2.5 per cent. It is noteworthy that flour and grist mill products show a decline in all the items listed except the value added by manufacturing, whereas the other industries indicate a remarkable increase during the census period.

Table 7 shows the growth of important manufacturing industries in Tacoma for 1904 and 1909. The value added by manufacturing in 1909 for the several industries shown in the table, as compared with the total for all industries in the city indicated in Table 4, is as follows: Lumber and timber products, 36 per cent; foundry and machine-shop products, 7.7 per cent; slaughtering and meat packing products, 7 per cent; and flour and grist mill products, 4.8 per cent. The increase in value added by manufacturing during the interval from 1904 to 1909 is materially lower than the same figures for Seattle in the lumber and timber and foundry and machine shop industries. The flour and grist-mill industry, however, has shown a much more substantial growth in Tacoma than in Seattle, and the percentage increase is greater than that for this industry in the whole State.

The foregoing deductions clearly show that lumber and timber products represent the bulk of the manufacturing carried on in the State of Washington. The mill waste of this industry is so great under present methods that in almost every establishment it is more economical to use it as fuel for generating steam power than to utilize hydroelectric energy. Hence it is doubtful whether water power will find a market in this field. It may be found advantageous, however, to use electric motors in the planing and finishing mills, some of which are separated from the large sawmills. A large proportion of the power in use at present by the flour and grist mill and the foundry and machine-shop industries is supplied from hydroelectric sources.

The economy attained in Europe by the use of the electric furnace in ore reduction and refining processes reveals an unexploited field for water utilization in mineralized regions supplied with good water-power possibilities. The Tacoma smelter has taken advantage of this use of electrical energy and consumes approximately 1,000 continuous horsepower. It is possible also that the increasing power development will encourage electrochemical industries to meet the needs of the Pacific coast.

POPULATION OF THE PACIFIC COAST STATES.

The advance in industrial activity in the Pacific coast States has been shown to be very great, but it has scarcely kept pace with the growth in population. An important item to be considered in forecasting the probable use of power in any given district is the number of inhabitants that will be served with electric current. Where the demands are confined to the utilization of energy for lighting, power, and traction it is necessary to consider the urban separately from the rural population. Ordinarily the urban population is taken to include cities and towns having more than 2,500 inhabitants. Table 8, compiled from reports of the Bureau of the Census, indicates the total and urban population of the Pacific coast States, together with percentages of increase during the intercensal periods from 1890 to 1910.

TABLE 8.—*Total and urban population of Pacific coast States for 1890, 1900, and 1910.*

State and census year.	Total population.	Per cent of increase.	Per cent of increase in continental United States.	Urban population.	Per cent of increase.	Percentage of urban to total population.
California:						
1910	2,377,549	60.1	21.0	1,469,739	89.1	61.8
1900	1,485,053	22.4	20.7	777,699	31.9	52.4
1890	1,213,398			589,464		48.6
Washington:						
1910	1,141,990	120.4	21.0	605,530	186	53.0
1900	518,103	45.0	20.7	211,477	66.3	40.8
1890	357,232			127,178		35.6
Oregon:						
1910	672,765	62.7	21.0	307,060	131	45.6
1900	413,536	30.2	20.7	133,180	51.5	32.2
1890	317,704			85,093		26.8

The percentages given in the table for the increase in urban population do not correctly represent the rate of growth for intercensal periods, because small towns listed in the rural population for one census may grow beyond the 2,500 limit in population during the intercensal period and be listed as urban population in the next census. Hence it would be necessary to include these towns in the earlier census to make the percentage growth comparable. In estimating the probable use of power by the urban population in a given area, however, this correction is not important, because the demand for power is a direct function of the size of the cities served by central electric stations.

It is interesting to note that Washington leads the other two States on the Pacific coast not only in the increase in total population but also to almost as great a degree in the growth of the urban population. On the other hand, California has a considerably greater proportion of urban to total population than Washington or Oregon.

There are 39 counties in the State of Washington, ranging in population, according to the Census returns, from 2,887 in Skamania County to 284,638 in King County. Of the 61 cities which are enumerated in the last census report, 3 have a population greater than 80,000, 8 greater than 10,000, and 12 in excess of 5,000. It will be noted that the urban population of Washington was 53 per cent of the total in 1910 and 40.8 per cent in 1900. The same percentages for the continental United States were 46.3 per cent and 40.5 per cent. The differences in local conditions in Washington are so great and the future use of power will be so diversified that the data at hand will not permit a thorough analysis of market conditions for the whole State. The power schedules and descriptions embraced in this report are wholly on the west side of the Cascade Mountains. Accordingly the detailed consideration of market influences will be limited to this region. The total and urban population of counties west of the mountains is listed in Table 9.

TABLE 9.—*Total and urban population (cities and towns above 2,500) of counties west of Cascade Range in Washington for 1900 and 1910.*

County.	Total.		Per cent of increase.	Urban.		Per cent of increase.	Per cent of urban to total population.	
	1910	1900		1910	1900		1910	1900
Chehalis	35,590	a 15,124		21,831	6,355	244	61	42
Clallam	6,755	5,603	21					
Clarke	26,115	13,419	95	9,300	3,126	198	36	23
Cowlitz	12,561	7,877	60					
Island	4,704	1,870	152					
Jefferson	8,337	5,712	46	4,181	3,443	21	50	60
King	284,630	a 110,053		239,934	80,671	197	84	73
Kitsap	17,647	6,767	161	2,993			17	
Lewis	32,127	15,157	112	11,818			37	
Mason	5,156	3,810	35					
Pacific	12,532	5,983	109	3,023			24	
Pierce	120,812	55,515	117	88,287	37,714	134	73	68
San Juan	3,603	2,928	23					
Skagit	29,241	a 14,272		4,168			14	
Skamania	2,887	1,688	71					
Snohomish	59,209	a 23,950		28,058	7,838	258	47	33
Thurston	17,581	9,927	77	6,996	3,863	81	40	39
Wahkiakum	3,285	2,819	17					
Whatcom	49,511	a 24,116		24,298	11,062	120	49	46
Total	732,291	326,590	124	444,887	154,072	189	61	47

a The county was redistricted during the interval between 1900 and 1910. Hence no comparison can be made.

Half the counties in the State are included in the section west of the Cascade Range, and the land area is approximately 38 per cent of the total. The population for 1910 as indicated in the above table was 732,291, or 64 per cent of the total. The urban population in 1910 was 73 per cent of the total for the State and 61 per cent of the total in the area under consideration. It is obvious, therefore, that conditions are more favorable for the demand for power by cities and towns in the section chosen than in any other part of the State. It will also be noted that the percentage of increase in the total and the urban population indicated in the table for the interval between 1900 and 1910 is slightly greater than for the State as a whole.

POWER UTILIZATION IN WASHINGTON.

The Cascade Range is a natural divide between the eastern and western portions of the State. If transmission lines were carried across this divide the distance between power sites and market centers would be excessive according to present limitations. In addition to this, there are good hydroelectric power privileges on the east side. Furthermore, the cost of maintenance of transmission lines in the mountainous area might be prohibitive. Other things being equal, the market requirements of the two sides of the mountains are so different that it is doubtful whether transmission of energy from one district to the other would prove economical. It is reasonable to assume that power will be used on the west side for industrial purposes, street and interurban railway service, and lighting and heating exclusively, and that the greatest demand for these purposes in the State will be centered around the Puget Sound region. Likewise it is probable that such demands will be only a secondary factor in power development on the east side, where the largest field for the use of energy will be pumping water for irrigation.

Reference has been made elsewhere to the marked tendency toward a centralization of power distribution systems in all parts of the United States. It appears that such centralization is necessary for economy in operation and for insuring continuity of service. Thus an enormous amount of capital is required for original development, and a number of years' operation is necessary to perfect the organization. In addition to this there is the interest charge on the large amount of capital necessary for construction and operation, and also the usual period required to place the development on a paying basis. Often this period extends over five or six years.

The obstacles to be overcome, as above mentioned, are so well recognized that it is difficult to induce capital to enter into close competition with existing centralized organizations. These circumstances result in artificial market provinces which are termed "zones of control." Thus far three such zones have been developed in the

State of Washington—the "Inland Empire" or northeastern section of the State, the southeastern section, and the Puget Sound region or northwestern section of the State. It is reported that an effort is being made to establish a central electric distribution system in southwestern Washington between the market centers controlled by the Puget Sound Traction, Light & Power Co. on the north and the Portland Railway, Light & Power Co. on the south.

CENTRAL SECTION OF PUGET SOUND REGION.

URBAN POPULATION.

It is probable that a portion of the available energy listed in the power schedules of this report will find a market in southwest Washington and in the region surrounding Portland, Oreg. The bulk of it, however, will be directed toward the Puget Sound region. Present utilization of electrically transmitted water power is concentrated in King, Pierce, and Snohomish counties. The small amount of current distributed in other portions of the region is consumed in the cities of Bellingham, Olympia, and Aberdeen, which are located in Whatcom, Thurston, and Chehalis counties, respectively. These small markets are somewhat isolated from the main center of utilization and their distribution systems are not connected with one another or with those of King, Pierce, and Snohomish counties. Consequently it is obvious that the demand for power in these sections would be greatly influenced by local conditions. Therefore, the community comprising King, Pierce, and Snohomish counties has been chosen for the purpose of analyzing the use of energy, and the district including these counties has been designated the central section of the Puget Sound region. Table 10 shows the total and urban population and the population served by central electric stations in this district.

TABLE 10.—*Total and urban population (cities and towns above 2,500) and population served by central electric stations in the central section of Puget Sound region for 1900 and 1910.*

	1910	1900	Per cent of increase.	Per cent of total population.	
				1910	1900
Total population	464,659	189,518	145	100	100
Population served by central electric stations[a]	364,552	133,472	173	78	70
Urban population	356,279	126,223	182	77	67

[a] The population served by central electric stations includes the population of the following towns: Seattle, Tacoma, Everett, Puyallup, Snohomish, Renton, Kent, Monroe, Auburn, Sumner, Spanaway Precinct, Issaquah, Kirkland, Steilacoom, North Bend, and Snoqualmie.

The population served is larger than the urban population, as a number of towns with less than 2,500 inhabitants are supplied with electric power. It will be noted, however, that the percentage difference is not very great between the two. The percentage of both items in respect to the total population increased considerably during the 10-year interval.

POWER AND DISTRIBUTION COMPANIES.

A brief description of the function of various operating and power companies in this section will be given.

The organization known as the Puget Sound Traction, Light & Power Co., operated by the Stone & Webster Management Association, is composed of the following companies: Seattle-Tacoma Power Co., Puget Sound Power Co., Pacific Coast Power Co., Everett Railway, Light & Water Co., Pacific Northwest Traction Co., Seattle Electric Co., Tacoma Railway & Power Co., and the Puget Sound Electric Railway Co.

The Seattle-Tacoma Power Co., originally organized in 1898 as the Snoqualmie Falls Power Co., was the first to provide the market in this locality with hydroelectric energy. It generates current at two plants, having an aggregate normal capacity of 18,500 kilowatts, located at Snoqualmie Falls, 30 miles east of Seattle. The energy is transmitted to Seattle, Tacoma, and Everett, where it is distributed, for the most part, in wholesale lots to other operating companies in the same organization, and under special contracts to large consumers for power and light purposes. It also provides the towns of Snohomish, Monroe, Issaquah, and North Bend with light and power, under special contract. The only energy sold to small consumers is delivered from a distribution system in the city of Seattle. The hydroelectric energy is supplemented by a small auxiliary steam plant in Seattle, which uses California crude oil for fuel, and is capable of generating 1,000 kilowatts.

The Puget Sound Power Co. operates a hydroelectric plant at Electron,[1] which has a normal output capacity of 14,000 kilowatts. It was built in 1903 and 1904, and is located 23 miles southeast of Tacoma on Puyallup River.

An increasing demand for electrical energy necessitated the building of the new White River plant [2] at Dieringer, 10 miles east of Tacoma. Construction work was begun by the Pacific Coast Power Co. in March, 1908, and the first current was delivered in November, 1911. The present installation of the White River plant provides for a normal capacity of 20,000 kilowatts and the future installation double this amount. The energy from both plants is transmitted to Seattle and Tacoma, where it is distributed and used by the Seattle

[1] A detailed description of this plant may be found on pages 72-73.

[2] A detailed description of this plant may be found on pages 87-90.

Electric Co., the Puget Sound Electric Railway Co., and the Tacoma Railway & Power Co.

The Everett Railway Light & Water Co. is furnished with energy from the Seattle-Tacoma Power Co. by means of a special transmission line from the Snoqualmie Falls plant to Everett. The Everett street-railway system is operated by this company and current is supplied to light and power consumers in the city. The water supply of the city is provided by electrically driven pumps working at "off-peak periods" whenever possible. An auxiliary steam installation with a capacity of 1,750 kilowatts is held in reserve for contingencies arising from interruptions in the hydroelectric service, and two steam pumps with a combined capacity of 3,500,000 gallons a day are also maintained to insure continuous water service for the city.

The Pacific Northwest Traction Co. operates a third-rail interurban railroad system between Seattle and Everett. The greater portion of the energy used by the company is supplied by the Seattle-Tacoma Power Co. A small amount of the required current, however, is furnished by the Seattle Electric Co.

The Seattle Electric Co. operates the street-railway system of the city of Seattle and distributes energy for power and light consumption in all parts of the city. It receives hydroelectric energy from the Puget Sound Power Co. and the Pacific Coast Power Co. for the greater part of its demand, but is occasionally provided with a small amount of current from the Seattle-Tacoma Power Co.'s mains. Two auxiliary steam plants are maintained in Seattle by the Seattle Electric Co., capable of furnishing 16,000 kilowatts at rated capacity to insure continuous service and to provide for peak loads.

The Tacoma Railway & Power Co. operates the street-railway system in Tacoma and furnishes some energy for power and light within the city of Tacoma. The latter item is small, for the city of Tacoma maintains a municipal distribution system. The energy distributed by the Tacoma Railway & Power Co. is furnished by the Puget Sound Power Co. and the Pacific Coast Power Co., and auxiliary demands are met by two steam plants having a combined normal capacity of 2,500 kilowatts.

The Puget Sound Electric Railway Co. also employs energy obtained from the Puget Sound Power Co. and the Pacific Coast Power Co. to operate an electric interurban third-rail system between Seattle and Tacoma, with a branch line to Renton. Energy is also distributed to power and light consumers in the small towns along the interurban line.

The lighting department of the city of Seattle operates a hydroelectric plant,[1] having a capacity of 10,400 kilowatts on Cedar River,

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[1] A detailed description of this plant may be found on pages 108-109.

35 miles southeast of Seattle, near Moncton. The plant was built in 1902–1904, and the first current was delivered January 10, 1905. The municipal plant furnishes energy for the city lighting and for other light and power consumption in all parts of the city. It is operating in direct competition with the Seattle Electric Co. and the Seattle-Tacoma Power Co.

The municipal lighting and a large percentage of all other light and power consumption within the city of Tacoma has been furnished by distributing mains installed and maintained by the city. The city water supply is also lifted to the reservoirs by motor-driven pumps operating at off-peak periods whenever possible. The energy delivered to the distribution mains and to the motors which drive the pumps is supplied by the Seattle-Tacoma Power Co. under contract with the commissioner of public works. A municipal hydroelectric plant,[1] having a proposed normal capacity of 20,000 kilowatts, is in course of construction on Nisqually River, 29 miles south and a little east of Tacoma, at Lagrande.

The Seattle, Renton & Southern Railway operates an interurban electric service between Seattle and Renton. The energy consumed is purchased from the Seattle-Tacoma Power Co.

GENERATION AND DISTRIBUTION OF ELECTRIC ENERGY.

Information regarding the amount of primary energy generated and its distribution was secured from the power and operating companies, and from the municipal organizations which supply the community served. The officials of the companies and organizations were very obliging in furnishing all available data and in assisting to interpret them. Some records of distribution, however, were not kept in such a manner that the information desired could be readily obtained. Accordingly it was necessary to estimate some values on a percentage basis to make the information complete for the whole region. The amount of energy distributed in some portions of the community was secured for a number of years, but the lack of similar records in other portions limits the period for which the results outlined in the following pages can be determined.

The output of generators at the hydroelectric plants and the auxiliary steam power produced at the distribution centers furnish the primary source of energy used in the district under consideration. A large amount of the information secured relative to the utilization of the electric current for light, power, and traction was furnished from meters recording the output of distributing mains. Therefore in order to make the use of energy for various purposes comparable the division was based on the output from distributing mains. Wherever the information furnished was recorded by meters at the customer's connection the values have been arbitrarily increased 10 per cent to

[1] A detailed description of this plant may be found on pages 61–62.

make them comparable to those recorded on the mains. Tables 11–13 summarize the sources of primary power by months for the years 1908 to 1911 and the total energy supplied from distributing mains by months for the years 1909 to 1911.

TABLE 11.—*Hydroelectric energy generated, auxiliary steam power, and total energy supplied from distributing mains in the central section of the Puget Sound region for 1908–9.*

[Values in 1,000-kilowatt hours.]

Month.	1908			1909			
	Hydroelectric output from plants.	Auxiliary steam power.	Total power generated.	Hydroelectric output from plants.	Auxiliary steam power.	Total power generated.	Total energy supplied from distributing mains.
January	14,330	2,039	16,370	18,460	1,886	20,350	16,160
February	12,260	2,528	14,790	17,070	1,612	18,680	14,800
March	13,900	1,985	15,880	18,080	2,161	20,240	15,940
April	13,610	1,194	14,800	17,040	2,211	19,250	15,270
May	14,780	982	15,760	18,620	989	19,610	15,630
June	14,320	427	14,750	19,860	2,053	21,910	18,000
July	14,870	300	15,170	20,520	1,554	22,070	18,940
August	15,640	445	16,080	20,170	3,648	23,820	19,730
September	15,630	1,808	17,440	19,320	5,387	24,710	20,420
October	17,010	2,159	19,170	19,630	6,247	25,880	21,590
November	17,470	1,977	19,450	21,010	3,205	24,220	20,240
December	19,040	2,579	21,620	20,320	4,137	24,460	20,650
Total	182,860	18,423	201,280	230,100	35,090	265,200	217,370
Average monthly	15,240	1,535	16,770	19,180	2,924	22,100	18,110
Maximum month	19,040	2,579	21,620	21,010	6,247	25,880	21,590
Percentage average to maximum month	80	60	78	91	47	85	84

TABLE 12.—*Hydroelectric energy generated, auxiliary steam power, and total energy supplied from distributing mains in the central section of the Puget Sound region for 1910 to 1911.*

[Values in 1,000-kilowatt hours.]

Month.	1910				1911			
	Hydroelectric output from plants.	Auxiliary steam power.	Total power generated.	Total energy supplied from distributing mains.	Hydroelectric output from plants.	Auxiliary steam power.	Total power generated.	Total energy supplied from distributing mains.
January	18,090	5,863	23,950	20,460	22,300	2,606	24,910	20,820
February	18,090	3,504	21,590	18,530	18,210	3,759	21,970	18,890
March	21,000	1,976	22,980	19,200	20,810	2,994	23,800	19,950
April	20,540	1,169	21,710	18,140	19,760	1,503	21,260	18,690
May	20,420	1,077	21,500	17,920	21,970	628	22,600	18,570
June	19,740	981	20,720	17,270	21,260	140	21,400	17,470
July	20,300	996	21,300	16,980	22,130	165	22,300	17,910
August	18,640	2,751	21,390	17,380	20,530	2,064	22,590	18,880
September	13,010	7,520	20,530	17,060	21,760	1,791	23,550	19,230
October	22,420	1,364	23,780	19,250	19,400	5,647	25,050	21,460
November	21,390	2,251	23,640	19,610	22,090	2,702	24,790	21,310
December	23,490	2,162	25,650	21,160	[a] 27,000	468	27,470	23,150
Total	237,130	31,614	268,740	222,960	257,220	24,467	281,690	236,330
Average monthly	19,760	2,634	22,390	18,580	21,440	2,039	23,470	19,690
Maximum month	23,490	7,520	25,650	21,160	[a] 27,000	5,647	27,470	23,150
Percentage average to maximum month	84	35	88	88	80	36	86	85

[a] Estimated.

TABLE 13.—*Summary of primary energy and that supplied from distributing mains in central section of Puget Sound region for 1908 to 1911.*

[Values in 1,000-kilowatt hours.]

Energy.	1908	1909	1910	1911
1. Total primary	201,300	265,200	268,700	281,700
2. Total from distributing mains	....	217,400	223,000	236,300
Percentage of item 2 to item 1	....	82.0	83.0	83.9

The foregoing tables indicate a slight increase in the generation and distribution of energy from 1908 to 1911 in the district chosen. In general, the use of power is much less during June, July, and August than in the remainder of the year, although an exception of this rule may be noted in 1909, when the demand occasioned by the Alaska-Yukon-Pacific Exposition was high during those months. The influence that the use of auxiliary power has on equalizing the monthly load is shown by the fact that the percentage of the average monthly load to the maximum month is greater for the hydroelectric output of plants than for the energy used from distributing mains.

Reference has been made to the difficulties encountered in securing the information necessary to account for the distribution of electric current in the entire district. The segregation of the energy used into light, power, and traction can be tabulated for a longer interval in Tacoma and Everett than in Seattle. If tables of segregation were given for each city, however, the operations of several of the companies included in the organization of the Puget Sound Traction, Light & Power Co. would be disclosed. Tables 14–17 indicate the aggregate use of power in all three cities and in a number of adjacent towns by months for 1909, 1910, and 1911.

TABLE 14.—*Utilization of electric energy from distributing mains for the central section of the Puget Sound region for 1909 and 1910.*

[Values in 1,000-kilowatt hours.]

Month.	1909	1910				
				Traction.		
	Total (not segregated).	Light.	Power.	Street car lines.	Interurban lines.[a]	Total consumption.
January	16,164	6,853	5,748	6,826	1,035	20,462
February	14,800	5,842	5,581	6,143	964	18,530
March	15,935	5,743	5,726	6,656	1,073	19,198
April	15,274	5,256	5,449	6,412	1,022	18,139
May	15,629	4,774	5,602	6,457	1,092	17,925
June	18,000	4,624	5,389	6,209	1,052	17,274
July	18,937	4,572	4,903	6,395	1,105	16,975
August	19,731	4,848	5,159	6,306	1,069	17,382
September	20,423	5,254	4,801	5,994	1,013	17,062
October	21,589	6,250	5,498	6,435	1,069	19,252
November	20,237	6,734	5,477	6,327	1,074	19,612
December	20,652	7,777	5,582	6,619	1,184	21,162
Total	217,371	68,527	64,915	76,779	12,752	222,973
Average monthly consumption	18,110	5,711	5,410	6,398	1,063	18,580
Maximum month	21,589	7,777	5,748	6,826	1,184	21,162
Percentage average to maximum month	84	73	94	94	90	88

[a] This item includes the following interurban lines: Puget Sound Electric Railroad, the Pacific Northwest Traction Co., and the Seattle, Renton & Southern Railway.

TABLE 15.—*Utilization of electric energy from distributing mains for the central section of the Puget Sound region for 1911.*

[Values in 1,000-kilowatt hours.]

Month.	Light.	Power.	1911 Traction. Street car lines.	Traction. Interurban lines.[a]	Total consumption.
January	7,071	6,004	6,601	1,148	20,824
February	6,184	5,620	6,086	998	18,888
March	6,264	5,909	6,676	1,102	19,951
April	5,769	5,412	6,487	1,026	18,694
May	5,569	5,239	6,727	1,038	18,573
June	4,987	4,888	6,599	996	17,470
July	5,025	4,888	6,919	1,081	17,913
August	5,606	5,247	6,934	1,090	18,877
September	6,046	5,277	6,843	1,065	19,231
October	7,120	6,006	7,199	1,132	21,457
November	7,452	5,883	6,914	1,058	21,307
December	8,835	6,017	7,155	1,140	23,147
Total	75,928	66,390	81,140	12,874	236,332
Average monthly consumption	6,327	5,532	6,762	1,073	19,690
Maximum month	8,835	6,017	7,199	1,148	23,147
Percentage average to maximum month	72	92	94	94	85

[a] This item includes the following interurban lines: Puget Sound Electric Railroad, the Pacific Northwest Traction Co., and the Seattle-Renton & Southern Railway.

TABLE 16.—*Percentage of light, power, and traction to total consumption in the central section of the Puget Sound region for 1910 and 1911.*

	1910	1911	Average.
Light	30.8	32.1	31.4
Power	29.1	28.1	28.6
Traction:			
Street car lines	34.4	34.4	34.4
Interurban lines	5.7	5.4	5.6
	100.0	100.0	100.0

TABLE 17.—*Utilization of electric energy from distributing mains in kilowatt hours per inhabitant and number of passengers carried per inhabitant in central section of Puget Sound region for 1909 to 1911.*

	1909	1910	1911	Mean.
Light	......	188	197	192.5
Power	......	178	172	175.0
Traction:				
Street car lines	......	211	212	211.5
Interurban lines	......	35	33	34.0
Total consumption	635	612	614	620.3
Passengers carried:				
Street car lines	319	282	261	287
Interurban lines	21.7	20.8	20.2	20.9

NOTE.—The population served in 1910 is shown in Table 10 to be 364,552. Similar values for 1909 and 1911 are estimated as 342,000 and 385,000, respectively.

The total consumption and the amounts used by street car and interurban lines as shown in Tables 14 and 15 are thought to be very near correct. The items for light and for power consumption, however, are not so accurate, because the energy for light and power utilization sold under contract in large quantities was commonly measured by a single meter. It was necessary, therefore, to approximate the amount used for each purpose by means of assumed percentages of the total. Nevertheless the approximations represent only a small proportion of the monthly totals for the whole community and the results are believed to be correct within 5 per cent.

It is interesting to note that the percentage of average month to maximum month is above 90 per cent of the average monthly load for the items of power and traction and that the lighting load is less uniform. This is occasioned by the greater demand for light during the winter months. The same percentages for total consumption indicate that under the present development of demand monthly load factors must necessarily be considerably below 85 per cent.

Table 16 indicates the relation of light, power, and traction to the total consumption. The operation of street car lines is seen to provide the greatest demand for power and the consumption of the interurban service the least demand. The use of light is slightly in excess of the use of power, and the combined use of electric energy for these purposes is about 60 per cent of the total consumption.

Population estimates of the community served were made for the years 1909 and 1911 on the basis of the census enumeration of 1910, and the kilowatt-hour consumption per inhabitant was derived as shown in Table 17. It will be noted that the total consumption is shown to be somewhat greater in 1909 than the two succeeding years. This can be accounted for by the fact that the Alaska-Yukon-Pacific Exposition was held at Seattle from June to October of that year. The demand for energy for all purposes and especially for lighting was considerably above the normal for those months.

COMPARISON OF UTILIZATION OF ELECTRIC ENERGY IN PUGET SOUND AND WILLAMETTE VALLEY REGIONS.

The large market center nearest to the region under consideration and one which thrives under very similar conditions is the lower Willamette Valley in northwestern Oregon.

Information similar to that secured in the central section of the Puget Sound region was obtained for this province for the year 1911, in order that the use of electric energy in the two localities might be compared.

The Portland Railway, Light & Power Co. controls the generation and distribution of electric current in this region. Street railways are operated in Portland and Salem and interurban lines connecting

Portland with Salem and Vancouver, Wash., are provided with power. The principal demand for electric current is furnished by Portland, but distribution systems are also maintained for the other small cities and towns in the region.

Hydroelectric energy is furnished by three power plants having an aggregate normal generating capacity of 31,380 kilowatts, two of which are located on Clackamas River and one on Willamette River. The plant on the Willamette at Oregon City, 12 miles south of Portland, uses about 40 feet of fall and has a capacity of 7,230 kilowatts. A second unit of the generation system utilizes 135 feet of fall on the Clackamas at Cazadero, about 20 miles southeast of Portland, and is capable of providing 14,250 kilowatts at a normal load. The most recent development of the Portland Railway, Light & Power Co. was put into operation during the fall of 1911 and is located at Estacada, on the Clackamas, about 4 miles below the Cazadero plant. A head of 84 feet is realized, and the present installation has a capacity of 9,900 kilowatts. Two auxiliary steam power plants supply peak-load demands and insure continuity of service. They have a combined capacity of 10,550 kilowatts and use California crude oil and sawdust as fuel.

The data secured in the Willamette Valley have been subjected to the same analysis that was given to the information obtained in the Puget Sound region. The consumption of current for light and power is measured by customers' meters in the southern region, and the values for those items have been increased 12 per cent to give equivalent output quantities from distributing mains, which lead from the transformers. The use of energy for light, power, and traction purposes in the two regions is summarized in Table 18, and the source and amount of primary power generated is also indicated.

TABLE 18.—*Electric energy utilized from distributing mains and generated at power plants in central section of Puget Sound and in Willamette Valley regions for the year 1911.*

[Values in 1,000-kilowatt hours.]

Region.	Utilized.					Generated.		
	Light.	Power.	Traction.		Total.	Hydro-electric.	Auxiliary steam.	Total.
			Street-car lines.	Inter-urban lines.				
Central section of Puget Sound...	75,900	66,400	81,100	12,900	236,300	257,200	24,500	281,700
Per cent of total.............	32.1	28.1	34.4	5.4	100	91.3	8.7	100
Willamette Valley...............	36,300	39,200	30,200	21,600	127,300	131,500	20,800	152,300
Per cent of total.............	28.5	30.8	23.7	17.0	100	86.3	13.7	100

The percentages of the total electric power utilized and generated in the two districts are useful in comparing the demand for various purposes and the amount of auxiliary steam power necessary for meeting these demands. It will be noted that the percentages for light and street-car consumption are less in the Willamette Valley than in the Puget Sound region. In the Willamette Valley a slightly greater proportion of electric current is used for power purposes, and the energy supplied to interurban lines is considerably greater than that utilized for the same purposes within the Puget Sound region. The use of a larger percentage of auxiliary steam in the Puget Sound region is due chiefly to a difference in water supply of streams supplying hydroelectric devėlopments in favor of the Willamette Valley.

The two districts vary considerably as regards the concentration of the population served. Portland is the only large city in the Willamette Valley, and the number of small cities and towns supplied with electric current is much greater than in the northern province. Hence it is evident that a marked difference in the per capita consumption might be expected. Practically all the demand supplied in the Puget Sound province arises in the three cities—Seattle, Tacoma, and Everett. Therefore, in order to assume a basis which will make a comparison of per capita consumption reasonable, it is necessary to neglect the portion of the Willamette Valley outside of the city of Portland. Table 19 indicates the kilowatt-hour consumption in the central section of the Puget Sound region and in Portland.

TABLE 19.—*Utilization of electric energy, in kilowatt hours per inhabitant, and number of passengers carried on street-car lines per inhabitant, in central section of Puget Sound region and in Portland for the year 1911.*

	Central section of Puget Sound region.	Portland.
Light	197	146
Power	172	157
Traction street-car lines	212	140
Total, exclusive of interurban service	581	443
Number of passengers per inhabitant carried on street-car lines	261	308

NOTE.—The population served in each locality in 1911 has been estimated on a basis of the 1910 census enumeration. This estimate indicates a population of 385,000 for the central section of the Puget Sound region and 216,000 for Portland.

One of the surprising features shown in the above comparison is that less energy is used for each of the three items of consumption listed in the table in Portland than in the Puget Sound province. Notwithstanding this fact the number of passengers per inhabitant carried in Portland is considerably in excess of the number for the other region. One reason may be cited for this difference of consumption in the two districts. The activity of municipalities in entering the field of competition in the northern district has stimulated a greater development of the market for power and a consequent reduction of rates has made the use of electric energy more economical.

VARIATION IN DEMAND.

General conditions.—The economy attained in a hydroelectric system is largely dependent on uniformity of demand and every effort is made to minimize excessive fluctuations. It is especially desirable to secure a uniform load where storage is not available for regulating stream flow. Under these circumstances a considerable amount of energy will be lost unless the demand can be spread evenly over the 24 hours.

Generally speaking, the use of electric power for manufacturing purposes furnishes the most steady demand, and that for lighting load the most variable. In a western community, where industrial activities are undeveloped, the principal requirements are for lighting and traction, and the use of power during "off-peak periods" is encouraged by offering low rates for such periods. The determination of price is based on a study of the load curve and a consideration of the length and period of service. The demand on systems serving a community requiring light, power, and traction is subject to daily, weekly, and seasonal variations. In order to show these fluctuations in the region under consideration, daily and monthly diagrams have been prepared from data secured from companies and municipalities within the district.

Daily fluctuation.—The diagrams shown in figure 5 represent the different daily load conditions which exist for the Seattle Electric Co. during both summer and winter periods. The load indicated furnishes energy for traction, lighting, and power, and is proportioned approximately as follows: Traction, 55 per cent; lighting, 25 per cent; and power, 15 per cent. Two peaks are shown in both diagrams. The larger of these occurs from 4 to 7 in the afternoon and the smaller from 6 to 8 in the morning. During the summer these peaks are occasioned solely by an increase in the traffic requirements of the street-car lines. In the winter season, however, they are greatly accentuated on account of the lighting load coming on during these intervals. The slight decrease noticeable for the noon hour is caused by discontinued use of power motors in industrial plants. The minimum demand for the 24 hours occurs between 2 and 5 in the morning and does not appear to be affected by the season, as each diagram indicates a minimum load of 4,000 kilowatts. The amount of auxiliary steam power supplied to the distribution mains is shown

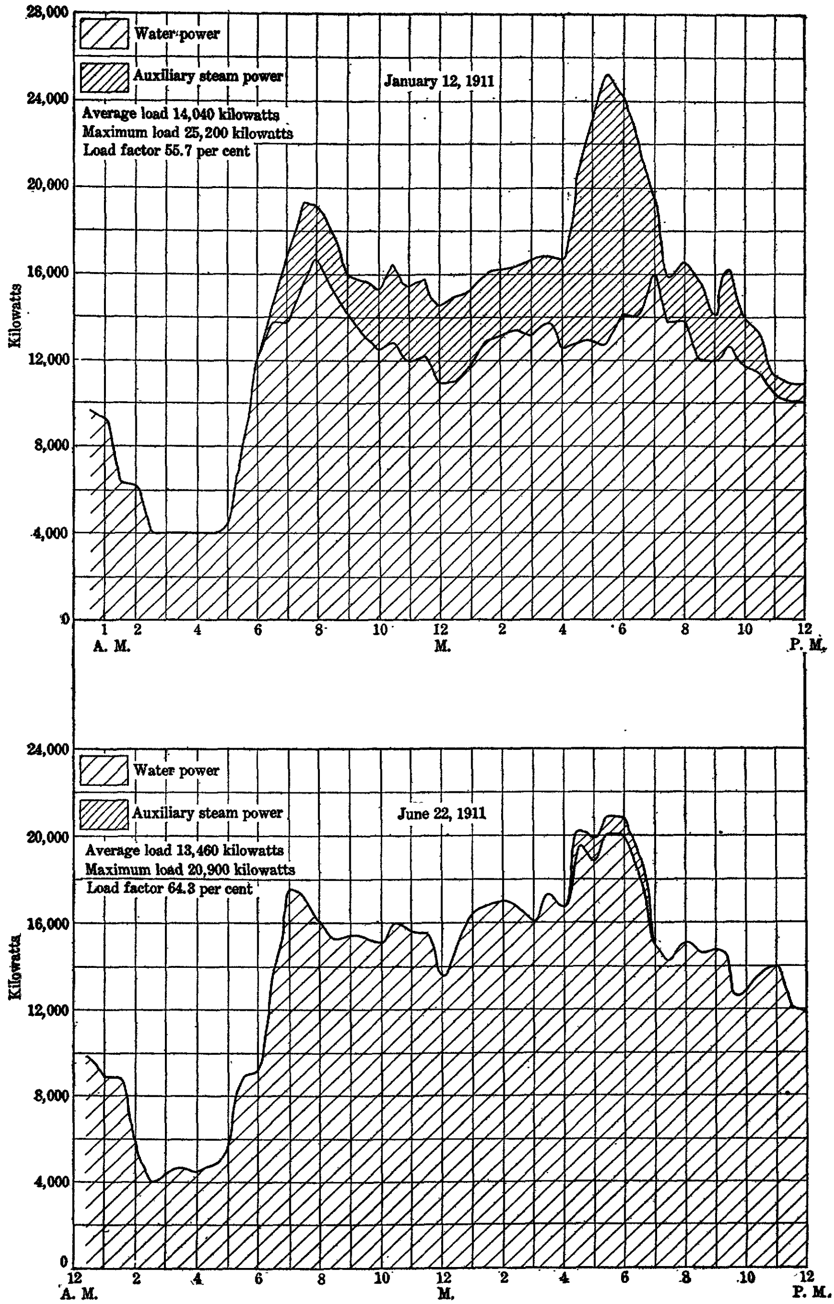

FIGURE 5.—Daily load diagram, Seattle Electric Co.

by the cross hatched area on the diagrams. It will be noted that the maximum demand on the hydroelectric generating plant shown in the diagram, for January 12, 1911, is 16,000 kilowatts and for June 22, 1911, 20,000 kilowatts. This marked difference in the amount of energy supplied from hydroelectric sources is explained by the fact that the minimum flow of Puyallup River at the Electron plant headworks occurs during January and February, instead of the usual low-water period shown on other streams during the summer. As the maximum demand of the year also comes at this season the auxiliary plant is forced to take a large percentage of the load.

The daily load diagrams of the Seattle-Tacoma Power Co. shown in figure 6 indicate fluctuations of a different kind of demand. It has been stated elsewhere that the Seattle-Tacoma Power Co. deals chiefly with contracts to supply energy in wholesale quantities. The local distribution of light and power in Seattle is a comparatively small item of the total output, and the only energy supplied for operating city street-car lines is that used in the city of Everett. A very small percentage of the total load, however, is furnished to the Seattle, Renton & Southern Railway Co. for interurban service. The use of energy for driving motors and for other industrial purposes represents a large proportion of the aggregate demand. This fact is shown very clearly by the decided drop in the demand during the noon hour. The peak loads for the Seattle-Tacoma Power Co. also occur in the morning and afternoon, but they extend over a much longer period than those for the Seattle Electric Co. The afternoon peaks, which indicate the maximum for the day, are caused by the lighting demand coming on before the industrial motors are cut out of the circuit, for both diagrams represent the load conditions which prevail during the winter season. It appears that the minimum load is carried between midnight and 5 a. m. It represents 53 per cent of the maximum load for December 7, 1909, and 48 per cent for October 31, 1910. The load factors of this system are considerably higher than those of the Seattle Electric Co. for the reason that energy is sold in wholesale lots and contracts for large quantities of power during off-peak periods are encouraged by low rates. On the other hand the Seattle Electric Co. handles a more localized distribution, supplying the needs of customers who require for the most part small quantities of energy during the peak load intervals. The portion of the peak loads carried by auxiliary steam power is shown to be small. The chief function of auxiliary steam power in connection with the Seattle-Tacoma Power Co.'s plant is to supplement the load that can be carried by the Snoqualmie Falls plant during the low-water period, which occurs in August and September.

Weekly fluctuations.—Weekly fluctuations in the load are occasioned chiefly by a difference in the consumption during average week days

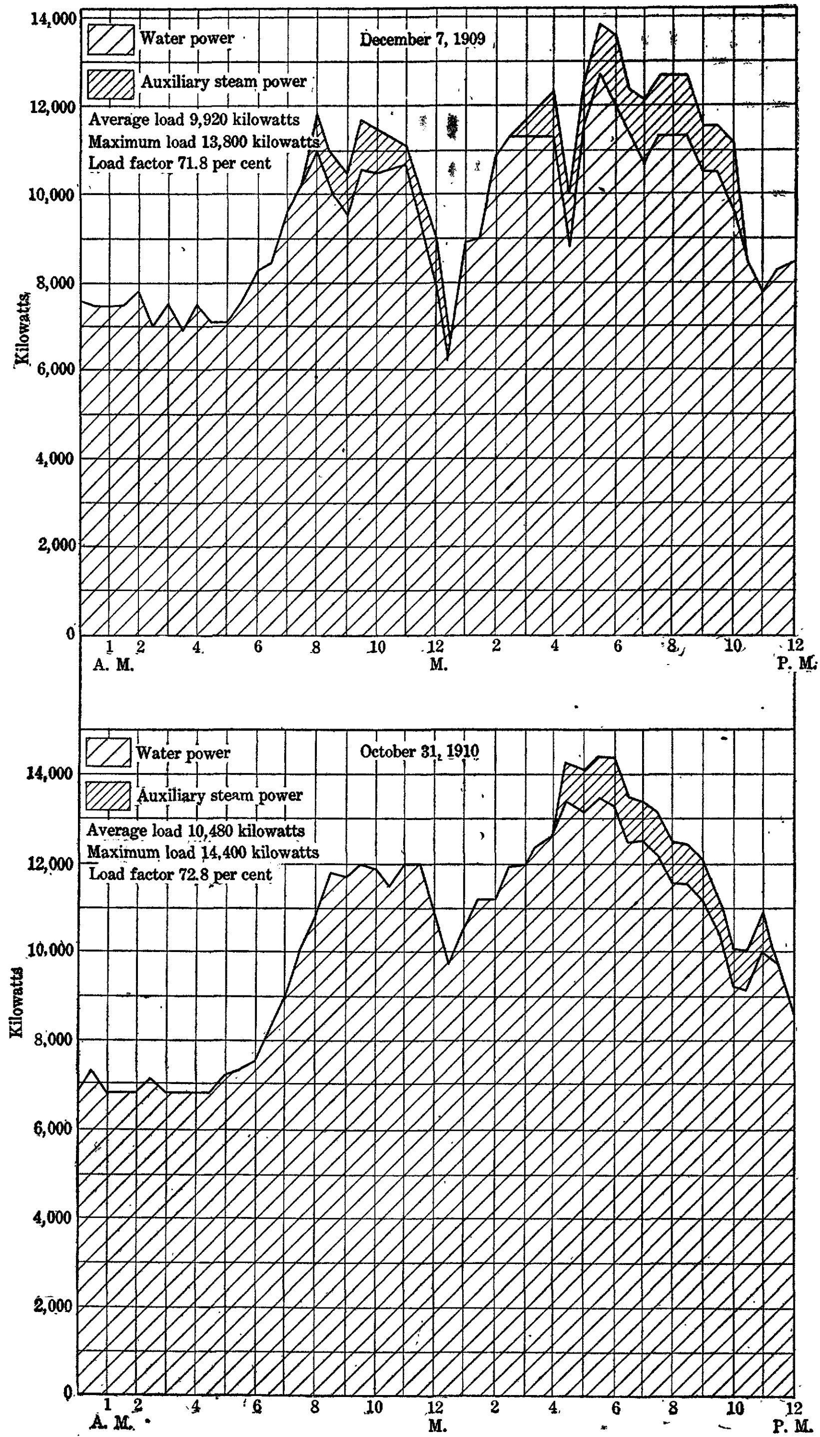

FIGURE 6.—Daily load diagram, Seattle-Tacoma Power Co.

from that of Saturday and Sunday. The Sunday load of street-car lines and for lighting is not greatly at variance with the week-day loads, although the peaks come at slightly different hours of the day. The diminished use of industrial power on Sunday, however, results in a lower average load for that day than other days in the week. A comparison of daily loads at the Electron power plant for the period June to October, 1911, indicates that the Sunday load is 92 per cent of the average week-day load. The maximum demand for a week often comes Saturday afternoon and evening, especially in the winter season, when the requirements for light, power, and traction overlap.

Seasonal fluctuation.—The seasonal variation is due to a very appreciable increase in the use of light during the winter months. As the low-water flow of most of the streams on the west side of the Cascade Range occurs during August and September this is a fortunate condition. Diagrams indicating the average monthly distribution of the Seattle Electric Co. from 1905 to 1911, and of the Tacoma municipal distribution from 1903 to 1911, are shown in figures 7 and 8.

The output of the Seattle Electric Co. indicates a minimum load for the summer months for all years except 1909. The demand due to the Alaska-Yukon-Pacific Exposition, during September of that year, was 32 per cent greater than the mean for the year. The growth of the system was so great during the years 1905 to 1917 that the seasonal variation does not appear to be so great as it would otherwise. The fluctuation shown for 1908 to 1911 is more nearly representative of the normal variation that might be expected for a system in this region carrying a load similar to that of the Seattle Electric Co.

The Tacoma municipal distribution system furnishes a striking example of the great seasonal variations that may occur for a lighting load. The amount of energy used for lighting in this system is 97 per cent of the total distributed and the remainder is employed to operate direct-current motors. The difference between the maximum monthly demand and the average for the year ranges between 59 per cent for 1903 and 1904 and 75 per cent for 1911. The enormous and fairly uniform growth of the municipal system is also noteworthy. The average yearly consumption increased 360 per cent within the period indicated on the diagram.

The maximum output for each month, average monthly output, and monthly load factor of the Seattle municipal hydroelectric plant is shown by means of diagrams in figure 9. The energy furnished by this system is consumed solely for light and power purposes within the city of Seattle. The use for power purposes constituted 60 per cent of the total demand in 1910 and 43 per cent in 1911. As might be expected, the fluctuation of the maximum demand is somewhat greater than that of the average monthly load, but the shape of the

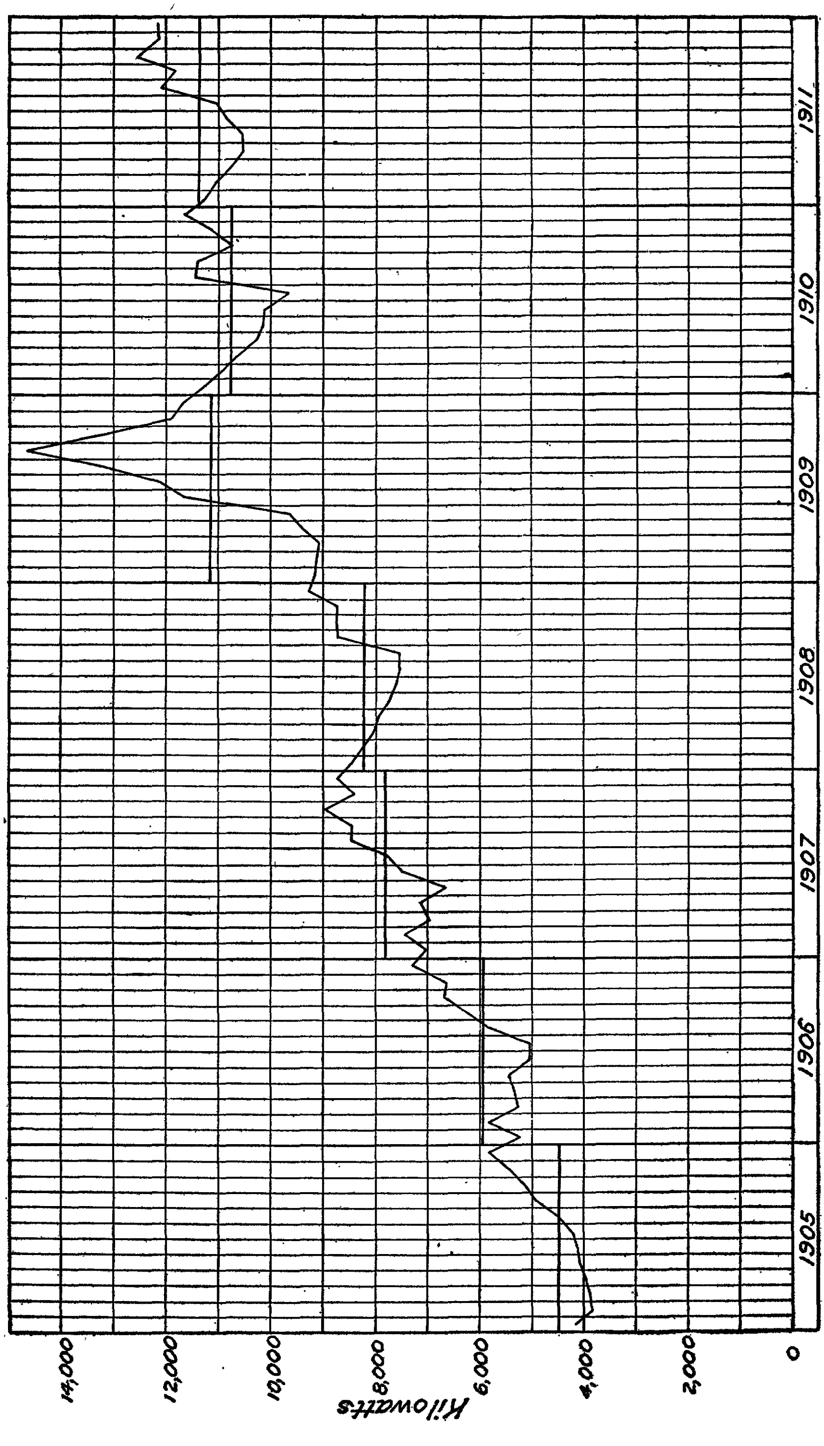

FIGURE 7.—Diagram of mean monthly and yearly load, Seattle Electric Co.

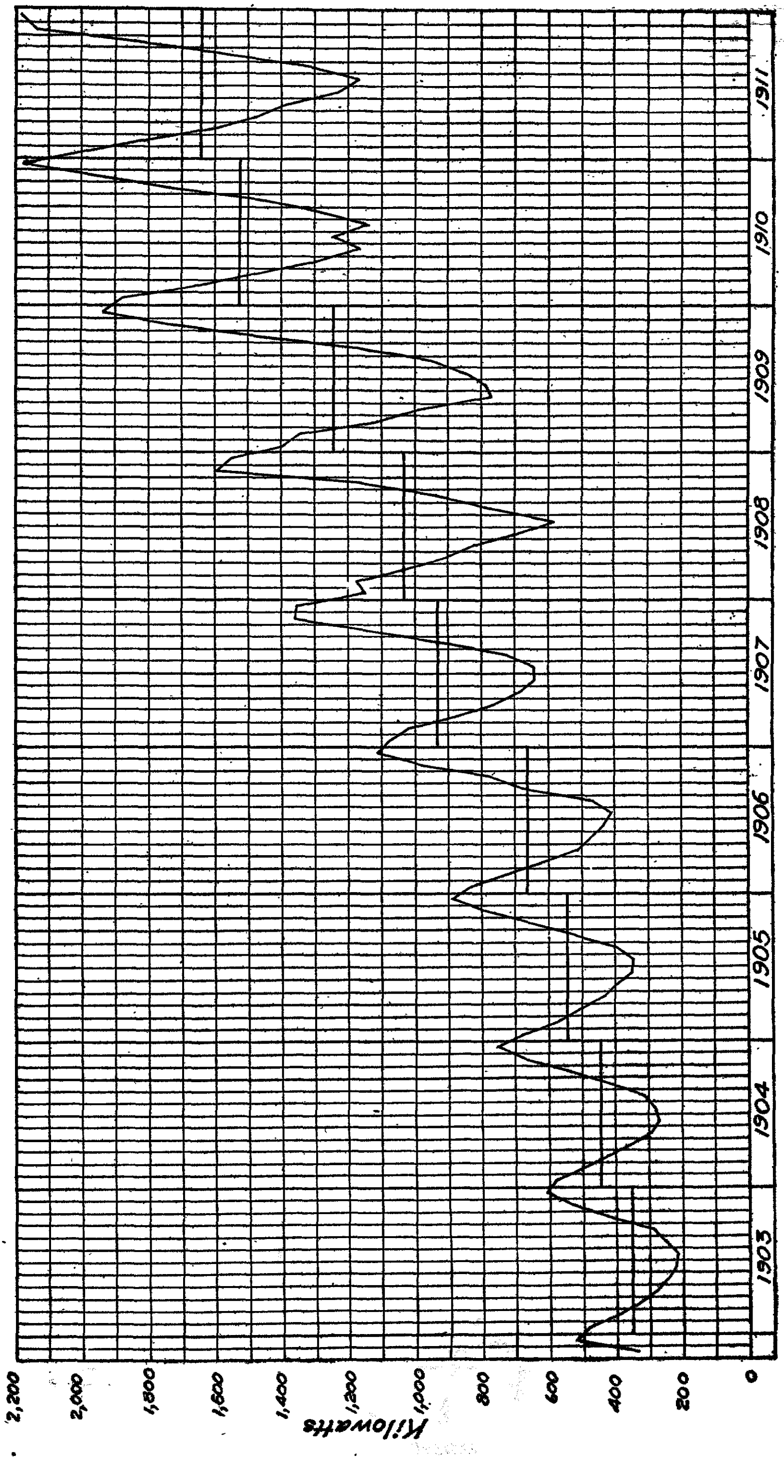

FIGURE 8.—Diagram of mean monthly load purchased from Seattle-Tacoma Power Co. for Tacoma municipal distribution.

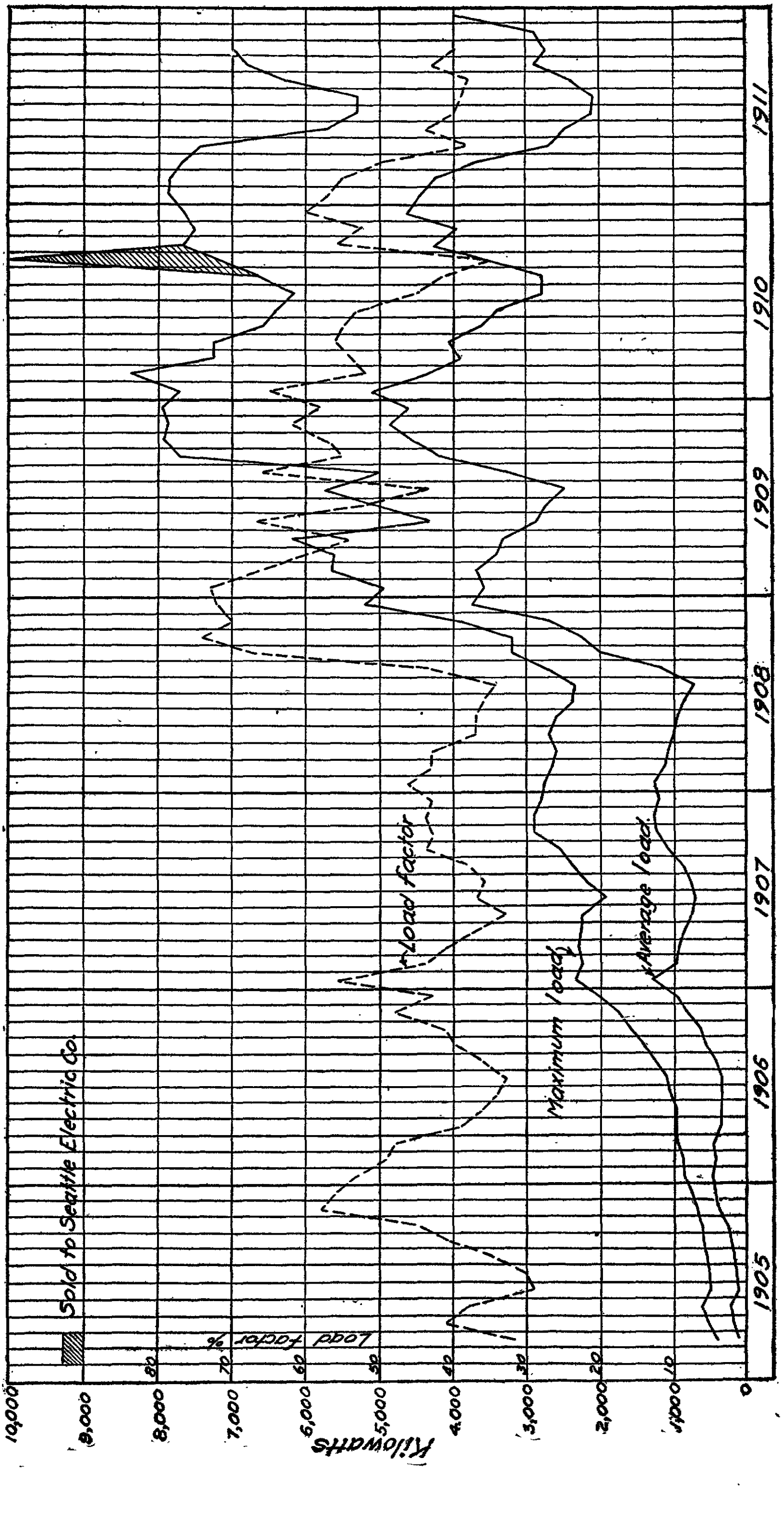

FIGURE 9.—Maximum and average load and monthly load factor, Seattle city lighting plant.

former diagram conforms very closely to the variations of the latter. The monthly load factor, which is the relation of the maximum demand for the month to average load for the month, is seen to be considerably higher during the latter part of 1908 and throughout 1909 than for the other years. This was occasioned by a large use of energy at off-peak periods to pump water for hydraulicking in the city regrading work. The contract for this service was drawn in such a manner that the circuit connecting the pump motors with the distribution system could be cut out without notice. From September 19 to 25, 1910, the Electron power plant was shut down on account of a break in the flume which diverts water from Puyallup River. Consequently it was necessary for the Seattle Electric Co. to purchase energy from the municipal system to supplement the auxiliary steam plant in carrying the company's demand during that interval. This circumstance accounts for the high maximum demand and consequent small monthly load factor of the municipal system for the month mentioned. A maximum monthly load factor of 74 per cent was obtained during October, 1908, and the minimum occurred in June, 1905, before the system had developed a substantial market for energy.

Load factors.—The revenue of a generation and distribution system varies in direct proportion to the salable energy which it delivers. On the other hand, the initial cost of installation varies directly with the capacity of plant that must be held in readiness to serve the demand. As the average load is an index of the energy sold and the maximum load represents the necessary machinery capacity, the relation between these amounts, or the load factor, is a very important item to be considered in designing plants and in determining the value of storage or of auxiliary steam power to supplement the low-water flow, which ordinarily limits hydroelectric development.

Monthly load factors were secured from operating systems in the central section of the Puget Sound region to account for the fluctuation of about 75 per cent of the total load distributed. Sufficient information was also obtained to approximate the remaining 25 per cent of the load with a fair degree of accuracy. It is therefore possible to estimate maximum demands of the several systems and to derive maximum aggregate demands for the region. These values, together with the average demands and the corresponding load factors, are given in Table 20. No doubt the maximum aggregate demands shown are somewhat greater than the true maximum demand, because no account is taken of the diversity factor which would obtain in uniting the loads of the six systems. The load factors given in the table are therefore conservative and if used in design would allow a margin of safety. The influence of the diversity factor could only be determined by a careful study of daily maximums of the different systems.

TABLE 20.—*Maximum aggregate demand, average load, and load factor for distribution systems in the central section of the Puget Sound region for 1909–1911.*

Month.	1909			1910			1911		
	Maximum aggregate demand.	Average demand.	Load factor.	Maximum aggregate demand.	Average demand.	Load factor.	Maximum aggregate demand.	Average demand.	Load factor.
	Kw.	*Kw.*	*Per ct.*	*Kw.*	*Kw.*	*Per ct.*	*Kw.*	*Kw.*	*Per ct.*
January	42,700	21,700	50.8	51,700	27,500	53.2	56,000	28,000	50.0
February	42,900	22,000	51.3	52,700	27,600	52.4	54,400	28,100	51.6
March	40,700	21,400	52.6	48,300	25,800	53.4	50,900	26,800	52.6
April	39,100	21,200	54.2	46,200	25,200	54.6	49,100	26,000	53.0
May	39,200	21,000	53.6	43,500	24,100	55.4	48,700	25,000	51.3
June	41,900	25,000	59.6	42,600	24,000	56.3	47,200	24,300	51.5
July	44,100	25,400	57.6	44,100	22,800	51.7	45,700	24,100	52.8
August	46,500	26,500	57.0	45,100	23,400	51.9	52,500	25,400	48.4
September	51,800	28,300	54.6	49,000	23,700	48.4	55,100	26,700	48.5
October	57,200	29,000	50.7	53,600	25,900	48.3	59,300	28,800	48.6
November	53,000	28,100	53.0	54,800	27,200	49.6	63,300	29,600	46.8
December	54,900	27,700	50.5	55,800	28,400	50.9	68,700	31,100	45.2
Mean	46,200	24,800	53.8	48,900	25,500	52.2	54,200	27,000	50.0
Maximum	57,200	29,000	59.6	55,800	28,400	56.3	68,700	31,100	53.0
Load factor for year		43.4			45.7			39.3	

For some unaccountable reason the monthly load factors listed in the foregoing table decreased from 1909 to 1911. The high figures for the summer months of 1909 can be explained by the enormous use of electric energy during the Alaska-Yukon-Pacific Exposition, and it is possible that a discontinuance of the Seattle regrading operations in 1911 may partially account for the smaller figures for that year. The mean yearly maximum demand increased during the three years in about the same proportion as the yearly average demand.

STEAM POWER.

Auxiliary steam power.—The total auxiliary steam power maintained by systems of the Puget Sound Traction, Light & Power Co. amounts to 21,250 kilowatts, or about 31 per cent of the maximum aggregate demand for December, 1911, as shown in Table 20. It therefore appears that greater economy can be obtained in supplying energy from a combination of steam and water power plants than from hydroelectric sources alone. The steam installations were put into operation while the primary water power was furnished from Snoqualmie Falls and Electron. Neither of these plants is provided with storage facilities more than sufficient for regulating the daily fluctuation in load. It is probable that the large amount of storage available in the new White River project will make it feasible to abandon a portion of the steam installation.

A large portion of the energy included in the power schedules of this report is based on the minimum flow of streams, for the reason that storage possibilities are lacking. An abundance of good steaming coal near the market centers and the low price of California crude oil will probably render auxiliary steam plants a necessity to economical performance in developing such power.

Coal.—It has been mentioned that Washington is the only State west of the Rocky Mountains in which the production of coal is an important industry. The principal coal fields of the State lie on the west side of the Cascade Range and for the most part are located near the Puget Sound waterfront. The quality ranges from subbituminous to bituminous coking coals, of which a large proportion of the supply delivered to the market is suitable for use in generating steam. Estimates made by M. R. Campbell, of the United States Geological Survey,[1] indicate an original coal supply of 20,000,000,000 short tons. The total consumption from 1860 to 1910 has amounted to 53,647,802 tons, which represents an exhaustion of 80,000,000 tons. Hence only four-tenths of 1 per cent of the original coal supply of the State was exhausted at the end of 1910. The use of Washington coal for producing steam on ocean-going vessels and to furnish primary power for industrial purposes has constituted the principal demand, although the manufacture of coke has assumed considerable proportions. The yearly output of all the mines in the State, together with the average price per short ton and the percentage of the total produced in King and Pierce counties, is given in Table 21.

TABLE 21.—*Annual coal production of Washington, in short tons, for 1906–1910.*

Year.	Loaded at mines for shipment.	Total mined.	Per cent of total produced in King and Pierce counties.	Average price per ton at mine.
1906	3,008,148	3,276,184	56	$1.80
1907	3,365,097	3,680,532	55	2.09
1908	2,715,920	3,024,943	49	2.21
1909	3,302,237	3,602,263	51	2.54
1910	3,522,347	3,911,899	52	2.50

Oil.—The increasing use of California crude oil in competition with coal in the Pacific coast States has greatly influenced coal production in Washington. During the past two years the transcontinental railroads have all provided oil-burning locomotives for main-line and switching purposes. The largest and most up-to-date steam power plant in the State utilizes oil for fuel. This plant has a normal capacity of 13,000 kilowatts and is maintained by the Seattle Electric Co. in Seattle to supplement hydroelectric service. The use of oil in auxiliary steam plants is especially advantageous, for the reason that it is not necessary to maintain banked fires to insure a quick development of steam to meet unexpected peak loads.

[1] Parker, Edward W., Production of coal in 1910: Advance chapter from Mineral Resources U. S. for 1910, U. S. Geol. Survey, 1911, p. 215.

It is estimated[1] by Ralph Arnold, formerly of the United States Geological Survey, that the known oil fields of California will yield 5,000,000,000 barrels to 8,000,000,000 barrels. The exhaustion of this supply will require 45 to 80 years at a yearly consumption of 75,000,000 barrels or 50 per cent greater than the present yearly consumption.

The production of oil in California and the cost per barrel at the wells and at Seattle is given in Table 22.

TABLE 22.—*Annual production of petroleum in California for 1906 to 1910.*

Year.	Quantity produced (barrels).	Increase (per cent).	Average price per barrel at wells.	Price delivered at Seattle.[a]
1906	33,098,598		$0.239	$0.70
1907	39,748,375	20	.370	1.20
1908	44,854,737	13	.522	1.10
1909	55,471,601	24	.554	1.00
1910	73,010,560	32	.490	.90
1911				.75

[a] These values were furnished by the Standard Oil Co.

Coal versus oil.—With a continuity of supply assured, the economy obtained in the use of oil for fuel has a marked influence on the industrial activities in the Pacific coast States. The fact that oil is being used in large quantities in the very heart of the coal-producing section of Washington seems to indicate that oil will eventually dominate the market completely. Various tests and estimates indicate that in number of heat units supplied 1 short ton of Washington coal is equivalent to 2.8 to 3.8 barrels of California crude oil. The relation between the two varies greatly on account of the considerable difference in the grades of both products. Ordinarily the ratio between California crude oil and Washington coal is taken as 3.5 barrels to 1 ton, and it is probable that a large proportion of the steaming coal would not give a much greater duty than that when compared with the average grade of oil on the market. The ratio of 3.8 to 1 has been obtained in actual practice, but is considerably more favorable to coal than other known tests and estimates indicate.

The remarkable efficiency shown by the Diesel oil engine in European practice has only recently been obtained in American industry. There is no reason to doubt the adaptability of California crude oil to the Diesel engine, and it is reasonable to anticipate that steam installations on the Pacific coast will be gradually displaced by this type of primary power.

[1] Day, David T., Production of petroleum in 1910: Advance chapter from Mineral Resources U. S. for 1910, U. S. Geol. Survey, 1911, pp. 91 and 95.

RATES.

METHODS OF ESTABLISHMENT.

One of the most essential elements to be considered in studying the market conditions in a given locality is the schedule of rates in operation for the various uses of electric current. The revenues must permit a profit on the capital invested in generation and distribution systems. The lack of uniformity in demand is a serious drawback to the economical operation of electric installations in view of the fact that the fixed charges are no greater for a continuous load than for a varying one. This in a great measure is also true of operating expenses. It has been shown elsewhere that the fluctuations caused by some classes of service is very great, so that peak demands are much larger than the average demand. Therefore, rates must be differentiated to stimulate the use of electric current at off-peak periods and to avoid high loads for short intervals.

The use of energy for lighting constitutes the principal short-service demand, and accordingly higher rates are imposed on that class of business. Obviously power for industrial purposes could be supplied more cheaply than for a lighting load, because the load factor is larger. Where the consumption can be limited to off-peak periods by contract, power loads can be carried by hydroelectric installations with practically no additional expense, and the rates governing such service can be made much lower than the average cost of production.

Numerous and often complicated methods are adopted in establishing rates. The purpose of all systems, however, is to adjust the expenses and profit charges equitably among the various classes of load and to encourage long-service demands. This is often accomplished by multiple rates, based on quantity of energy consumed. A more scientific method, however, is to base the rates on the load factor as actually determined by maximum demand meters or as estimated from full connected load.

The rates in operation in the Puget Sound region follow both schemes. Rates for residence lighting are based on the quantity consumed, and the commercial lighting and power rates vary with the load factor. The published schedules of the various systems in the region lack uniformity, and an effort has been made to express the data presented in the following pages in analogous terms.

RATES IN SEATTLE.

Residence lighting.—The schedule of rates for residence lighting is based on kilowatt-hour consumption directly, without taking into account variable load factors. The following rates are levied by both the Seattle Electric Co. and the Seattle municipal system. The first 60 kilowatt hours is sold at 7 cents a kilowatt hour and for all additional consumption a rate of 4 cents a kilowatt hour is charged.

Free lamp renewals are granted. The minimum monthly charge of the Seattle Electric Co. is $1 and of the Seattle municipal system 75 cents.

Commercial lighting.—The commercial lighting rates are determined by load factors based on the connected load. The Seattle Electric Co.'s schedule requires the selection of a guaranteed monthly rate for the year by the customer. The most economical rate for any given demand depends on the accuracy with which the load factor of that demand can be estimated. The municipal rate per kilowatt hour is determined by the quantity of energy supplied per connected kilowatt during the month. Tables 23 and 24 indicate the rates charged by the two companies.

TABLE 23.—*Commercial lighting schedule of Seattle Electric Co.*

Rate per kilowatt hour (cents).	Kilowatt hours per connected kilowatt per month.	Load factor (per cent).	Guaranteed minimum monthly charges per connected kilowatt for the year.
8	41.9	5.7	$3.35
7	52.9	7.2	3.70
6	66.7	9.1	4.00
5.5	82.0	11.2	4.50
5	100	13.7	5.00
4.5	123	16.8	5.55
4	154	21.1	6.15
3.5	191	26.2	6.70
3	243	33.3	7.30
2.5	314	43.0	7.85
2.25	373	51.1	8.40
2	452	61.9	9.05
Flat rate..	....	(a)	9.50

a Economical above 65 per cent.

NOTE.—Free lamp renewals are granted, including and above 3.5 cents a kilowatt hour. Quantity discounts are given on statements as follows: First $100, a discount of 10 per cent; second $100, a discount of 15 per cent; all over $200, a discount of 20 per cent.

TABLE 24.—*Commercial lighting schedule of Seattle municipal system.*

Rate per kilowatt hour (cents).	Kilowatt hour per connected kilowatt per month.	Load factor (per cent).	Rate per month.
8	0- 60	8.2	$1.00-$4.80
7	72.5	9.9	5.08
6	90	12.3	5.40
5	116	15.9	5.80
4	160	21.9	6.40
3	240	32.9	7.20
2.5	312	42.7	7.80
2	425	58.2	8.50
1.5	640	87.6	9.60

NOTE.—The minimum charge per month is fixed by the superintendent of the municipal system, but is not less than $1 a month.

Free lamp renewals are granted for all lamps furnished by the city.

Where the kilowatt-hour consumption lies between values given in the table intermediate rates are charged.

Power.—The power rates are based on the load factor and the size of the motor installation. The rate per kilowatt hour is dependent on the number of kilowatt hours used for each connected kilowatt per month and the horsepower capacity of the motors. The schedule of rates is given in Tables 25 and 26.

TABLE 25.—*Power schedule of the Seattle Electric Co.*

Rate per kilowatt hour (cents).	1 to 20 horsepower.		21 to 100 horsepower.		101 horsepower and over.	
	Kilowatt hours per connected kilowatt per month.	Load factor (per cent).	Kilowatt hours per connected kilowatt per month.	Load factor (per cent).	Kilowatt hours per connected kilowatt per month.	Load factor (per cent).
6	0- 65	0- 8.9	0- 65	0- 8.9	0- 60	0- 8.2
5	80	11.0	75	10.3	75	10.3
4	105	14.4	100	13.7	90	12.3
3	155	21.2	140	19.2	120	16.4
2	255	34.9	220	30.1	185	25.3
1.5	375 and over.	51.4	305	41.8	245	33.6
1	....	....	485 and over.	66.4	370	50.7
.9	....	....	....	....	415	56.8
.8	....	....	....	....	465	63.7
.75	....	....	....	....	535	73.3

NOTE.—The minimum charge per connected horsepower is $1 a month. The rate for electric elevators is 3 cents a kilowatt hour subject to a minimum charge of $2 per horsepower a month. Where the kilowatt hour consumption lies between amounts given in the table, intermediate rates are charged.

TABLE 26.—*Power schedule of the Seattle municipal system.*

Rate per kilowatt hour (cents).	1 to 20 horsepower.		21 to 100 horsepower.		100 horsepower and over.	
	Kilowatt hours per connected kilowatt per month.	Load factor (per cent).	Kilowatt hours per connected kilowatt per month.	Load factor (per cent).	Kilowatt hours per connected kilowatt per month.	Load factor (per cent).
7	0-52	0-7.1	0-52	0-7.1	0-52	0-7.1
6	63.5	8.7	62	8.5	60.75	8.3
5	80.04	11.0	76.4	10.5	73	10.0
4	106	14.5	99	13.6	91.4	12.5
3	154	21.1	137.5	18.8	122	16.7
2	257	35.2	218	29.9	184	25.2
1.5	375	37.7	305	41.8	246.6	33.8
1	624 and over.	85.5	483	66.2	371.8	50.9
.9	....	....	545	74.6	414	56.7
.8	....	....	624	85.5	466	63.8
.7	....	....	....	....	534	73.2
.6	....	....	....	....	624	85.5

NOTE.—Commercial lighting rates apply to installations of less than 1 horsepower. The minimum charge is $1 a month per connected horsepower. Special rates for current used between 8 a. m. and 4 p. m. or for such other hours as may seem expedient are made by the superintendent of the municipal system. Where the kilowatt-hour consumption lies between amounts given in the table, intermediate rates are charged. Power for driving elevator motors is sold under separate contracts.

RATES IN TACOMA.

Residence lighting.—Practically all of the energy used for lighting in Tacoma is distributed from the municipal system. The city rates are based solely on consumption and are not influenced by load factor. The following rates apply for both residence and commercial lighting. The first 50 kilowatt hours is sold at a rate of 6 cents a kilowatt hour, subject to a minimum monthly charge of 50 cents. Additional consumption between 50 and 100 kilowatt hours is sold at 5 cents a kilowatt hour and between 100 and 2,000 kilowatt hours at 4 cents a kilowatt hour. The rate for all consumption above 2,000 kilowatt hours is 3 cents a kilowatt hour. Hospitals and kindred charitable institutions are furnished with electric current at a discount of 20 per cent from the regular rates if the bills are paid promptly.

A small percentage of the lighting load in Tacoma is carried by the Tacoma Railway & Power Co. and the Puget Sound Electric Co. The principal distribution of the latter company, however, is in the small towns between Tacoma and Seattle. The rates of both are the same and are as follows:

The first 20 kilowatt hours are scheduled at 10 cents a kilowatt hour, the second 20 at 9 cents a kilowatt hour, and the third 20 at 8 cents a kilowatt hour. For all consumption over 60 kilowatt hours a rate of 5 cents a kilowatt hour applies. The minimum charge of the Tacoma Railway & Power Co. is 10 cents per 16 candlepower equivalent, but not less than $1 a month. The minimum charge of the Puget Sound Electric Co. is $1 per month.

Commercial lighting.—The municipal and the Tacoma Railway & Power rates for commercial lighting are the same as those given for residence lighting. The Puget Sound Electric Co. has a special rate for commercial lighting which is based on the hours used and connected load. The first 60 kilowatt hours per connected kilowatt are sold at 10 cents a kilowatt hour and additional consumption at 3 cents a kilowatt hour. The minimum monthly charges are 10 cents per 16-candlepower equivalent, but not less than $1.

Power.—The charges for the use of energy for power by the Tacoma municipal system are fixed by the commissioner of public works, subject to the approval of the fire and water committee of the city council. The minimum charge is $1.50 a month.

The schedule of rates for power consumption fixed by the Tacoma Railway & Power Co. is based on load factor and a minimum monthly guaranty. The rates are shown in Table 27.

TABLE 27.—*Power schedule of Tacoma Railway & Power Co.*

Rate per kilowatt hour (cents).	Kilowatt hours per connected kilowatt per month.	Load factor (per cent).	Guaranteed minimum monthly charge per connected kilowatt for the year.
3.0	44.7	6.1	$1.34
2.75	61.1	8.4	1.68
2.5	80.4	11.0	2.01
2.25	104	14.2	2.34
2.0	134 and over.	18.4	2.68

The Puget Sound Electric rates are based on quantity consumption. The first 20 kilowatt hours are sold at 8 cents a kilowatt hour, the second 20 at 7 cents a kilowatt hour, and the third 20 at 6 cents a kilowatt hour. A charge of 4 cents a kilowatt hour applies for all consumption over 60 kilowatt hours. Special rates may be made in accordance with a contract with the public-service commissioner by both the Tacoma Railway & Power Co. and the Puget Sound Electric Co.

RATES IN EVERETT.

Residence lighting.—The residence lighting schedule in Everett follows the multiple-rate system, as do those of Seattle and Tacoma, and is based solely on the quantity consumed. The first 20 kilowatt hours is sold at 11 cents a kilowatt hour, the second 20 at 10 cents a kilowatt hour, and the third 20 at 9 cents a kilowatt hour. All consumption over 60 kilowatt hours is scheduled at 8 cents a kilowatt hour. The minimum charge per month is $1.11 and free carbon lamp renewals are granted. All bills are subject to a discount of 10 per cent if paid within 10 days after date of issuance.

Commercial lighting.—The commercial lighting rates are based on the relation between demand and connected load. They require the selection of a guaranteed minimum monthly charge for the year, so that the economy of the rate is dependent on the accuracy of the load-factor determination. The maximum demand is based on the full connected load or is determined by a maximum-demand meter. The maximum as recorded by the meter is used until November of the year in which it is made. Thereafter a new demand is established in the months of November, December, or January for the succeeding year. The minimum charge per month is $1.11 and free carbon lamp renewals are given. All bills are subject to a discount of 10 per cent if paid within 10 days after date of issuance.

The schedule of commercial lighting rates of the Everett Railway, Light & Water Co. is given in Table 28.

TABLE 28.—*Commercial lighting rates of the Everett Railway, Light & Water Co.*

Schedule rate (cents).	Discounted rate (cents).	Kilowatt hours per connected kilowatt per month.[a]	Load factor [a] (per cent).	Guaranteed minimum monthly charge per connected kilowatt for the year.
8.88	7.99	34.9	4.8	$2.79
8.33	7.50	44.7	6.1	3.35
7.77	6.99	55.9	7.7	3.91
7.22	6.50	68.8	9.4	4.47
6.66	5.99	83.8	11.5	5.02
6.11	5.50	101	13.8	5.58
5.55	5.00	123	16.8	6.15
5.00	4.50	149	20.4	6.70
4.44	4.00	182	24.9	7.27
3.88	3.50	223	31.1	7.82

[a] These figures are computed from the discounted rates.

Power.—The power rates are based on the size of motor equipment and the number of hours use per month of each connected kilowatt or maximum demand as determined by meter. The rates of the Everett Railway, Light & Water Co. are identical with those of the Seattle municipal system in Seattle. However, the Everett schedule does not include as low rates per kilowatt hour for high load factors. The minimum rate for motors from 1 to 20 horsepower is 1½ cents a kilowatt for a consumption per connected kilowatt of 375 kilowatt hours or over. The minimum rate for motor installations of 21 to 100 horsepower capacity is 1 cent for 483 kilowatt hours or more per connected kilowatt, and that for motors of over 100 kilowatts is 0.75 cent for 534 kilowatts or more per connected kilowatt. The minimum monthly charge is $1 per horsepower of connected motor installation.

COMPARISON.

It is impossible to give a correct relation between different systems of rates in tabulated form. Therefore diagrams have been prepared to show the differences between the various schedules for residence lighting, commercial lighting, and power. In order to simplify the diagrams and to make them consistent with one another the monthly charge has been taken as one of the coordinates instead of the rate per kilowatt hour. The kilowatt hours consumed per month has been chosen for the other coordinate.

The schedules shown in the residence lighting diagrams in figure 10 are all multiple rates based on quantity consumption. The Tacoma municipal rates are shown to be the lowest for this class of load.

The commercial-lighting diagrams in figure 11 are a little more complicated than the residence-lighting diagram, and for this reason radial lines, representing rates per kilowatt hour, have been drawn to facilitate interpretation. The rates are based on hours use per month per connected kilowatt, or in other words the load factor. In addition, the rates of the Everett Railway, Light & Water Co. and the Seattle Electric Co. are subject to the selection of a minimum monthly charge, which applies throughout the year. Therefore the monthly charges of those companies as shown on the diagram are the minimum charges that can obtain under that system. The customers' charges will follow the diagram very closely if the minimum charge chosen corresponds with the true load factor for the load carried. The schedules of the Seattle municipal system and the Puget Sound Electric Co. represent actual charges and the corresponding rates per kilowatt hour are determined in accordance with the relation to the metered consumption and the connected load.

The schedules for power are shown in figure 12. They are based on hours use per month and the capacity of the motor installation. The

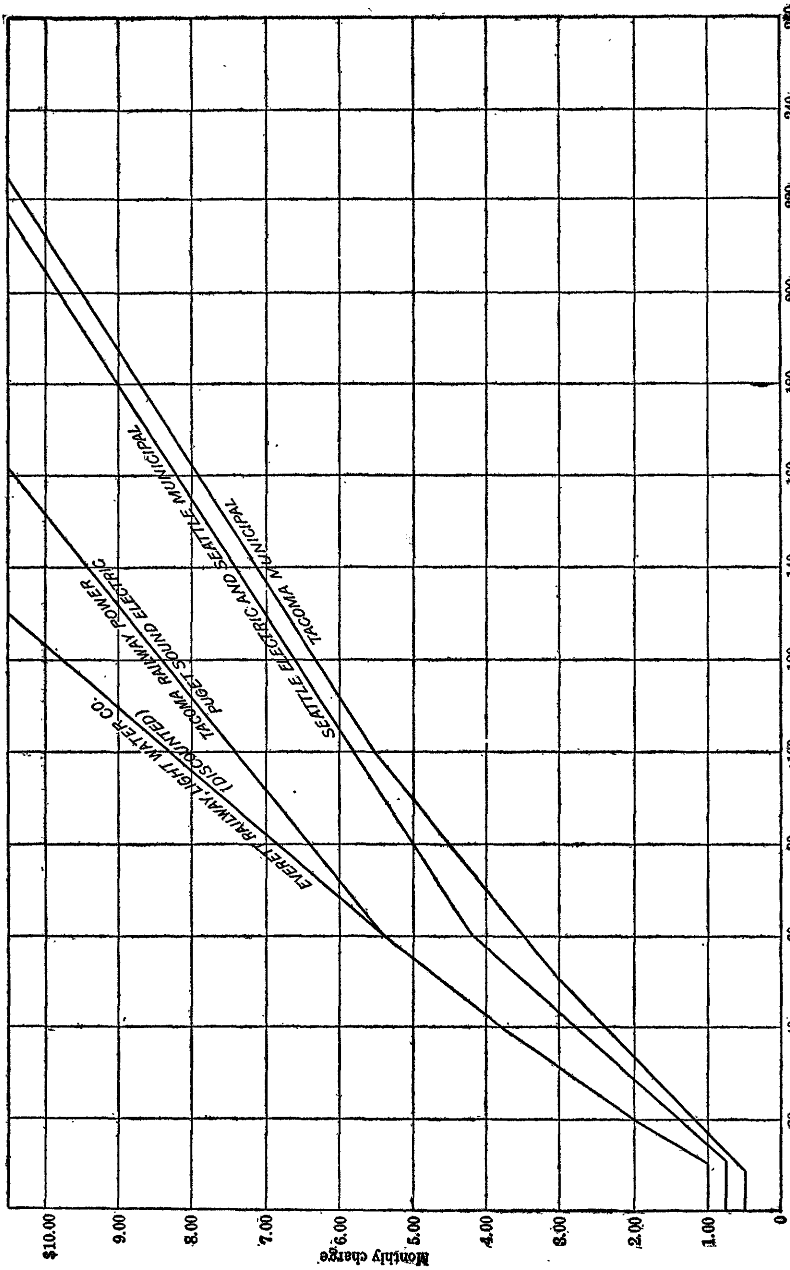

FIGURE 10.—Graphic representation of residence-lighting rates, central section of Puget Sound region, for 1911.

diagrams of the Seattle Electric Co. and the Seattle municipal system follow each other very closely for each classification of capacity. It

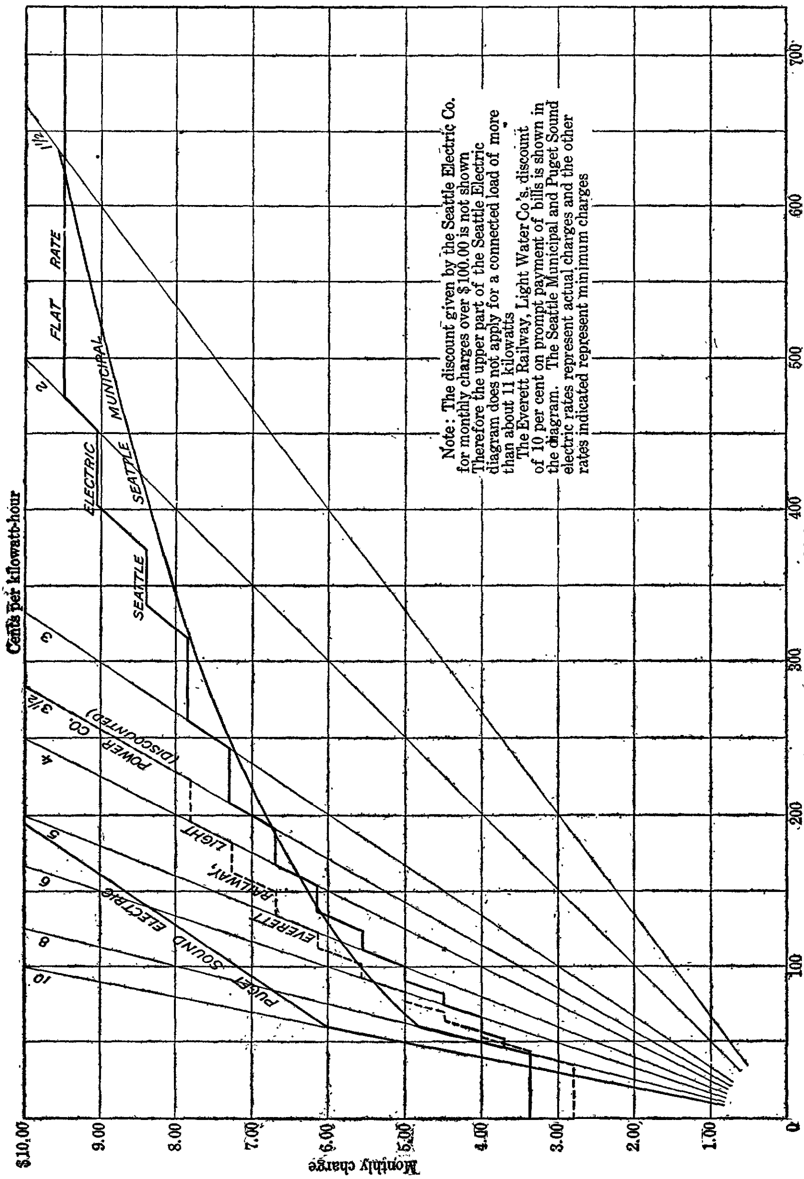

FIGURE 11.—Graphic representation of commercial-lighting rates, central section of Puget Sound region, for 1911.

will be noted that the schedule for a capacity of 101 horsepower and over approximates a horizontal line for a consumption of over 50 hours use. This indicates that the schedule is very near a flat rate.

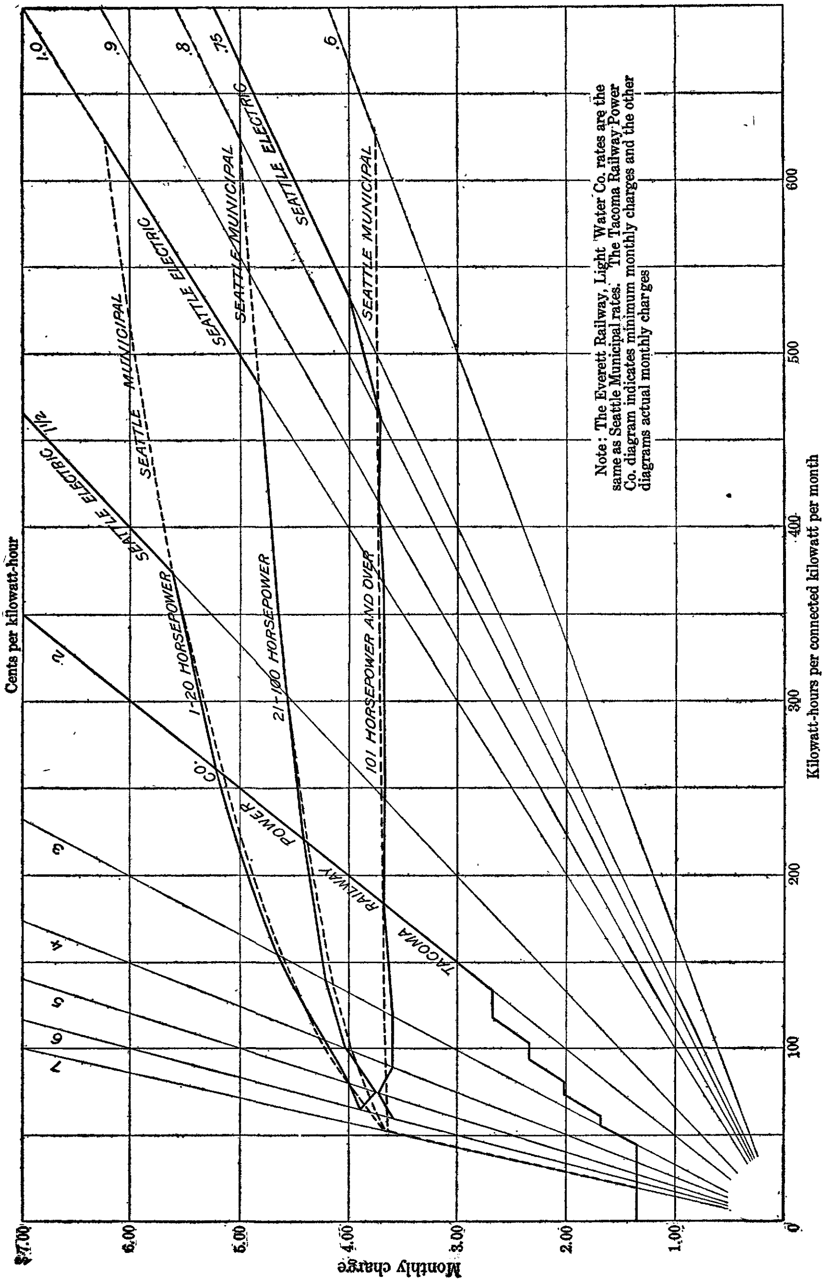

FIGURE 12.—Graphic representation of power rates, central section of Puget Sound region, for 1911.

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