Waterpower Resources in Nehalem River Basin Oregon

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1610-C

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By L. L. YOUNG *and* J. L. COLBERT

With sections on GEOLOGY OF SITES

By D. L. GASKILL *and by* A. M. PIPER

WATERPOWER RESOURCES OF THE UNITED STATES

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An estimate of the potential water-power of the river and a discussion of possibilities for developing it

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WATERPOWER RESOURCES IN NEHALEM RIVER BASIN, OREGON

By L. L. Young and J. L. Colbert

ABSTRACT

The potential waterpower of the Nehalem River is estimated on the basis of the streamflow for the period 1940–54 with complete development within the basin or with diversion of some water to the Columbia River.

The Nehalem River originates near Timber and empties into the Pacific Ocean near Wheeler in northwestern Oregon. The drainage basin is in a mountainous area and is sparsely settled. As is normal for Oregon coastal rivers, its waters are derived principally from rain rather than snow. Precipitation occurs in a seasonal pattern; about 80 percent of the annual runoff is concentrated in the 5-month period of November through March. In comparison with other coastal streams, the Nehalem River is well endowed with natural storage sites for regulating flow. Preliminary examinations indicate that these damsites and reservoir sites are geologically feasible.

The high winter runoff and the availability of storage sites for adequate regulation of the streamflow combine to make the Nehalem River attractive for power development, particularly during wintertime. An illustrative plan of development, including five sites, was considered in estimating the potential power of the stream. Storage sites in the basin could have regulated the streamflow to provide for the continuous generation of 70,000 kw during the period studied. If utilization of the water had been confined to the November 1–March 31 period, 170,000 kw could have been generated. The theoretical potential power of the stream, based on average discharge and gross head, is 97,000 kw. This potential, however, would require complete regulation of the streamflow, which is not possible.

Another way to use the Nehalem River for power production would be to divert it to the Columbia River. About half of the flow now passing the Foss gage could be diverted to a powersite on the Columbia River near Woodson. The potential power of a diversion by gravity at an altitude of 540 feet above sea level is about 51,000 kw, continuously. If the water were pumped into a higher level reservoir and diverted through a shorter tunnel at an altitude of 800 feet, a large block of peaking power would be available. Pumped-storage development at other sites is also possible.

Because of its proximity to the growing metropolitan area of Portland, any study of the water resources of the Nehalem River basin must include the possibility that water will be diverted to the Portland area. Indications are that an average of about 400 cubic feet per second could have been diverted for use in the Portland suburban area in the Tualatin River basin during the period studied.

INTRODUCTION

PURPOSE AND SCOPE

This report presents the results of studies of water-power resources made by the Geological Survey in the Nehalem River basin. The basic data used are topographic quadrangles of the basin, a special map of the river, large-scale damsite surveys, geologic reports, and stream-flow records, all gathered by the Geological Survey. In addition, precipitation and evaporation records of the U.S. Weather Bureau and an isohyetal map, prepared by the Corps of Engineers U.S. Army and showing rainfall intensities and distribution in western Oregon, were used in the study.

The contribution that the river might make to the Pacific Northwest power network was examined and found to be significant, particularly in supplying peaking power during the winter months when the Columbia River network will need it. Sites for developing reservoirs for streamflow regulation are discussed and preliminary geologic examinations of them are reported. Only those sites that might reasonably be expected to become economically feasible in the future are included; however, cost studies were not made.

The potential power of the Nehalem River is estimated by considering probable plans of development entirely within the basin, and an alternative plan is discussed in which the Nehalem River water would be diverted to the Columbia River by gravity or by pumped storage.

As power projects become otherwise feasible, problems relating to fish and wildlife and to population relocations will remain. These obstacles are not necessarily insurmountable, however. Opposition to power developments is lessened by improved methods of getting fish over dams and otherwise protecting them from harm by project works, by added recreational benefits afforded by the lakes, by the construction of new and better roads in the vicinity of power projects, and by adequate compensation to dislodged property owners.

PREVIOUS INVESTIGATIONS

E. C. LaRue and E. C. Murphy, engineers of the U.S. Geological Survey made investigations that included the Nehalem River. Mr. LaRue's study was made in 1917 to evaluate the water resources of lands forefeited by the Oregon and California Railroad Co. Mr. Murphy studied the coast streams of Oregon in 1923 to determine which additional lands in addition to those forfeited should be reserved for waterpower purposes. The reports on these investigations were not made available to the public.

The following reports on the Nehalem River have been placed in the U.S. Geological Survey open file:

12–R–20 Report on potential waterpower of Nehalem and Wilson River basins, Oregon, by B. E. Jones and Warren Oakey, 1924, 16 pages.

12–R–33 Geologic features of damsites in Nehalem, Rogue, and Williamette River basins, Oregon, by A. M. Piper, 1937, 111 pages.

12–R–34 Water utilization within the Nehalem River basin, Oregon, by R. O. Helland, *with* Geology of damsites by A. M. Piper, 1937, 41 pages.

12–R–43 Waterpower of the coast streams of Oregon, by R. O. Helland, 1953, 46 pages.

Power companies and utility districts gave little thought to the possibilities of developing the power potential of the Nehalem River in the past. Recently, however, the Tillamook County Public Utilities District considered a development on the river and in 1959 had the firm of Cornell, Howland, Hayes, and Merryfield, Consulting Engineers, Corvallis, Oreg., make a study of waterpower possibilities. The firm's findings were submitted to the utility district in a report entitled "Report of Reconnaissance Study of Hydroelectric Development of Nehalem River." The utility district has suspended its plans for the Nehalem but has applied for and has been granted, a preliminary permit by the Federal Power Commission, project 2274, to investigate the Trask River.

MAPS RELATING TO THE AREA

A survey of the Nehalem River was completed by the U.S. Geological Survey in 1936 and published in 1938 under the title "Plan and Profile of Nehalem River from Mohler to Timber, Oregon, and Tributaries, Miscellaneous Damsites." That survey covered 102 miles of the river between sec. 36, T. 3 N., R. 10 W., near Mohler, to sec. 22, T. 3 N., R. 5 W., near Timber. It consists of seven sheets (four plan and three profile) at a scale of 2 inches=1 mile. The contour interval of the river-survey map is 20 feet for land and 5 feet for water. Five damsites were surveyed at a scale of 1 inch=400 feet with contour interval of 10 feet. The following damsite surveys were published on plan sheets of the river survey:

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Damsite	At mile—	Location			Topography above river (ft)
		Section	T. N.	R. W.	
Tideport	36.9	23, 24	5	7	210
Elsie	30.4	4	4	7	250
Salmonberry	15.5	10	3	8	240
Nehalem Falls	8	23, 27	3	9	280
Stonehill	4.9	34	3	9	80

In 1957, additional surveys were made in the basin by the U.S. Geological Survey and the resulting map of a reservoir site on Fishhawk Creek and a tunnel route to the Columbia River entitled "Fishhawk Creek Reservoir and Damsite, Oregon," was published in 1957 at a scale of 1 inch=2,000 feet (1:24,000) with a contour interval of 20 feet. The 1957 surveys included the following damsites surveyed at a scale of 1 inch=400 feet with contour interval of 10 feet:

Damsite	At mile—	Location			Topography above river (ft)
		Section	T. N.	R. W.	
Fishhawk Creek		29	7	7	300
Squaw Creek	45.6	33	6	6	150
Upper Wakefield	14.4	15	3	8	430

The Squaw Creek and Upper Wakefield damsite maps were published in 1957 by the U.S. Geological Survey together with other damsite surveys under the title "Plan, Miscellaneous Damsites, Coast Streams, Oregon."

U.S. Geological Survey 15-minute quadrangle maps at a scale of 1:62,500 (approximately 1 inch=1 mile) cover the entire basin; they are listed below with the date of the last field check:

Quadrangle	*Date*	*Quadrangle*	*Date*
Birkenfeld	1955	Nehalem	1955
Cannon Beach	1955	Saddle Mountain	1955
Cathlamet	1953	Sensen	1955
Clatskanie	1952	Timber	1955
Enright	1955	Vernonia	1955

GENERAL DESCRIPTION OF THE BASIN

PHYSICAL CHARACTERISTICS

The Nehalem River drains an area of about 850 square miles of mountainous timberland in northwestern Oregon. The river heads near Cochran, 40 air miles northwest of Portland, in the Coast Range in mountains over 2,000 feet high. Its course is east to Timber, thence northeast to Vernonia and Pittsburg, northwest to Mist, west to Birkenfeld, southwest to Jewell, Tideport, Elsie, Batterson, and Foss. It flows west and northwest past Foss to Mohler, meanders in large S-curves in a broad valley, passes Nehalem and Wheeler, and empties into Nehalem Bay. The mouth of the bay is about 5 miles southwest of Wheeler and about 65 air miles northwest of Portland. The basin is outlined by a broken line on figure 1.

The Nehalem River basin is bounded on the west by the basins of the Necanicum River and of other small streams which empty directly into the Pacific Ocean. The ridge line between the basins here averages about 1,900 feet in altitude. The lowest pass in the ridge is 720 feet and the highest feature (Onion Peak) is 3,064 feet in altitude. U.S. Highway 26 (the Sunset Highway) between Portland and the coast leaves the basin by a pass about 1,100 feet in altitude.

On the northwest, north, and east the adjacent drainage is all to the Columbia River. The adjacent basins are those of the Youngs and Klaskanine Rivers on the northwest, Clatskanie River on the north, and Scappoose Creek on the east. The average altitude of the divides is about 1,600 feet. Saddle Mountain (3,283 ft), Nicolai Mountain (3,020 ft), Clatskanie Mountain (2,680 ft), and Bunker Hill (2,040 ft) are among the higher peaks. The Tidewater Summit Pass on the Nehalem Highway (State Highway 202) is 1,221 feet high. The lowest altitude on these divides is 1,200 feet.

On the southeast, Tualatin River drainage adjoins for a short distance. The average altitude of the dividing ridge line is over 1,800 feet and there are several peaks over 2,000 feet in altitude. The lowest pass is 880 feet; it is on the Timber to Glenwood road (State Highway 8). U.S. Highway 26 enters the basin through a pass about 1,360 feet in altitude. The highest part of the Nehalem basin rim is on the south between it and the Wilson River basin. The average altitude there is 3,080 feet. The higher peaks in the reach are Larch Mountain (3,449 ft) and Lookout Mountain (3,510 ft). The lowest pass is 1,520 feet in altitude, but most are over 2,700 feet. The rest of the south and the southwest boundary adjoins drainage into Tillamook Bay by way of the Kilchis and Miami Rivers. The average altitude here is 2,100 feet and the extremes are Kilchis Peak (2,294 ft) and sea level. A pass near the coast has an altitude of 250 feet.

Altitudes in the interior of the basin are comparable with those on the ridge line, and, except for a rather large valley between Vernonia and Elsie, the canyons are narrow and deep. Foley Peak, with an altitude of 2,275 feet, is only 5 air miles from the ocean. The Nehalem River is still actively cutting through a plateau that lies diagonally between Saddle Mountain to the northwest (20 air miles from the coast) and Larch Mountain to the southeast (25 to 30 air miles from the coast). The river enters the plateau region near Elsie, about 20 miles

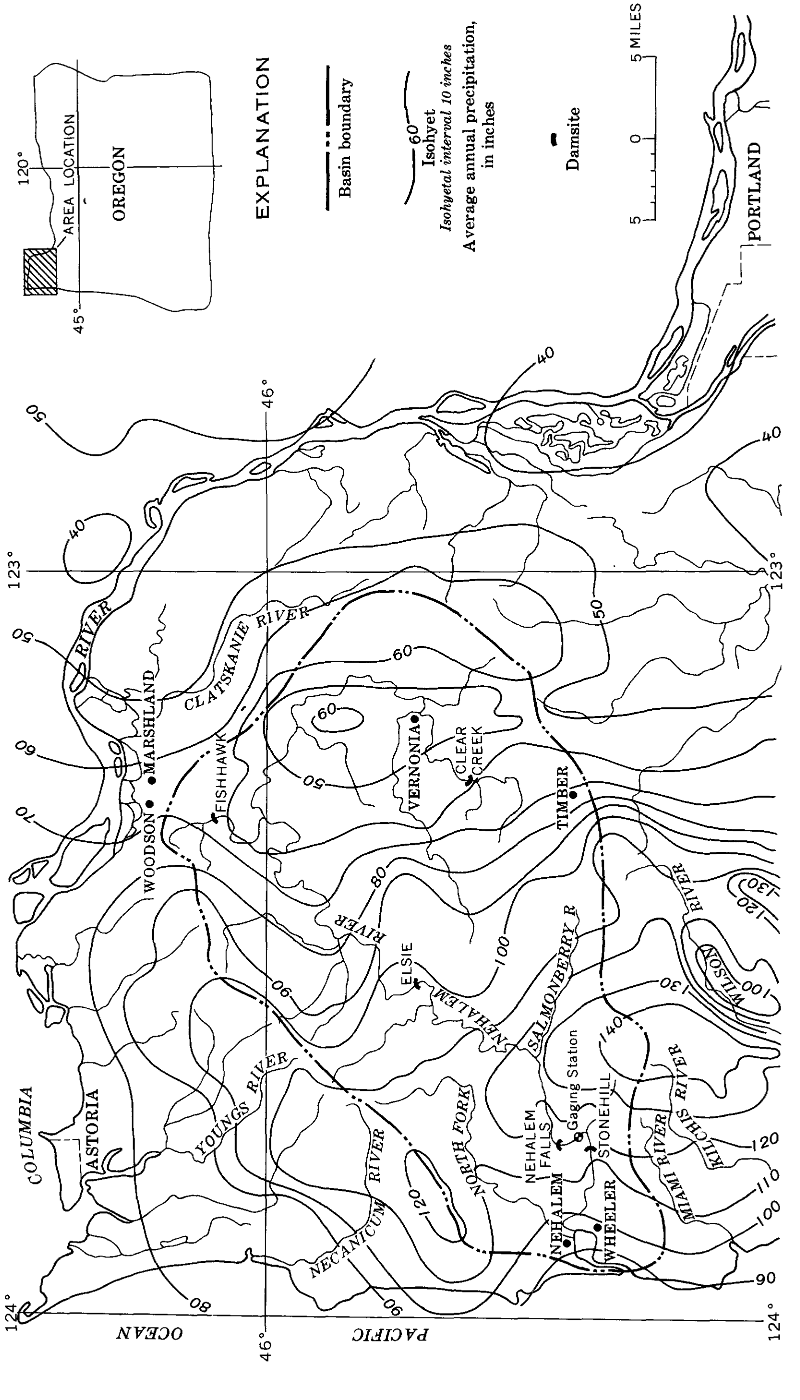

FIGURE 1.—Nehalem River basin, Oregon, with isohyets.

by air from the coast. The lower end of Nehalem Falls, at the west end of the active reach is only 8 miles from sea level.

ECONOMICS

The first paragraph under physical characteristics names the towns and most of the settlements in the basin. Vernonia, Columbia County, and Nehalem and Wheeler, Tillamook County, may be classed as towns. There are post offices at Timber, in Washington County, Mist and Birkenfeld, in Columbia County, Jewell, in Clatsop County, and Mohler, in Tillamook County.

The population of the basin has declined an estimated 18 percent since 1950. On July 1, 1960, Vernonia had a population of 1,095, a decline of 28 percent since 1950; Nehalem had a population of 244, a decrease of 16.2 percent; and Wheeler had a population of 230, a decrease of 14.8 percent (Oregon State Board of Census, 1960). The populations of the smaller communities and the number of farms appear to have remained much the same as they were in 1950.

Settlement of the Nehalem basin began about 1867 and some 150 people were there by 1877. There was little growth until 1920. Vernonia was named in 1876 for Vernonia Cherrington (Oregon Historical Society, 1941), the daugther of the first schoolteacher. The area is served with electric power by the R.E.A., West Oregon Electric, which is connected with Bonneville generating facilities. The Spokane, Portland and Seattle railway serves Vernonia and a 60-mile-long valley which includes the localities of Timber, Pittsburg, Mist, Birkenfeld, Jewell, and Tideport. The southern Pacific railroad line from Portland to Tillamook follows the Nehalem River upstream from Timber, then the Salmonberry and Nehalem Rivers to Wheeler.

A surfaced highway follows the river from Vernonia to Elsie and low-class roads provide access to the remaining reaches of the stream and branch into the mountains to afford access to timber and for fire protection. The main highway between Portland and the coast, U.S. 26, crosses the basin and would be affected by construction of the Rocky Point and Elsie dams. The Rocky Point reservoir would flood about a mile of the present highway, and a new bridge might be necessitated at Elsie.

The pioneers found the Nehalem basin covered by a dense forest that was difficult to penetrate. It was the exploitation of these abundant timber resources in the 1920's that brought the greatest number of people to the area; Vernonia is said to have been a town of over 2,500 population during that period (St. Helens Centennial, 1954).

Lumbering has been, and probably will continue to be, the principal industry. However, there is no longer sufficient timber to maintain the former rate of production, and operations at the principal mills in the area are being curtailed. A reduction of operations at the International Paper Co.'s Long Bell mill at Vernonia is the principal cause of the decrease in the town's population. Other occupations in the basin are dairying, growing small fruits (berries), and diversified farming.

The basin has good possibilities for improvement of existing outdoor recreational activities. The river is fished for trout, steelhead, and salmon and there is a 9-hole golf course at Vernonia. If dams are constructed on the river, facilities for fish passage should be included. The new reservoirs would be beneficial to these recreational values.

WATER SUPPLY

PRECIPITATION

The U.S. Weather Bureau has records of precipitation at Vernonia for 24 years, and at Jewell Guard Station and Nehalem for short and intermittent periods. Stations of the Weather Bureau outside the basin at Seaside, Astoria, Clatskanie, and Tillamook, maintain precipitation records, which are indices of precipitation for the general area. In addition, the Corps of Engineers, U.S. Army, has prepared an isohyetal map of western Oregon that includes the Nehalem basin. From these data, a new isohyetal map was prepared that conforms closely to the topography of the basin as shown by quadrangle maps. The new map was used in estimating runoff by measuring the areas between the several isohyets for the drainage basin units under consideration. The isohyets of the map are approximated on the Nehalem River basin map (fig. 1), and the rainfall averages determined are shown in table 1.

The headwaters area of the basin is on the lee side of the Coast Range and therefore receives less precipitation than the western, or windward, slope. Annual precipitation varies from a minimum of about 50 inches in the eastern part to over 140 inches in the mountains in the southwestern part of the basin. The entire basin has the usual coastal-type distribution, heavy in the fall and winter and light in the spring and summer.

RUNOFF

Records of discharge of the Nehalem River at a gaging station near Foss where the drainage basin area is 667 square miles are complete from October 1939. A 3-year record of discharge (1926–28) was obtained for Rock Creek near Keasey, and records of miscellaneous measurements are available including those on the North Fork Nehalem River and on Salmonberry River. The difference between the

TABLE 1.—*Area, estimated average annual precipitation, and estimated average annual runoff at selected sites in Nehalem River basin*

Site	Drainage area (sq mi)	Estimated average annual precipitation (inches)	Estimated average annual runoff		Percent of runoff at Foss gage
			Inches	Acre-feet	
Rocky Point damsite	70	71	45.5	171,000	8.9
Rock Creek gage	38	81	61.0	123,000	6.3
Fishhawk damsite	11	67	41.5	23,650	1.2
Squaw Creek damsite	398	63	37.5	795,950	41.4
Tideport damsite	463	67	41.5	1,023,000	53.2
Elsie damsite	498	68.5	43.0	1,140,000	59.3
Spruce Run damsite	549	72	46.5	1,360,000	70.6
Salmonberry damsite	573	73.5	48.0	1,462,000	76.0
Upper Wakefield damsite	644	78	52.5	1,800,000	93.5
Wakefield damsite	647	78	52.5	1,810,000	94.0
Nehalem Falls damsite	660	79	53.5	1,877,000	97.4
Foss gage	667	79.5	54.0	1,923,000	100.0
Stonehill damsite	700	82	56.5	2,105,000	109.3
Gods Valley damsite	45	117	91.5	220,000	11.4
North Fork Nehalem Basin	96	114.5	89.0	457,000	23.7
Nehalem River Basin	850	87	61.5	2,788,000	145.0

estimated precipitation average and the measured runoff depth for the drainage area above the Foss gage was 25.5 inches. That amount was subtracted from the precipitation to obtain the runoff depth at each of the damsites considered in the section on regulation and storage sites.

The loss apparently varies throughout the basin, because a similar comparison of measured runoff at Rock Creek with the estimated precipitation indicates a loss of about 20 inches annually. However, the 3-year record on Rock Creek shows considerable variation from year to year and the indicated loss of 20 inches is probably not reliable because of the short period of record. The miscellaneous measurements of runoff on the North Fork Nehalem River also indicate that losses between rainfall and runoff may be less than 25.5 inches for this part of the basin. An annual loss of 25.5 inches is considered a conservative estimate for any subpart of the basin. Estimated annual runoff at the selected damsites and at other locations are shown in table 1. A comparison of the runoff at the Foss gage with precipitation at Vernonia in the upper part of the basin indicates a lag of 1 to 2 months between winter precipitation and runoff. On the average, the highest monthly percentage of annual precipitation occurs in December and the highest monthly percentage of annual runoff occurs in February. Lowest percentage of annual precipitation is in July and lowest percentage of annual runoff is in August.

A flow-duration analysis of the Nehalem River near Foss for the water years 1940–54 shows $Q95$ (discharge in cubic feet per second that is equaled or exceed 95 percent of the time) = 107 cfs (cubic feet per second) (0.16 cfs per sq mi), $Q50$ = 1,100 cfs (1.65 cfs per sq mi), and Q mean = 2,656 cfs (3.98 cfs per sq mi). The seasonal distribution of this runoff shows heaviest runoff during the period November through March and very light runoff from July to the end of September. The average monthly discharge in cubic feet per second per square mile and in percentages of total runoff are shown below:

Month	Discharge (cfs per sq mi)	Percent of total runoff	Month	Discharge (cfs per sq mi)	Percent of total runoff
October	1.30	2.77	April	3.64	7.51
November	5.27	10.87	May	1.98	4.22
December	9.15	19.51	June	.843	1.74
January	8.82	18.80	July	.397	.85
February	10.50	20.38	August	.216	.46
March	5.77	12.29	September	.293	.60

This runoff pattern, modified to reflect wet and dry years as shown in figure 2, was used for making estimates throughout the basin.

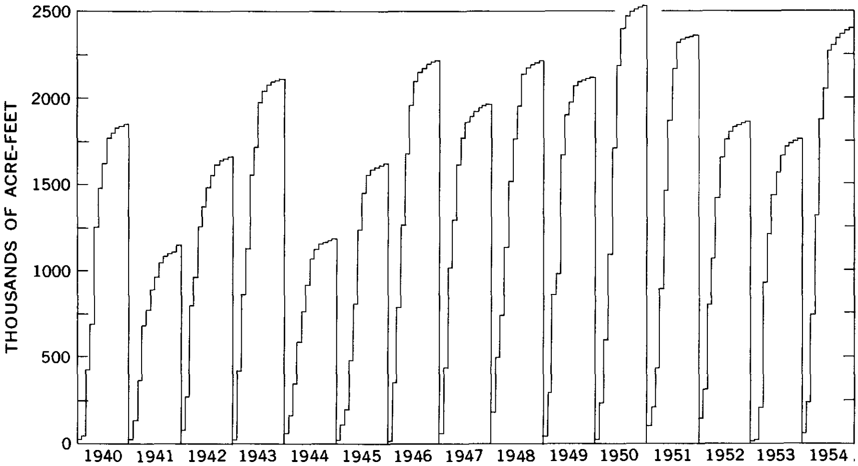

FIGURE 2.—Runoff in acre-feet accumulated monthly for water years 1940–54 for gage near Foss.

REGULATION AND STORAGE SITES

The distribution of annual runoff is such that reservoirs are necessary to regulate the flow by reducing the high winter runoff and increasing low summer flows. There are no reservoirs in the basin at present but there are a number of topographically suitable reservoir sites. Land acquisition, highway and forest road relocations, and the necessity for fish protection are factors which would tend to limit the construction of reservoirs.

To compute the storage requirements of the sites, the estimated total water yield at each damsite was distributed over the period studied by adapting the mass diagram and accumulated second-foot-day table for the Foss gage to the particular site. In other words, the Foss gage provides the runoff pattern.

Estimates of evaporation losses were made from Weather Bureau records of evaporation rates in Oregon. An average loss in inches was determined for each month and these were totaled appropriately and multiplied by the surface of the reservoirs when they contained one-half their usable capacities to get the evaporation loss for yearly, winter, and summer periods. An additional allowance equal to 10 cfs plus one-fifth the annual evaporation loss rate was made for leakage and other unmeasurable losses. The total loss was rounded to the nearest 5 cfs.

During reservoir-filling periods or during times when diversions from the basin were being made, a conservation release equal to the flow at the sites 95 percent of the time for all reservoirs from Tideport upstream and 50 cfs for downstream reservoirs was assumed. The losses and conservation-release data for Rocky Point are used for the Gods Valley reservoir site on the North Fork Nehalem River. The dam and reservoir sites discussed below are shown on the river profile in figure 3.

ROCKY POINT RESERVOIR SITE

The Rocky Point damsite is at river mile 92.8, about 10 miles upstream from Vernonia, in sec. 23, T. 4 N., R. 5 W. The area of the drainage basin is 70 square miles and the water surface altitude at the site is 667 feet. An earthfill dam for raising the water surface to the 800-foot contour would have a volume of about 600,000 cubic yards, and would store 114,000 acre-feet. The reservoir would be 8.5 miles long and would have a surface area of 2,300 acres. Eight miles of State Highway 8 and a mile of U.S. Highway 26 would have to be relocated for a reservoir that has a maximum water surface altitude of 800 feet. The capacity of the reservoir at altitude 800 feet would be sufficient to store two-thirds of the estimated annual runoff at the damsite. Storage required to sustain the average annual discharge is about 250,000 acre-feet; this discharge would require a dam to the 850-foot altitude. The area and capacity data for the Rocky Point reservoir site are shown in table 2.

TABLE 2.—*Area and capacity of Rocky Point reservoir site, damsite at mile 92.8, secs. 22 and 23, T. 4 N., R. 5 W.*

Altitude (feet)	Area (acres)	Capacity (acre-feet)	Altitude (feet)	Area (acres)	Capacity (acre-feet)
667	0	0	780	1,720	74,000
680	25	150	800	2,300	114,200
700	210	2,500	820	2,700	164,000
720	490	9,500	840	3,100	222,000
740	820	22,600	860	3,800	291,000
760	1,300	43,800	880	4,600	375,000

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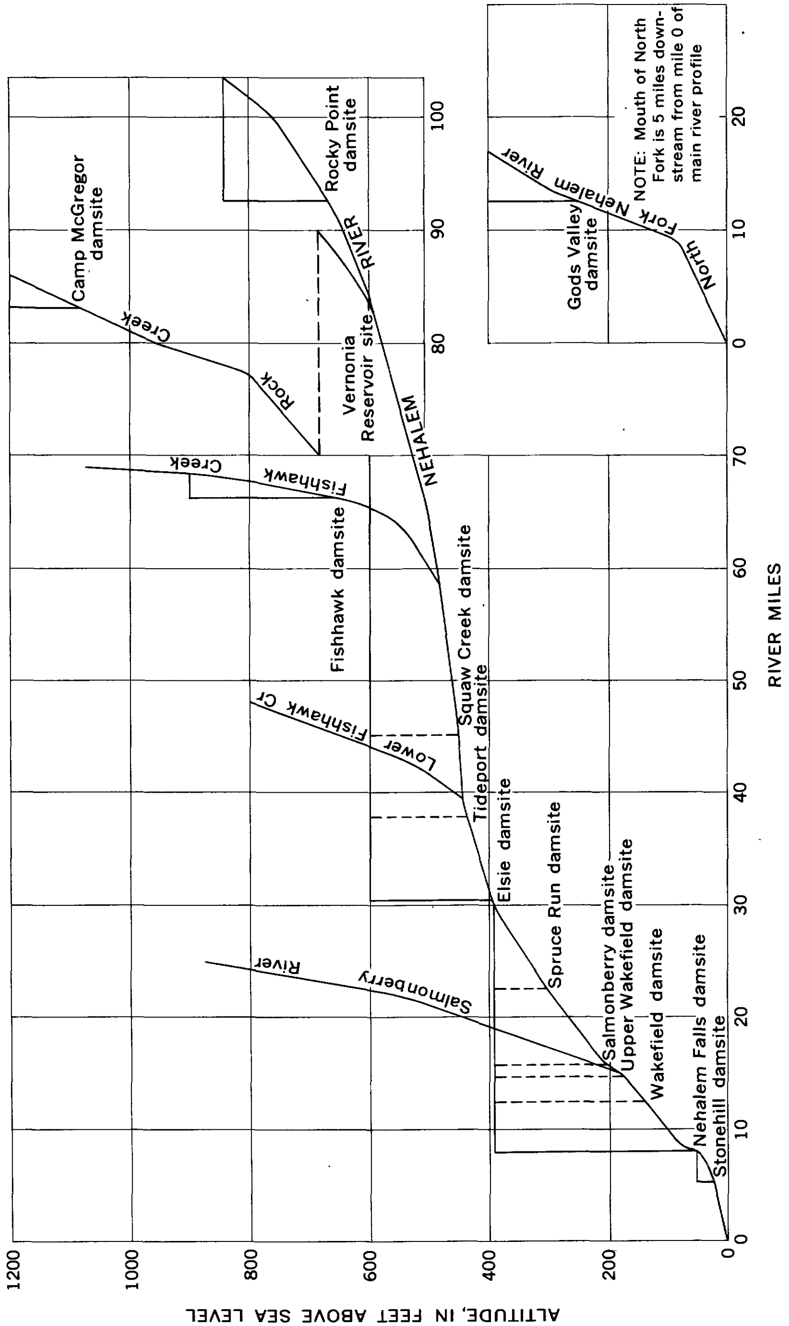

FIGURE 3.—Profile of Nehalem River showing prospective damsites and storage basins.

A reservoir with 114,000 acre-feet of active storage would have regulated the flow to 435 cfs after losses during the 5 winter months and 10 cfs after losses during the remaining 7 months of the year in the period studied, or a continuous discharge of 185 cfs after losses could have been maintained. A 250,000 acre-foot reservoir might be desirable if water is to be diverted to the Tualatin River basin. The larger reservoir would afford complete control of the stream and would shorten the tunnel length or the pumping head, depending upon the method chosen for diversion.

A possible use of water stored in a reservoir at the Rocky Point site might be for irrigation. The amount of irrigable land and possible water requirements have not been investigated. A reservoir of 100,000 acre-feet at the Rocky Point site would have provided a minimum of 355 cfs during a 4-month period June through September for all of the 15 years of record. Most of the time this irrigation-season flow would have been in excess of 400 cfs and there would have been substantial amounts of uncontrolled flow during years of above average flow.

A regulating dam at the Rocky Point site would be very beneficial to the downstream river basin. It could be so operated as to increase low flows and thus enhance the value of the river for fish, and farm and pasture lands between Vernonia and Elsie could be irrigated by releasing water during the dry season. If used for power or for diversion of water out of the basin, the other benefits would be reduced.

Rocky Point storage is not reflected in the data for any of the downstream sites because the purposes for which this reservoir is likely to be built may detract from, rather than add to, downstream power. The damsite has not been examined geologically.

VERNONIA RESERVOIR SITE

The Nehalem River has a rather flat gradient from Elsie, mile 30, to Vernonia, mile 83. This section is designated as the Vernonia reservoir site in this report. The maximum altitude for the development of this site would likely be 600 feet, to avoid inundation of Vernonia. Three alternative damsites are considered in this report for the development of the Vernonia reservoir site: (1) Squaw Creek near mile 46, (2) Tideport near mile 37, and (3) Elsie near mile 30. The Elsie damsite has probably been given the most consideration in development plans for this section of the river.

SQUAW CREEK DAMSITE

GENERAL FEATURES

The Squaw Creek damsite is at Nehalem River mile 45.6 in sec. 33, T. 6 N., R. 6 W., about three-quarters of a mile upstream from the confluence of Squaw Creek. Drainage area at the site is 398 square miles and the water surface altitude is 450 feet. An earthfill dam 150 feet high that would raise the water surface to the 600-foot altitude would have a volume of about 1,500,000 cubic yards and create a reservoir of about 700,000 acre-feet capacity. By comparison with the runoff at the gage at Foss, the estimated average runoff at the site is 1,100 cfs. Control of this amount of runoff would require a reservoir of 1,160,000 acre-feet. Storage of this volume would require a dam about 30 feet higher. Such a dam is not considered to be feasible at this site. Area and capacity data for this reservoir site are shown in table 3.

TABLE 3.—*Area and capacity of Vernonia reservoir site, with dam at Squaw Creek site, mile 45.6, sec. 33, T. 6 N., R. 6 W.*

Altitude (feet)	Area (acres)	Capacity (acre-feet)	Altitude (feet)	Area (acres)	Capacity (acre-feet)
450	0	0	540	4,100	132,000
460	80	400	560	8,700	260,000
480	500	6,000	580	10,500	453,000
500	1,700	28,000	600	13,950	700,000
520	2,300	68,000			

A dam at Squaw Creek is considered only because a reservoir smaller than one formed by a dam at a downstream site might be better suited for the Fishhawk-Tunnel Ridge diversion to the Columbia River; a dam here is not considered justified for any other purpose. Usable capacity of the reservoir would be 570,000 acre-feet (the water stored above an altitude of 540 feet, the probable elevation for a diversion tunnel entrance). An advantage of the Squaw Creek site over downstream sites is that farms around Jewell and between Tideport and Elsie would not be affected.

Assuming a usable capacity of 570,000 acre-feet in the Vernonia reservoir behind Squaw Creek dam, a minimum flow of 870 cfs could have been diverted during the period studied. This minimum flow would have been met easily after the end of the critical period, April 1940 to January 1947. During spilling periods between January 1947 and April 1954, flow averages had a range of 1,450 to 2,650 cfs.

The 570,000 acre-feet of storage could be used to regulate flows released during the 5-month winter period November through March and thereby assure a minimum flow of 2,190 cfs. For this regulation the critical period was between November 1, 1940, and March 1, 1944. The reservoir would have been nearly empty on March 1, 1944, and would have refilled in 1948. There would have been excess water thereafter except for the drawing periods ending March 31, 1952 and 1953. The greatest excess would have been 190,000 acre-feet in the November 1949 to March 1950 period.

In computing the divertible water in the above examples, a minimum discharge of 40 cfs ($Q95$) was left in the river for conservation purposes and the appropriate losses were subtracted.

GEOLOGY

By D. L. Gaskill

At the Squaw Creek damsite (pl. 1), the Nehalem River cuts strata of the Pittsburg Bluff Formation (Warren and Norbisrath, 1946). These strata consist of alternating well-stratified micaceous thinly laminated to thick-bedded silty claystone, siltstone, and silty to fine-grained sandstone. The rocks are composed of subangular to subrounded grains of quartz, minor feldspar, and some tuffaceous material. Most of the finer grained beds are firmly compacted but contain little or no cementing material. A few thick beds of sandstone are well cemented with calcite. Crossbedding, ripple marks, mudcracks, carbonaceous material, calcareous clay and iron concretions, and other sedimentary features are present locally. The sedimentary beds probably grade laterally from one type to another within short distances. Fresh angular blocks of dark-gray dense very fine grained basalt form part of the slope wash on the east abutment of section *B–B′* (pl. 1). The basalt does not crop out in the damsite area and is probably derived from a dike or flow remnant near the crest of the ridge.

Bedrock exposures occur in the river channel at section *A–A′*, on the west bank at locality 3, and in highway and logging roadcuts. Thick flood-plain deposits of coarsely graded sand, gravel, and alluvium mantle most of the valley floor.

Structure of the bedrock is largely obscured by vegetation, deep weathering, and surficial movement. Large areas of valley and abutment slopes are slumping, and wet clay zones are exposed at most outcrops. Bedding attitudes vary, probably owing to bedrock slump, large-scale crossbedding, or possible faulting. The attitude of some resistant sandstone beds on valley slopes subject to surficial movement suggests a moderate downstream dip of the strata, whereas less competent strata in the river bed near section *A–A′* dip obliquely upstream into the east abutment. Beds are conspicuously fractured at locality 1 (pl. 1), and a few widely spaced joints cut bedrock near section *A–A′*. These fractures may be associated with a zone of minor folds and contorted bedding that trends about N. 70° W. across the river here. Aerial photographs reveal a few widely spaced lineaments that possibly represent faults or bedrock fractures. One lineament strikes about N. 30° E. through the damsite area.

The sedimentary beds exhibit a wide variation in texture, composition, and minor structures. They are generally weak, in part plastic when wet, and are subject to differential compaction, expansion, slumping, slaking, and disaggregation. Foundation and abutment rocks may fail along weak water-saturated bedding planes. The instability of abutment slopes is shown by the frequency of slumps and landslides, which are due in part to deep weathering and general absence of cementing material in bedrock. Bedrock dips slightly upstream at section *A–A′* in the river channel, but other bedrock exposures are probably influenced by some degree of surficial movement. The zone of folding in foundation bedrock at section *A–A′* should be investigated. Other areas of indicated structural weakness, as at locality 1, and the hypothetical lineament at locality 2 require exploration. Leakage should be anticipated through some friable sandstone or along bedding planes. Abutments will probably require deep excavation of slumped and loosely consolidated weathered rock. Some deep-seated sliding and creep of surface mantle into the reservoir area may be expected, particularly where valley slopes have been denuded of forest cover. A chute-spillway site at section *A–A′* might be developed on the west abutment. A spillway at section *B–B′* would probably have to be a side channel tied to the east end of a dam here. Spillways would have to be concrete lined. An impervious cutoff wall would probably be necessary along the top of the west abutment at section *A–A′*, dependent on reservoir level. Attitude and permeability of beds are particularly critical on the west abutment at section *A–A′*.

Impervious materials and aggregate are probably available from alluvial deposits in the Nehalem River valley. Nonfragmental and coarse fragmental volcanic rock is exposed in the Nehalem River valley near Jewell, about 8 miles downstream.

In conclusion, the Squaw Creek damsite has little to recommend it aside from topography, but it is probably adaptable to a flexible wide-base earth or rockfill structure.

TIDEPORT DAMSITE

GENERAL FEATURES

The Tideport damsite is at river mile 37, secs. 23 and 24, T. 5 N., R. 7 W., about half a mile upstream from the community of Tideport. The drainage area is 463 square miles. An earthfill dam that would raise the water surface from its present altitude of 437 feet to 600 feet would have a volume of about 1,500,000 cubic yards and store 1,060,000 acre-feet of water. Storage required for complete regulation to an estimated mean flow of 1,415 cfs is about 1,500,000 acre-feet, which would require a dam to near the 620-foot altitude. A dam to that height has not been considered because of the altitude of the town of Vernonia. Area and capacity data for this reservoir site are shown in table 4.

TABLE 4.—*Area and capacity of Vernonia reservoir site, with dam at the Tideport site, mile 37, secs. 23 and 24, T. 5 N., R. 7 W.*

Altitude (feet)	Area (acres)	Capacity (acre-feet)	Altitude (feet)	Area (acres)	Capacity (acre-feet)
437	0	0	520	5,000	141,000
440	40	200	540	7,000	261,000
460	420	5,000	560	12,000	445,000
480	1,380	23,000	580	15,000	716,000
500	2,700	64,000	600	19,600	1,063,000

The reservoir would provide about 70 percent of the storage required for complete regulation of the stream whereas the Squaw Creek site would provide only 60 percent of the storage required at that site. Lands that would be flooded by a dam at the Tideport site are perhaps more valuable than those farther upstream. A dam at Tideport of necessity would be higher but would have about the same volume of material as one at Squaw Creek. During the period studied, the reservoir could have assured a discharge of about 1,240 cfs if its entire contents were used as active storage. The reservoir would have an active capacity of 800,000 acre-feet above altitude 540 feet. This capacity could have provided a constant diversion of about 1,185 cfs to the Columbia River. If all the water were diverted during the 5-month period November through March, a uniform flow of 2,900 cfs could have been maintained.

The conservation release at Tideport is 50 cfs.

GEOLOGY

By A. M. PIPER

The bedrock at and near the Tideport damsite consists of thinly stratified shale and earthy sandstone overlain by dense nonfragmental volcanic rock (basalt) and fragmental volcanic rocks (basaltic tuff and agglomerate). In general, the rocks dip 5°–35° in a N. 20°W. to N. 20° E. direction. At the damsite, the exposures of bedrock are scarce and geologic features must be interpreted largely from regional features. A geologic map of this site is shown on plate 1.

At the site, dense volcanic rock is exposed at the base of the west abutment to a height of about 40 feet above a roadcut and for about 350 feet along the road. The exposed rock includes a layer of dense fine-grained basalt about 45 feet thick; another layer of basalt about 40 feet thick contains small globular masses of secondary nonmetallic minerals (amygdule fillings), and fine-grained fragmental material (tuff). These layers seem conformable and contacts are tight. These rocks are inferred to form the greater part of the thin spur above the exposure that extends to the margin of the mapped area. Similar volcanic rock is inferred to underlie the opposite, or left, bank of the river.

The dense nonfragmental volcanic rock exposed at the Tideport damsite has high crushing strength; however, it probably will not form a rigid and thoroughly stable foundation at the right abutment, because the rock is highly fractured and partly altered. The exposure described in the preceding paragraph is crossed by two large fractures that strike N. 20° E. and dip about 70° westward. Between these two fractures all the rock is cut by closely spaced cross-fractures that strike in many directions; some of the rock is crushed thoroughly. In this fracture zone, many of the blocks are rotated rather steeply and their faces commonly are partly decomposed although some faces are silicified. All these features indicate that the exposed rocks are in a fault zone of appreciable displacement. The fault that strikes N. 20° E. locally controls the course of the river farther upstream. This fault suggests a line of serious weakness at the damsite. Other fracture zones may be concealed beneath the slope wash.

Coarse fragments of volcanic rock 2 feet across in a dense basaltic matrix form extensive outcrops on the left bank of the river downstream from the damsite. This rock is likely to occur at the site beneath the cover of slope wash and is moderately weaker than the nonfragmental volcanics.

The sedimentary rocks in the vicinity of the damsite are largely shale but include some earthy sandstone beds. These rocks are moderately low in bearing power and are probably plastic when wet. At or near the site these weak rocks are exposed on the right (west) bank at three places: (1) along the road at the downstream edge of the basalt outcrop described above, where they dip 70°–85° W. and strike N. 70° W. and are deeply weathered and air-slaked; (2) at an altitude of about 750 feet along the thin spur forming the west abutment; and (3) in shallow cuts along the road 1,300 to 1,600 feet upstream from the site where they dip 20°–35° N. 20° W. They probably form most of the right bank both upstream and downstream from the basaltic spur. The upper hillsides in these areas are scarred by several landslides. The scars are shallow and only a few yards across. Whether sedimentary rocks occur on the opposite, or left, bank is not known.

The line A–B on the map of the Tideport damsite (pl. 1) indicates the most feasible position for a dam having its foundation and abutments largely or entirely on the volcanic rocks. At this position the permissible maximum height of a dam probably is limited by the bearing power and perviousness of the narrow basaltic spur forming the right abutment. Neither of these two limitations can be thoroughly evaluated from the data now available. However, this position seems wholly unsuited for a high rigid narrow-based dam because of the fractures that have been described and because of the extensive sheets of weak fragmental material (tuff) that may separate some of the layers of basalt. The position might be suitable for an earth or rock-fill dam.

At line C–D (Tideport damsite, pl. 1), a dam would be slightly narrower and both abutments would have considerable mass. There, the right abutment is probably the weak shale and sandstone beds; the character of the bedrock in the left abutment is unknown. Only a flexible dam that has a comparatively broad base would be stable. In summary, the Tideport site seems to be distinctly inferior geologically as a possible damsite to the alternative site near Elsie, which is described in the following section.

ELSIE DAMSITE

GENERAL FEATURES

The Elsie damsite is at river mile 30.4, sec. 4, T. 4 N., R. 7 W. The drainage area is 498 square miles and the water surface is at an altitude of about 395 feet. The axis of the dam would be near the present U.S. 26 highway bridge. An earthfill dam that would back water to the 600-foot level would have a volume of about 1,840,000 cubic yards and the reservoir a capacity of 1,500,000 acre-feet. A considerable acreage of farm, pasture, and timber lands, as well as numerous access roads and highways would be flooded. Complete regulation of the runoff at the site during the period 1940–54 would require a storage capacity of 1,600,000 acre-feet, on the basis of a comparison with runoff at Foss. This capacity would require a reservoir with a maximum altitude of 605 feet. The area and capacity data for this reservoir site are shown in table 5.

TABLE 5.—*Area and capacity of Vernonia reservoir site, with dam at the Elsie site, mile 30.4, sec. 4, T. 4 N., R. 7 W.*

Altitude (feet)	Area (acres)	Capacity (acre-feet)	Altitude (feet)	Area (acres)	Capacity (acre-feet)
395	0	0	520	7,500	309,000
420	200	2,000	540	10,100	485,000
440	1,300	17,000	560	15,200	738,000
460	1,900	49,000	580	18,700	1,077,000
480	3,300	101,000	600	23,600	1,500,000
500	5,000	184,000			

The available storage in the Vernonia reservoir between altitudes 470 feet and 600 feet at the Elsie site would be 1,425,000 acre-feet and

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it is assumed that it would not be desirable to draw the reservoir lower in regulating for power production. To insure conservative estimates, an active capacity of 1,400,000 acre-feet has been used. This volume is sufficient to have maintained a uniform flow of 1,450 cfs (92 percent of the average) during the period from April 1, 1940, to September 30, 1954. The 1,400,000 acre-feet would have been drawn out by about October 31, 1945, and the reservoir refilled by January 15, 1951. The reservoir would have been drawn down only 600,000 acre-feet between January 15, 1951, and September 30, 1954. This favorable circumstance would have permitted operating from the top of the reservoir.

If the reservoir were to be used for firming winter flows, it could have maintained a firm flow of 2,195 cfs during the 5-month period from November through March and 1,000 cfs during the rest of the year. The greatest drawdown would have been about 1,370,000 acre-feet at the end of October 1945. The reservoir would have refilled by mid-January 1951, with only minor storage requirements thereafter through 1954. By reducing the summer flow to 50 cfs a minimum discharge of 3,535 cfs could have been assured for November through March of each year.

If water were to be diverted to the Columbia River via Fishhawk Creek, only 1,000,000 acre-feet (that part of the Vernonia reservoir above 540 ft in altitude) would be active storage. This storage could have provided a year-round diversion of 1,300 cfs of water. Other possibilities for diversion could have included a combination of a summer discharge of 470 cfs and a winter discharge of 2,645 cfs, or a November through March concentration of 3,280 cfs. After supplying these amounts, a minimum flow of 50 cfs would have been left in the river at all times.

GEOLOGY

By A. M. Piper

Three distinct bedrock units are recognized at the Elsie damsite (pl. 1) and they differ greatly in perviousness and bearing power. From oldest to youngest they are shale, nonfragmental volcanic rock (basalt), and fragmental volcanic rocks (also basalt).

The shale is thinly laminated, bluish gray when fresh, extremely fine grained, and moderately indurated. It is virtually impervious and low in bearing power. In part, the shale is somewhat clayey and probably is plastic when wet. Where exposed at the surface, it slakes and weathers deeply to a yellowish-brown clayey soil. Good outcrops of shale were mapped at four places along the left (east) bank of the stream, as follows: (1) in roadcuts 20 to 30 feet above the river near the downstream edge of the mapped area, where the shale dips

20° in a N. 40° W. direction; (2) at the inner edge of the Nehalem River flood plain about 450 feet downstream from line A–B (Elsie damsite, pl. 1), where the beds are nearly horizontal; (3) in a test pit for a pier of a highway bridge at an altitude of 440 feet 100 feet upstream from the line A–B; and (4) at the inner edge of the flood plain about 200 feet farther upstream, where the shale dips 30° to 90° eastward and may not be in place. Except in the central part of the site, along the line A–B (Elsie damsite, pl. 1), this shale is inferred to underlie the volcanic rocks.

The nonfragmental basalt is noncellular and microcrystalline throughout, and has a high crushing strength. This rock is exposed only in the central part of the site along the line A–B (Elsie damsite, pl. 1), where the river pierces it in a narrow chute. The outcrop is 200 to 400 feet wide along the river and rises to an altitude of about 480 feet on each side of the river, or about 90 feet above low river stage. In its lower half, this nonfragmental basalt displays conspicuous radial columns that average about 3 feet across; in the upper part, it fractures concentrically into shells from 3 to 8 feet thick (fig. 4). These partings firmly join one another and gouge is absent. The rock as a unit is impermeable.

The basalt outcrop just described is inferred to be the uppermost part of a steeply dipping dike that trends east across the river. The dike would form a rigid, near-vertical plate below river level.

The fragmental volcanic rocks, which are all basaltic, overlie both the shale and the dike of nonfragmental basalt and are probably as thick as 225 feet over most of the area (Elsie damsite, pl. 1). The fragmental rocks vary widely in physical character. On the right (west) bank of the river they are massive and are composed of a dense basaltic matrix in which fragments of basalt as much as 2 feet across are embedded. Here they form a nearly vertical bluff 100 to 150 feet high and therefore are believed to be fairly resistant and to have moderate bearing power. They probably are not highly pervious except where fractured. On the opposite, or east, side of the river the rocks are decidedly inferior in bearing power, in part are unstable, and probably are pervious inasmuch as they are composed of (1) coarse basaltic tuff and agglomerate in a weak fragmental matrix, all somewhat decomposed and cut by veinlets and scattered masses of silica; (2) discontinuous sheets of fine-grained basalt, most of which have been reduced to rubble by random fractures from 1 foot to 8 feet apart; and (3) a few thin ribs (dikes?) of fine-grained or glassy basalt, which ordinarily are brecciated throughout and at some places are silicified. In general, the fragmental rocks on the east bank are incoherent; thus, along the Wolf Creek Highway, which was built in 1937 across the

FIGURE 4.—Concentrically fractured columnar basalt at the Elsie damsite as viewed from the left bank. Photograph by A. M. Piper, 1937.

damsite area, a cut 700 feet long and 53 feet deep was excavated without blasting. (This road is now part of U.S. Highway 26.) Fully 90 percent of the hillward face of the cut exposes only a rubble of basalt blocks less than 1 foot across embedded in an earthy matrix (fig. 5). Not even at the base of the cut does massive basaltic rock crop out. Further evidence of the instability of these rocks is provided by the fact that several landslides have occurred along this road.

In addition to the slope wash that covers most of the Elsie damsite, the unconsolidated materials include landslide rubble and discontinuous stream deposits on the bed and banks of the stream and in a terrace about 20 feet above the stream.

FIGURE 5.—Basalt rubble in highway cut along the flank of the left abutment at the Elsie damsite. Photograph by A. M. Piper, 1937.

The stream deposits are composed of sand, pebbles, and cobbles and some boulders of local origin. In the central third of the mapped area they are not extensive and probably are thin; commonly they rest on rock shelves a few feet above river level.

Landslide rubble forms two flats along the left bank of the river; the southern edge of one is near the line A–B (Elsie damsite, pl. 1) and the other begins about 500 feet downstream from this line. The upstream flat lies at the foot of a landslide scar which is 450 feet wide and has a scarp with a vertical height of approximately 150 feet. The slide originated in the fragmental volcanic rocks. Above stream level the landslide rubble is composed of clayey earth mingled with basaltic blocks as much as 20 feet long. The earth matrix has been washed away where the rubble underlies the stream.

The weak shale described previously crops out at the sole of each of these two slides; thus, the cause of failure in the volcanic rocks most probably resulted from plastic deformation in the shale. The third slide formed in the same manner at a highway cut 0.6 mile east of the the damsite (fig. 6) within a year after the cut was made. The slide block at this locality is about 700 feet long and 50 feet in maximum thickness; its upper half is composed of fragmental volcanics, the lower

FIGURE 6.—Slide in fragmental basalt and shale in highway cut 0.6 mile east of the Elsie damsite. Photograph by A. M. Piper, 1937.

half of shale. All these features suggest that (1) the excessive fragmentation of the basaltic rocks on the east bank is due in part to subsidence, and (2) a considerable part of the area between the highway and the river on the east bank is unstable. Indeed, the entire east bank, which is characterized by large-scale hummocky topography, may be an old landslide whose form has been somewhat modified by erosion.

The lines A–B and C–D (Elsie damsite, pl. 1) indicate the two positions that seem to be best suited for dam construction at the Elsie site. The downstream position (A–B) crosses the mass of dense nonfragmental basalt that is interpreted to be a rigid, steeply dipping plate extending to considerable depth through the shale. Accordingly, this position seems suitable for a thin rigid dam that is arched for stability to a height of about 90 feet above the river. This conclusion should not be considered firm, however, until the vertical extent of the nonfragmental basalt has been determined by test drilling in the river bed and on either bank along the axis of the proposed dam. Neither this position nor any other within the area (Elsie damsite, pl. 1) seems suitable for a thin rigid dam of greater height, because the upper part of either abutment would be composed of the fragmental volcanics.

If the site at Tideport were superseded by a dam at the Elise site, the pond level would reach an altitude of 600 feet or more—that is, at least 200 feet above the river. To be stable, a dam that would confine this depth of water should be broad and flexible. A fill of earth or rock is suggested as most feasible. The left, or east, abutment of a flexible dam at the downstream position (A–B) may even be unsound above an altitude of 480 feet. The reasons for the instability of this abutment are as follows: (1) the potential leakage may be excessive all along the abutment for about 2,000 feet from the river, and (2) a considerable part of the abutment may prove unstable if saturated to or above an altitude of 600 feet.

The upstream position (C–D) is suggested as a more feasible site than the downstream position (A–B) for a flexible dam up to an altitude of 600 feet. The advantages of that position, which tend to compensate for a moderately greater length, are: (1) because both abutments are broad, excessive leakage seems unlikely, and (2) the weak shale, which is a major cause of instability in the fragmental volcanics, is inferred to lie below stream level and therefore potential landsliding would be avoided.

For a rockfill dam, the nonfragmental basalt near the site is suitable. At any place above 600 feet in altitude, the rocks are fragmental volcanics; if quarried for erecting a dam, a moderately large proportion of these rocks probably would need to be rejected. The most promising quarry site seems to be the flank of the ridge that overlooks the right abutment.

Percolation under a low rigid dam could easily be restrained by grouting the fractures in the nonfragmental basalt. A high flexible dam would call for more extensive cutoff measures; how extensive cannot be estimated without thorough test drilling. The most critical requirement seems to be an impervious connection from the dam deep into the shale that underlies the volcanic rocks, unless the volcanic rocks are proven to extend far beneath river level.

Except for the nonfragmental basalt and the more massive parts of the fragmental volcanics, all materials that form the Elsie damsite would be eroded rapidly by swiftly flowing water of considerable depth. Thus, the design of an adequate spillway involves critical problems.

For the low rigid dam, an overflow spillway seems feasible because firm rock probably underlies the streambed at shallow depth for at least 500 feet downstream from the line A–B. Accordingly, an extensive downstream apron probably would not be necessary, although riprap or some other measure to protect the left bank might be desirable. As an alternative, a spillway tunnel could be driven through the massive rock in the right abutment without undue difficulty.

For a high dam, an overflow spillway seems undesirable. A spillway at the side of the dam would be topographically feasible across the east abutment only if the dam were placed in the less desirable downstream position (A–B). For assured stability, a spillway structure there would require a substantial and extensive cutoff and an extensive pavement downstream.

An alternative spillway site could be located in a saddle about 1.2 miles northwest of the damsite (Elsie spillway area, pl. 1). This site is equally suited for dam construction at either of the two positions shown on plate 1 (Elsie damsite). Within 1,000 feet of this saddle in every direction the bedrock seems to be entirely composed of shale. Like the shale that crops out at the damsite, this shale is thoroughly decomposed to a moderate depth beneath the land surface. Even if it were unweathered it would have low bearing power and would be abraded easily by swiftly flowing water. However, it is virtually impervious. Any spillway structure across this saddle should have an extensive pavement downstream. If the main dam is to rise above an altitude of 600 feet, the spillway structure must also serve as a dike to close the saddle. For this dual purpose, the structure should have a wide base and should be seated on unweathered shale. Its maximum feasible height cannot be estimated closely without loading and percolation tests of the foundation material.

SPRUCE RUN RESERVOIR SITE

The Spruce Run damsite is at Nehalem River mile 22.5 (sec. 24, T. 4 N., R. 8 W.) just downstream from the mouth of Spruce Run Creek and approximately 8 miles downstream from the Elsie damsite. The water surface at the Spruce Run damsite is about 305 feet in altitude and the drainage area is 549 square miles. Dams of various heights have been studied for the Spruce Run site. The damsite might be used either for a dam to back water to the Elsie or Tideport damsites or for a dam that would back water to Vernonia. Table 6 shows the area and capacity data for the reservoir site.

TABLE 6.—*Area and capacity of Spruce Run reservoir site, damsite at mile 22.5, sec. 24, T. 4 N., R. 8 W.*

Altitude (feet)	Area (acres)	Capacity (acre-feet)	Altitude (feet)	Area (acres)	Capacity (acre-feet)
305	0	0	440	3,000	125,000
320	80	600	480	5,400	254,000
340	130	2,700	520	9,520	552,000
360	320	7,100	560	19,190	1,126,000
380	545	15,700	600	28,520	2,000,000
400	885	30,000			

The approximate height and volume of earthfill dams and capacities of their respective reservoirs are as follows:

Purpose	Dam height (feet)	Volume (cubic yards)	Reservoir capacity (acre-feet)
Back water to Elsie damsite	90	260,000	30,000
Back water to Tideport damsite	132	615,000	115,000
Back water to Vernonia	295	5,200,000	2,000,000

The average discharge of the river at the damsite is estimated to be about 1,880 cfs. The 2,000,000 acre-foot reservoir would have completely regulated the stream during the test period and would make almost any desired water-use plan possible. The reservoir would hold 1,270,000 acre-feet above the 540-foot altitude. That amount of storage would have made possible a continuous diversion of about 1,600 cfs to the Columbia River during the test period.

The more likely use of the Spruce Run site, however, would be for a dam to back the water to the Elsie or Tideport sites, which are at altitudes 395 and 437 feet respectively. The total head created would be 90 or 132 feet and the reservoir would reregulate the releases from the upstream reservoir for power development.

The damsite area is shown on the previously described Saddle Mountain quadrangle, scale 1:62,500, and the 1936 river survey map, scale 1:31,680. A large-scale map has not been made, nor has a geologic examination been made of the area.

SALMONBERRY RESERVOIR SITE

GENERAL FEATURES

The Salmonberry damsite is in sec. 10, T. 3 N., R. 8 W., at Nehalem River mile 15.5, about half a mile upstream from the confluence of the Salmonberry River. Drainage area is 573 square miles and the water surface altitude is 205 feet. Table 7 shows the area and capacity data for this reservoir site. The water surface at the Spruce Run damsite is 305 feet, and at the Elsie site is 395 feet. The approximate height and volume of the earthfill dams that would back water to these sites or to Vernonia, and the capacities of the respective reservoirs, are as follows:

Purpose	Dam height (feet)	Volume (cubic yards)	Reservoir capacity (acre-feet)
Back water to Spruce Run damsite	100		16,000
Back water to Elsie damsite	190	940,000	115,000
Back water to Vernonia	395	8,400,000	2,500,000

Dams high enough to back water to Spruce Run or to Elsie seem quite reasonable whereas the larger one probably is a remote possibility.

TABLE 7.—*Area and capacity of Salmonberry reservoir site, damsite at mile 15.5, sec. 10, T. 3 N., R. 8 W.*

Altitude (feet)	Area (acres)	Capacity (acre-feet)	Altitude (feet)	Area (acres)	Capacity (acre-feet)
205	0	0	440	3,400	250,000
240	50	700	480	7,000	463,000
280	250	7,000	520	11,400	831,000
320	680	25,000	560	21,300	1,485,000
360	1,160	60,000	600	31,000	2,531,000
400	2,000	125,000			

A dam that would back water to the Elsie damsite seems the more likely. A 115,000 acre-foot reservoir between the Elsie site and the Salmonberry site could be used for reregulation of releases from a large reservoir at the Elsie site. The constant release from Elsie of 1,450 cfs on a continuous schedule could be regulated to a minimum flow at the Salmonberry site of about 1,845 cfs. Reregulating the summer (1,000 cfs) and winter (2,195 cfs) releases from Elsie could raise the summer minimum to about 1,310 cfs and the winter minimum to about 3,150 cfs at Salmonberry.

If the dam were constructed to the 600-foot altitude, complete control of the Nehalem at the Salmonberry site would be possible; in fact, only 2,100,000 acre-feet of storage would have been required for the period studied. That storage would have been depleted near the last of October 1945 and the reservoir would have refilled by the end of March 1951 with only minor drawdown thereafter.

The entire 2,500,000 acre-feet of water in a 600-foot altitude reservoir would be very valuable for peaking purposes, for it could be used at any time of the year in large or small amounts, or saved for use in dry years as needed. For example, a full reservoir in June 1940 could have been drawn upon at a rate greater than the average discharge through the dry years which ended during October 1945. This large reservoir would have enabled a plant at Salmonberry to furnish some of the power lost at plants that have less storage and the excess water used could have been recovered by reducing releases in subsequent wet periods when water was adequate at other powerplants.

The storage above 540 feet at Salmonberry would be 1,420,000 acre-feet. If this site were used as an alternative reservoir for diversion to the Columbia River, this storage would have been sufficient for a constant flow of 1,730 cfs for the period May 1, 1940, through February 15, 1949. Utilizing this same volume of storage for concentrating the winter flows would permit a winter flow of 4,275 and a summer flow of 115 cfs.

GEOLOGY

By D. L. Gaskill

At the Salmonberry damsite (pl. 2), the Nehalem River flows in a deep canyon that is cut in basaltic flows of probable early Eocene age (Tillamook Volcanic Series of Warren and others, 1945). Canyon slopes rise to altitudes 1,200 feet above the damsite in a horizontal distance of ¼ to ½ mile from the river.

Foundation rocks consist of thick to massive flow layers of dark-gray dense equigranular fine-grained basalt and porphyritic basalt containing phenocrysts of feldspar 1 to 4 mm in length. Individual flows include some coarse-textured and amygdaloidal basalts. Some of the flows are separated by volcanic breccia, agglomerate, or tuffaceous beds of gray to blackish-red indurated clay. Local alteration of the basalt gives some exposures a green or olive-gray.

Bedrock on the east abutment is generally concealed by vegetation, talus, landslide, or rockfall detritus, in contrast to the drier, stable well-exposed bedrock on the west abutment. The river seems to have been formerly blocked at the damsite by rockfall material originating high on the east canyon wall. As a result of this rockfall, the river current has been directed against the west abutment. Although the present channel is still compressed against the west bank and is partially choked by block rubble, the river is cutting bedrock at and below section *D–D′* (pl. 2). However, 300 feet upstream from section *D–D′*, the river is still excavating thick coarse alluvial materials which have been deposited behind this rubble dam.

The basaltic flows dip upstream. The flow layers strike roughly east-west and dip about 28° N. in the damsite area. Irregular flow structures guide exfoliation of the basalts. Fractured, brecciated, and oxidized zones indicative of fault movement were observed at several localities in and near the damsite area. Study of aerial photographs suggests that the region is broken by many diverse faults or major zones of bedrock fracture. The lineament trending northwest across the damsite area (pl. 2) follows a fractured, altered zone marked by deep gullies, but no offset of flows was observed. The lineament bisecting section *D–D′* is inferred from study of aerial photographs. A bed of indurated tuffaceous clay about 2 feet thick separates flow sheets on the west abutment at river level near section *D–D′*. About 200 feet downstream, a thin layer of basaltic agglomerate separates the massive flow layers at river level.

The attitude of the flow layers, at approximately right angles to the river and dipping upstream, is favorable for a dam here (fig. 7).

FIGURE 7.—Salmonberry damsite (section at *D–D′*, pl. 2), looking upstream. Photograph by D. L. Gaskill, 1957.

Fractures weaken the basalt, particularly on the east abutment where rock disintegration is facilitated by a moderate dip of the flow layers downslope. Most of the joint fractures are discontinuous and form tight random-sized interlocking blocks. The massive fine-grained basalt flows at river level and on the west abutment appear competent to sustain any proposed dam structure here. The thin beds of flow breccia, agglomerate, tuff, and clay are weak and permeable, but they represent only a small fraction of the exposed geologic section. These weak zones, in common with the massive flows, dip upstream and therefore oppose any tendency of a dam to overturn or slide downstream. The instability of the east abutment is perhaps the most serious handicap of this site. The dip of the basalt flows toward the river, in combination with an advanced state of solifluction, rock alteration, exfoliation, and deep fracturing, has caused rapid bedrock deterioration and landsliding. The abutments probably have been weakened by high-angle shear zones and by one or more possible faults parallel to the river on the east abutment. Several springs emerge from beneath landslide rubble on the east abutment at river level, and seepage was observed along clay partings in the west abutment. Some leakage might occur along flow contact zones susceptible to hydraulic pressure or along high-angle joint planes trending downstream, but such leakage would probably prove unimportant and controllable by grouting. Stripping should prove minimal on the west abutment, but would require removal of considerable rock debris and deteriorated bedrock on the east abutment. Unconsolidated rockfall material, perhaps more than 50 feet thick in places, is present on the lower slope of the east abutment. Thick talus deposits are also present higher on the east abutment above the main landslide deposit. Loose, incoherent, disintegrated mantle rock, 10 to 15 feet thick, is locally exposed in roadcuts near the damsite area. Careful examination of the structural stability of a broad bedrock rib immediately northeast and above section *D–D′* on the east canyon wall would be advisable. A slide or rockfall originating on this spur might directly damage a dam or create damaging reservoir waves.

Impervious and aggregate materials are locally available in river-bar and flood-plain deposits above and below the damsite. The dense fresh basalt from nonbrecciated nonamygdaloidal flows might be a source of aggregate in the damsite area.

The Salmonberry site seems suitable for either an earth-rockfill or concrete dam.

UPPER WAKEFIELD RESERVOIR SITE

GENERAL FEATURES

The Upper Wakefield damsite is below the mouth of the Salmonberry River in sec. 16, T. 3 N., R. 8 W., near Nehalem River mile 14.4. Drainage area is 644 square miles and the water surface altitude is 175 feet. The reservoir site has an estimated storage capacity of 2,740,000 acre-feet with a dam to the 600-foot altitude. The volume of an earth-fill dam to this height would be about 14,300,000 cubic yards. The average discharge of the river at the damsite is estimated to be 2,480 cfs. Storage required for complete regulation is estimated at 2,600,000 acre-feet. About 1,000 acres of the reservoir lies below the Salmonberry damsite, and most of this is in the Salmonberry River valley. The area and capacity data for this reservoir site is shown in table 8.

The most likely use of a dam at this site would be to raise water to the level of the Elsie site. Storage would amount to about 150,000

TABLE 8.—*Area and capacity of Upper Wakefield reservoir site, damsite at mile 14.4, sec. 16, T. 3 N., R. 8 W.*

Altitude (feet)	Area (acres)	Capacity (acre-feet)	Altitude (feet)	Area (acres)	Capacity (acre-feet)
175	0	0	400	2,400	164,200
200	31	400	480	7,650	566,200
240	130	3,600	520	12,230	963,800
280	390	14,000	560	22,290	1,654,200
320	900	39,800	600	32,170	2,743,400
360	1,460	87,000			

acre-feet. This amount could be obtained with an earthfill dam 220 feet high having an approximate volume of 2,460,000 cubic yards.

A branch of the Southern Pacific railroad follows the Salmonberry River and the Nehalem River to the coast and about 4 miles of it would be flooded by a dam backing water to the Elsie site. The cost and difficulty of relocating the railroad would have to be considered in planning a dam at this site.

GEOLOGY

By D. L. GASKILL

At the Upper Wakefield damsite (pl. 2), the Nehalem River is confined in a deep canyon that is cut in basaltic lava flows of the Tillamook Volcanic Series (Warren and others, 1945). Valley walls rise to altitudes 1,800 feet above the river here. Bedrock is similar to that described at the Salmonberry damsite a mile upstream. Individual flows vary in texture but the predominant rock is a dense dark-gray fine-grained to porphyritic basalt. The flows exhibit slightly irregular contacts and many are separated by pyroclastic rocks and brick-red zones of baked tuffaceous clay. Many flows have well-defined flow partings.

The river is actively cutting bedrock in the damsite area. At several places along the river channel, fine-grained and porphyritic feeder dikes have been intruded along near-vertical fractures trending in a northerly or northwesterly direction. These dikes reach a maximum of 5 feet in width and contain a high percentage of glass and accessory magnetite. The basaltic flows strike roughly N. 80° W. and dip approximately 27° N. Several small faults or shear zones are indicated on plate 2 (Upper Wakefield damsite). The faults mapped in the area of section B–B′ are intruded by dikes. Displacement on faults does not indicate recent movement. These old faults are probably not critical planes of weakness in respect to a dam here. Joint systems represented by near-vertical, closely spaced parallel fracture sets are common in the foundation rock along the river, although large areas or individual flows may appear almost joint free. The more conspicuous joint sets generally strike in a northerly direction and have secondary joints at right angles and diagonal to the major set. Most of the fractures are thin, tight, and discontinuous and probably do not seriously weaken the fresh unaltered bedrock. These joints are spaced about 3 to 6 inches apart in foundation rock at section B–B′ and at the river bend upstream from section A–A′.

Large areas of stable bedrock are exposed on the steep (40°–45° slope) north wall of the canyon. The north abutment is dryer and supports less vegetation than the heavily forested south abutment. Bedrock on the south side of the canyon is almost completely concealed by vegetation, talus, landslide rubble, and rock-soil creep. Limited areas of bedrock are exposed above an altitude of 300 feet on the south abutment along sections *A–A′* and *B–B′* (pl. 2). These rocks are separating from the cliff face in large blocks along vertical joint planes. West of the deep tributary gorge in the south canyon wall, most of the lower slopes below an altitude of 400 feet are covered by soil and rock debris that are in part saturated with water. This debris is more than 120 feet thick and is probably the result of landsliding. Slickenside surfaces observed on large boulder blocks comprising this material at river level indicate the presence of faults or landslip surfaces high on the south canyon wall. Many springs issue from the base of this debris along the south side of the river. The structurally weak and unstable character of the south abutment is due to the pronounced dip of the flow structures toward the river and the advanced state of bedrock disintegration and deterioration accompanying deep physical and chemical weathering.

Considerable excavation of deteriorated bedrock below the zone of open fractures would be necessary on the south abutment for a dam structure in this area. In contrast to the negligible stripping necessary on the north abutment at section *A–A′*, as much as 40 feet of talus debris would have to be removed on the south abutment below an altitude of 300 feet and 50 feet or more of bedrock above this altitude, depending upon the height of the dam.

Bedrock leakage probably would be limited to fractures and flow contacts, particularly the flow contacts dipping toward the river on the south abutment.

Core holes should be drilled along the south abutment profile to determine depth of unconsolidated material and bedrock deterioration.

An overfall type of spillway would subject the bedrock to some plucking, but would abrade the rock very slowly. A side-channel spillway or water-diversion tunnel on the north abutment would probably be feasible.

A damsite in the area of sections *A–A′* or *B–B′*, east of the tributary creek on the south abutment, would probably be suitable for a rockfill or concrete-type structure of any desired height. However, reconnaissance of possible sites immediately upstream or east of the mapped area (Upper Wakefield damsite, pl. 2) is recommended.

A brief discussion of available construction materials in this area is included in the discussion of the Salmonberry damsite (p. 31).

WAKEFIELD RESERVOIR SITE

A dam at Nehalem River mile 12.8, about 1.6 miles downstream from the Wakefield site (fig. 3) would make a reservoir for a given dam height where capacity would be only slightly more than that of a reservoir at the Upper Wakefield site. For this reason the two positions offer equal advantages as reservoir sites.

NEHALEM FALLS RESERVOIR SITE

GENERAL FEATURES

The Nehalem Falls damsite is at Nehalem River mile 8 in sec. 27, T. 3 N., R. 9 W., where the water surface altitude is 65 feet. Raising the water surface to 395 feet, which would back water to the Elsie site, would provide about 362,000 acre-feet of storage. The volume of an earthfill dam of the required height would be about 8,300,000 cubic yards. Table 9 shows area and capacity data for this reservoir site.

The average discharge at Nehalem Falls is estimated at 2,585 cfs. Complete regulation of the river at this point would require about 2,740,000 acre-feet of storage. This amount of storage is much beyond the capacity of a reasonable dam at this site. Creation of head and reregulation of releases from upstream reservoirs would be more likely uses of any reservoir at Nehalem Falls.

TABLE 9.—*Area and capacity of Nehalem Falls reservoir site, damsite at mile 8, sec. 27, T. 3 N., R. 9 W.*

Altitude (feet)	Area (acres)	Capacity (acre-feet)	Altitude (feet)	Area (acres)	Capacity (acre-feet)
65	0	0	240	850	51,000
80	6	40	280	1,200	92,000
120	90	1,400	320	2,000	153,000
160	250	8,200	360	2,750	248,000
200	540	23,000	400	3,900	380,000

If the river is regulated at Elsie to a continuous flow of 1,450 cfs, 347,000 acre-feet of storage at Nehalem Falls could reregulate to a constant flow of 2,200 cfs. This flow would leave 15,000 acre-feet of dead storage in a reservoir backing water to the Elsie site. If the river is regulated at Elsie to 1,000 cfs and 2,915 cfs for the April through October and the November through March periods, respectively, the reservoir at Nehalem Falls could regulate the river to 1,210 cfs and 3,900 cfs, respectively. By concentrating all the flow at Elsie except a conservation requirement of 50 cfs in the winter period, a flow of 3,535 cfs there could be increased to 5,385 cfs at Nehalem Falls.

Another possible plan of development that might affect the use of the Nehalem Falls reservoir would be to divert all the flow except a conservation release of 40 cfs at Squaw Creek to the Columbia River basin. In that event, the Nehalem Falls reservoir could be used to regulate discharges from the drainage basin downstream from Squaw Creek; the average flow at Nehalem Falls would be about 1,525 cfs (40 cfs conservation release at Squaw Creek and 1,485 cfs from the intervening drainage area). The 362,000 acre-feet of storage at Nehalem Falls would permit a minimum regulated flow of about 1,030 cfs after reservoir losses. If water is diverted to the Columbia River from a reservoir behind a dam at Tideport or Elsie, discharge at Nehalem Falls would be smaller but might still be large enough to warrant development there.

GEOLOGY

By A. M. Piper

The damsite at Nehalem Falls seems to involve only two extensive rock units—an incoherent terrace deposit, and a volcanic unit (basalt). A view of the damsite is shown on figure 8.

The terrace deposit consists largely of poorly sorted sand, pebbles, and cobbles as much as 3 inches in diameter that were derived from dense volcanic rocks, chiefly basalt. The rocks comprising the deposit are slightly weathered and all are bleached and iron stained. These stream-borne materials are exposed in the streamward faces of two terrace remnants about 30 feet above the river; one is on the left (east) bank at the upstream edge of the area shown on plate 2 (Nehalem Falls damsite), and the other is on the right bank near the downstream edge of the area. Near the landward edges of the two remnants, the stream-borne materials are mingled with slightly sorted slope wash. The terrace deposits rest on rock shelves from 2 to 15 feet above river level; the maximum thickness of the deposits is estimated to be about 30 feet. The unit as a whole is highly pervious and incompetent to sustain a rigid dam.

The greater part of the volcanic rock (basalt) is composed of several thick sheets that dip about 5° to 10° in a N. 30° E. direction or diagonally upstream. The basalt is fine grained, dense, and fresh; it has moderately high crushing strength, probably at least 20,000 pounds to the square inch. However, the following three features detract somewhat from its strength in mass:

1. Fractures which are undulatory, discontinuous, and commonly 10 feet or more apart are nearly vertical and form two sets. One

set trends northeast, the other northwest. A few fractures have crushed selvages as much as 4 inches thick. Cross fractures, random in strike and dip, are common. Taken as a whole, these fractures probably weaken large masses of the basalt only slightly, for the plates and blocks that intervene between fractures are random in size and shape and are rather closely interlocked. However, the thin spur that forms the east bridgehead near the downstream edge of the area is unstable and seems to be sliding toward the river; thus, the stability of the thin spurs on either side of the valley in the central part of the area also may be questioned.

2. Fragmental partings (basaltic scoria and flow breccia) separate the sheets of dense basalt at some places, as beneath the terrace deposit along the west bank of the river in the central part of the area. These fragmental partings are weak but, as exposed in fairly large and numerous outcrops, are neither thick nor extensive. Those that are exposed dip upstream and therefore would oppose the tendency of a dam to slide downstream.
3. Weak zones occur where the basalt is slightly or moderately decomposed or where it is cut by veinlets of nonmetallic minerals (drusy quartz and zeolites, in part cellular). Their number and extent are not fully disclosed by the outcrops, but they seem to be most extensive in the downstream half of the area.

A small part of the volcanic rock is composed of fine-grained dense basalt in thin dikes and of massive, coarsely fragmental rock (mostly basaltic agglomerate) similar to that at the Elsie site upstream. Both upstream and downstream near Nehalem Falls damsite, massive fragmental rock is extensive and commonly is deeply weathered. It may also be extensive in parts of the site that are covered by slope wash. This possibility is a critical feature of the site with respect to the erection of a dam, for the fragmental rock is materially weaker than the nonfragmental basalt and probably would not sustain an extremely thin dam. However, because landslide debris is absent, any fragmental rock at the Nehalem Falls site is probably stronger than that on the east bank of the river at Elsie site.

The best position for a dam at Nehalem Falls seems to be that indicated by the line *A–B* on plate 2 (Nehalem Falls damiste). At that position, both abutments are broad and it is inferred that fractures do not make either unstable. Nearly continuous exposures of dense nonfragmental basalt of high bearing power extend across the stream bed and also form the full height of the right abutment. The unconsolidated stream deposits are neither extensive nor very thick and can be removed with little trouble. However, the nature of the bedrock in

FIGURE 8.—Nehalem Falls damsite viewed upstream from the road bridge. Photograph by A. M. Piper, 1937.

the left abutment is not known and should be explored by core drilling. If all the bedrock is nonfragmental basalt such as forms the right abutment, the site probably is suitable for a rigid dam of gravity cross section, but the bedrock in the left abutment is largely fragmental, the site may be suitable only for a flexible dam. Such a dam might well be a fill of rock quarried from the dense basalt high on the right bank.

To restrain leakage, an impervious membrane seated in sound bedrock should extend somewhat below the floor of the chute which forms the "falls" about 250 feet downstream. In addition, a grout curtain to seal fractures in the abutments will probably prove desirable; the extent of such a curtain cannot be determined from data now available.

In the design of a permanent spillway, the geologic features of the damsite at Nehalem Falls offer no critical problems. The dense basalt that forms nearly all the bedrock along the stream is abraded very slowly by water flowing swiftly and in considerable depth; thus an overfall spillway seems feasible. Some paving may be necessary to prevent the plucking of small blocks from fracture zones but need not be extensive.

STONEHILL RESERVOIR SITE

GENERAL FEATURES

The Stonehill damsite is at mile 4.9, sec. 34, T. 3 N., R. 9 W., about 5 miles upstream from tidewater and 8 miles east of Nehalem. The water surface altitude at the damsite is about 23 feet. The average discharge of the river at the site is estimated to be about 2,900 cfs. An earthfill dam that would raise the water surface to the Nehalem Falls damsite, altitude 65 feet, would have a volume of 80,000 cubic yards. The reservoir would have a capacity of about 3,000 acre-feet. The purpose of the dam would be principally for creating head for power. Releases from the Nehalem Falls reservoir could be reregulated to some extent. One the basis of the Foss gage records the minimum flow increments to the Nehalem River between Nehalem Falls and Stonehill are estimated to be about 15 cfs during the driest months and about 170 cfs during the November through March period. The annual discharge, above reservoir losses, would be only 5 cfs and 160 cfs more than at Nehalem Falls for these periods.

GEOLOGY

By D. L. Gaskill

At the Stonehill damsite, the Nehalem River flows westward through a short valley constriction cut in rock of the Tillamook Volcanic Series (Warren and others, 1945). Bedrock consists of thick to massive flows of dark- to greenish-gray dense, finely crystalline and porphyritic basalt, altered chloritized porphyritic basalt, and flow breccia. Flow breccia is exposed at a small quarry on the north abutment east of section *C–C′* (Stonehill damsite, pl. 2) and along the railroad grade near bench mark PTBM 90. At the quarry, the flow breccia is about 40 feet thick and consists of greenish-gray angular welded blocks of pyroclastic material chloritized to a greenstone. Vesicular and amygdaloidal zones are common, especially in the upper part of the flow. Joint faces are pyritized, veins of calcite cut the rock, and cavities are filled with quartz, calcite, and zeolite minerals. Massive flows of finely crystalline basalt and porphyritic basalt overlie and underlie the breccia. The flows at the quarry dip about 25° NE. Bedrock exposures on the steep north abutment include both unaltered and altered chloritized oxidized basalt. The river is abrading finely crystalline basalt along the base of the north abutment and seems to be flowing over bedrock a short distance upstream. Finely crystalline basalt and weathered porphyritic basalt outcrop locally along the abandoned rail grade on the south abutment. A thin bed of glauconitic(?) sandstone was observed between flows on the south bank near bench mark PTBM 66 (pl. 2). Most of the south abutment slope is covered by terrace and mantle deposits and obscured by vegetation. Only a thin veneer of alluvium is inferred to overlie bedrock in the river channel. Unconsolidated river terrace deposits are thin, probably less than 15 feet thick at section *C–C′*.

Bedrock on the north abutment is broken by numerous joint fractures. Lineaments plotted from aerial photographs and shown on plate 2 may represent weak fracture zones. Faulting is inferred on the north abutment, where highly oxidized zones are exposed along the highway and poorly exposed altered flow breccia crops out in railroad cuts. If the breccia is the same as that exposed at the quarry, a large displacement of flows is indicated, down thrown on the west. A series of northeast-trending faults cuts the volcanics and sedimentary rocks of the Cowlitz Formation several miles west of the damsite between Foss and Mohler, and a thick sequence of indurated faulted sediments (laminated hornfels) is exposed along the abandoned rail grade about half a mile east of the damsite on the south side of the river.

The north abutment seems to be structurally stable owing to the dip of the flow layers into the hill, in contrast to the inferred dip of the flows toward the river on the south abutment. The moderate upstream dip of the flow layers should afford good anchorage for a dam. Bedrock is weakened by joints and by local rock alteration, and probably by faults. The inferred fault zone mapped on the north abutment probably crosses the river and seems to be the most objectionable geologic feature of the damsite. Exploration would be required to determine the structure and degree of decomposition along this zone. Additional investigation of concealed bedrock structures, especially on the south abutment, is advisable. Joint planes and possible thin interbeds of tuff or sedimentary rock may be potential zones of reservoir leakage.

Impervious materials and aggregate appear to be available in large quantity from alluvial deposits in the Nehalem River valley near the damsite. Sand and gravel have been excavated from terrace deposits 2½ miles west of the damsite. Highway-metal quarries have been developed in and near the damsite area.

The Stonehill site is probably suitable for a wide base earth- or rock-fill structure.

GODS VALLEY RESERVOIR SITE

The Gods Valley damsite is in sec. 26, T. 4 N., R. 9 W., on the North Fork Nehalem River, about 1 mile upstream from Soapstone Creek. The water surface at the damsite is estimated to be about 240 feet in altitude. The only maps of the dam and reservoir site area are the U.S. Geological Survey 15-minute Cannon Beach and Saddle Mountain 1:62,500-scale quadrangles. A dam that would raise the water to the 400-foot altitude would have a crest length of about 500 feet; its volume is roughly estimated to be about 680,000 cubic yards. As measured from the quadrangle maps, the reservoir capacity would be about 75,000 acre-feet and would cover an area of 1,400 acres. There are no important roads or other improvements in the reservoir area. Average discharge at the site is estimated to be about 300 cfs. By using all the storage, a minimum discharge of 245 cfs could have been assured during the period studied. Other possibilities would be a minimum release of 535 cfs for power production during the November through March period or a diversion of as much as 300 cfs into an irrigation canal during a 4-month period June through September, after losses and a conservation release of 10 cfs.

A regulating reservoir at the Gods Valley site would be very beneficial to the North Fork basin regardless of whether a powerplant were included, and especially if it provided for passage or propagation of fish.

The damsite has not been examined geologically.

POTENTIAL POWER

Power development on the Nehalem River will not be practicable unless reservoirs are provided to regulate flow. Table 10 presents the regulated discharges and power that could have been available over the 15 water years 1940–1954, by regulation in four reservoirs on the main stem and one on the North Fork. Nehalem Falls benefits from storage at Elsie, and Stonehill from storage at Elsie and Nehalem Falls. Rocky Point storage is not reflected at any of the downstream sites because the purposes for which this reservoir is likely to be built may detract from, rather than add to, downstream power. The various regulating possibilities of the reservoirs were discussed in the section on regulation and storage. Table 10 shows three alternative plans for utilizing the reservoirs: (1) by continuous regulation, (2) by assuring a small amount of water for power production during the summer months (when the Columbia River is flowing at high stages) in combination with a maximum amount of the remaining water for winter power production (when the Columbia River is at low stages and when demand for power is high), and (3) by assuring the maximum regulation for the winter months if no water is released for power during the rest of the year.

Figure 3 shows several damsites and reservoir sites on the main river, and one dam and one reservoir site each on Fishhawk Creek and the North Fork. A total head of 705 feet on the main river is available for development by dams or by combinations of dams and conduits. Three hundred and forty feet of head could be developed at the site on the North Fork by means of a dam and conduit. The illustrative plan of development presented here includes four dams on the Nehalem River and a dam and conduit on the North Fork. Fishhawk Creek is discussed separately because it would divert water out of the basin and thereby reduce the power potential of downstream sites. The basin's hydroelectric power potential is estimated as the combined amount that could be developed by dams at the five following sites: Rocky Point, Elsie, Nehalem Falls, and Stonehill on the Nehalem River, and Gods Valley on the North Fork. Some of the alternative dams discussed on pages C10–C40 and other possibilities for power development may have equal or greater merit, but to avoid confusion they have not been included in this section. The illustrative plan of development was chosen for estimating the gross power potential and is not necessarily the optimum one. In fact, the best use of the Nehalem River for power development might be a pumped-storage diversion to the Columbia River. That possibility is discussed separately at the end of this section.

The most valuable potential contribution of the Nehalem River to the Pacific Northwest power supply might be for furnishing peaking or firming power during the winter. The Columbia flows at rates greater than average for 4 months, April, May, June, and July, and at rates less than average during the remaining 8 months. The Nehalem River flows at rates greater than average for 5 months, November through March, and less than average for the remaining 7 months.

TABLE 10.—*Potential power of the Nehalem River*

Time of use	Flow (cfs) and potential power (kw) at indicated site (average head, in feet)										Total	
	Rocky Point (105)		Elsie (170)		Nehalem Falls (270)		Stonehill (40)		Gods Valley (305)		Kw	Kwhr
	Cfs	Kw	Cfs	Kw	Cfs	Kw	Cfs	Kw	Cfs	Kw		
Continuous	185	1,320	1,450	16,800	2,200	40,400	2,205	6,000	245	5,080	69,600	609,700,000
Combination:												
April-October	[1] 355	2,500	1,000	11,600	1,210	22,200	1,215	3,300	[1] 300	6,200	45,800	230,000,000
November-March	[2] 10		2,195	25,400	3,900	71,600	4,060	11,000	10		108,000	391,000,000
Total combination												621,000,000
November-March only	435	3,100	3,535	40,900	5,455	100,000	5,615	15,000	535	11,000	170,000	616,000,000

[1] Covers the low-flow season only (June-September).
[2] Minimum with uncontrolled averages as much as 145 cfs for the October-May filling period.

The 5-rate months thus occur when the Columbia River is low; these are also the months when demand for power is highest. Figure 9 compares the monthly percentages of average annual discharge for the Nehalem and Columbia Rivers.

If the Vernonia site is utilized for a large reservoir, a high degree of control will be afforded and the schedule for producing power can be correspondingly flexible. Three different schedules are shown in table 10 for the five-dam development. The plan for continuous generation would have the lowest capability, but it would be 98 percent of the combination plan, which has the highest potential, and for that reason the energy output is almost the same regardless of the time of use. These high potentials are due to the regulating value of the Vernonia reservoir site. The greater value of winter peaking power makes the winter-use plans attractive, but the undesirability of completely closing plants during the summer is favorable to the combination or the continuous arrangement.

Diversion of water to the Columbia by pumping from the Vernonia reservoir with a dam at Elsie and by operation for year-round regulation could produce 666,000,000 kwhr of energy. A combination of winter and summer operations could produce 703,000,000 kwhr annually. Operated to produce winter peaking power only, the plan would produce 696,000,000 kwhr which would require expending about 350,000,000 kwhr of off-peak energy for pumping requirements.

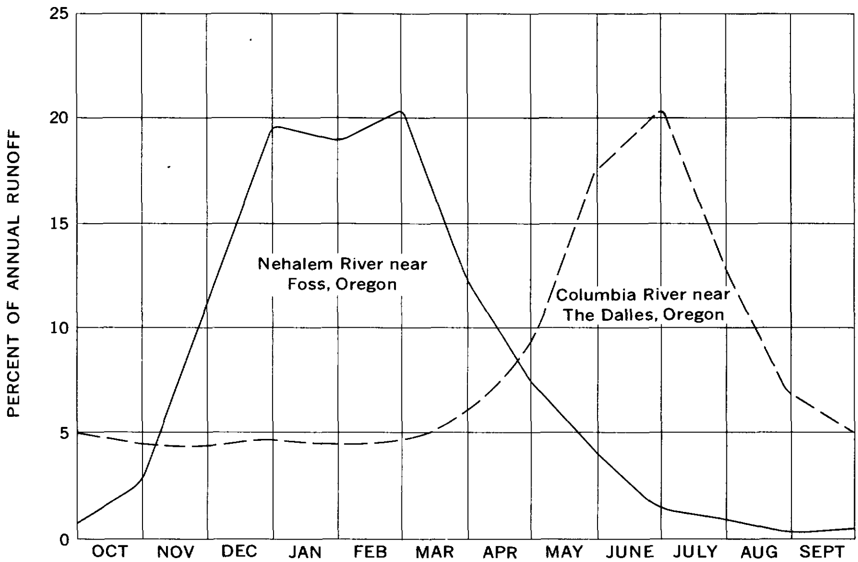

FIGURE 9.—Mean monthly percent of average annual flow for Nehalem River near Foss and Columbia River near The Dalles.

Table 11 summarizes potential power of the individual sites for the uncontrolled river, for continuous regulation and for maximum utilization of water between November 1 and March 31. These data show power potentials under existing conditions and by possible regulation. The data also indicate the importance of regulation in any practical waterpower development on the Nehalem River.

If the Rocky Point dam is constructed for irrigation or conservation, it might be found economic to include a powerplant. The reservoir operations might assure a minimum year-round flow, concentrate the flow in the winter months for power production, or hold the water for summer irrigation and fish propagation.

TABLE 11.—*Summary of potential power under natural-flow and regulated-flow conditions*

[Computations are for 80 percent efficiency]

Damsite	Head (ft)	Percent of time or period	Estimated flow (cfs)	Power (kw)
		Natural flow		
Rocky Point	130	Q95	10	90
		Q50	100	900
		Qmean	235	2,100
		November-March mean	465	4,100
Elsie	205	Q95	65	900
		Q50	650	9,000
		Qmean	1,573	21,900
		November-March mean	3,110	43,300
Nehalem Falls	330	Q95	105	2,350
		Q50	1,070	24,000
		Qmean	2,585	58,000
		November-March mean	5,110	115,000
Stonehill	42	Q95	117	334
		Q50	1,200	3,420
		Qmean	2,900	8,280
		November-March mean	5,738	16,360
Gods Valley	340	Q95	10	230
		Q50	125	2,890
		Qmean	300	6,930
		November-March mean	600	13,900
Total		Q95		3,900
		Q50		40,210
		Qmean		97,210
		November-March mean		192,660
		Regulated flow		
Rocky Point	105	Continuous	185	1,320
		November-March	435	3,100
Elsie	170	Continuous	1,450	16,800
		November-March	3,535	40,900
Nehalem Falls	270	Continuous	2,200	40,400
		November-March	5,455	100,000
Stonehill	40	Continuous	2,205	6,000
		November-March	5,615	15,000
Gods Valley	305	Continuous	245	5,080
		November-March	535	11,000
Total		Continuous		69,600
		November-March		170,000

A reservoir behind a dam at the Elsie site would store more than 1,400,000 acre-feet between altitudes 470 and 600 feet. It might be operated to produce a uniform year-round flow, a moderate flow from April through October with a firming winter flow about twice as great from November through March, or a concentrated winter flow with the summer release limited to water for operating fish ladders.

Regulated flows for the Nehalem Falls and Stonehill sites are based on regulated discharges from the Vernonia reservoir with a dam at Elsie.

If the Gods Valley dam is constructed for providing irrigation water, for fish propagation, or for other water-conservation purposes, addition of a powerplant might be feasible. A 3½-mile pressure conduit along the left bank of the North Fork Nehalem River at the 240-foot altitude would reach a favorable location for a penstock in sec. 32, T. 4 N., R. 9 W., where the river surface is estimated to be about 60 feet above sea level. The head would vary between 180 and 340 feet depending upon the water level in the reservoir. The purpose for which the reservoir is built would determine the type of water-power operation.

FISHHAWK CREEK DIVERSION TO COLUMBIA RIVER AND PUMPED STORAGE

The Nehalem and Columbia Rivers are separated by a distance of only about 8 air miles across Tunnel Ridge in the area of Birkenfeld on the Nehalem and Marshland on the Columbia. Water raised to an altitude of 600 feet in the Vernonia reservoir site would back up Fishhawk Creek toward the Columbia and thus shorten the distance between the two streams, and the water could be pumped into a storage site upstream on Fishhawk Creek. This arrangement would shorten the tunnel route and increase the head. This and other possible diversion sites are shown on plate 3.

FISHHAWK DAM AND RESERVOIR SITE

GENERAL FEATURES

The Fishhawk damsite is in sec. 29, T. 7 N., R. 5 W., on Fishhawk Creek, a tributary to Nehalem River. The water surface of the creek at the damsite is 670 feet above sea level and the drainage area is 11 square miles. An earthfill dam that would raise water to the 900-foot level would have a volume of about 3,300,000 cubic yards. The reservoir would store 45,000 acre-feet of water when filled. Table 12 shows the area and capacity data for this reservoir site. Runoff at the damsite is estimated to be about 23,000 acre-feet per year.

TABLE 12.—*Area and capacity of Fishhawk reservoir site (damsite in sec. 29, T. 7 N., R. 5 W.)*

Altitude (feet)	Area (acres)	Capacity (acre-feet)	Altitude (feet)	Area (acres)	Capacity (acre-feet)
670	0	0	860	400	25,000
700	5	75	900	600	45,000
740	40	975	940	840	74,000
780	130	4,000	980	1,220	113,000
820	240	12,000	1,020	1,670	172,000

GEOLOGY

By D. L. GASKILL

The geologic reconnaissance map of Fishhawk Creek and vicinity (pl. 4) covers a maturely dissected area of high relief athwart Tunnel Ridge which is the divide separating the Nehalem River-Fishhawk Creek drainage from the Columbia River drainage. The area contains no valuable mineral resources of record or material improvements other than a few unimproved access roads and an abandoned railroad grade across Tunnel Ridge. Much of the area is burned or logged over. The remainder is largely second-growth forest land.

BEDROCK

Bedrock is obscured over most of the area by vegetation and a deep residual mantle. Middle Tertiary sedimentary rocks of the area probably include the upper part of the Pittsburg Bluff Formation and units of the Scappoose Formation (Warren and Norbisrath, 1946). The upper part of the Pittsburg Bluff Formation consists of fine- and medium-grained tuffaceous shaly sandstone and tuffaceous shale. These beds are locally crossbedded, conglomeratic, and commonly contain carbonaceous and pumiceous material. The overlying Scappoose Formation is lithologically similar to the upper units of the Pittsburg Bluff, but grades upward into massive friable medium-grained micaceous sandstone. The sedimentary beds are locally overlain by the Columbia River Basalt. The Columbia River Basalt consists of dense and fragmental basaltic flows of varying thickness. Some of the flows are separated by pyroclastics or water-laid sediments.

STRUCTURE

The area was probably uplifted after deposition of the Scappoose Formation. Uplift was followed by a long period of erosion and possible subsidence, terminated by extrusion of the Columbia River Basalt in Miocene time. Subsequent to the close of volcanism, the region was warped into gentle northwest-southeast folds and subjected to periods of erosion separable into several epochs of stream adjustment (Warren and Norbisrath, 1946, p. 237).

The sedimentary strata are comparatively flat lying. The overlying basalt flows rest unconformably on an erosional surface of considerable relief. Remnants of basalt overlie sedimentary strata on Tunnel Ridge at 1,400 feet altitude and extend down to an altitude of 700 feet on Fishhawk Creek. Flow remnants also overlie sediments 1,200 feet below Tunnel Ridge on the Columbia River side. Some of these flows seem to have originated on Clatskanie Mountain, about 2 miles east of the area. Lineaments mapped on plate 2 are interpreted from aerial photographs. They represent hypothetical bedrock fractures and probably include some faults. Most of the bedrock is jointed to some degree and stream alignments usually parallel a joint set.

DAMSITE

The Fishhawk Creek damsite (pl. 4) is underlain by a thick near-horizontal bed of compact, very fine grained tuffaceous micaceous sandstone and siltstone (fig. 10). Downstream, near locality 1 (Fishhawk Creek and vicinity, pl. 4), these sediments contain calcareous concretions of fossil fragments and carbonaceous material as much as a foot in diameter. At locality 1 a thick bed of fine-textured tuff crops out and extends downstream. This weak bed apparently underlies the tuffaceous sand and siltstone at the damsite.

Basaltic flows unconformably overlie the tuffaceous beds on abutments and cross Fishhawk Creek at the upstream edge of the damsite

FIGURE 10.—Tuffaceous siltstone in bed of Fishhawk Creek, downstream from section $A-A'$ (pl. 4). Photograph by D. L. Gaskill, 1957.

area (pl. 4). The basal flow is very agglomeratic and has tuffaceous clay matrix and lenses of clayey tuff and basaltic fragments. Finely crystalline basalt overlies the fragmental flow. A water-laid pebble to boulder conglomerate in a quartzose and tuffaceous sand matrix was observed locally at the base of the unconformity about 100 feet above Fishhawk Creek on the west abutment.

In the area of section A–A′ (pl. 4) on Fishhawk Creek, the sedimentary rocks are inconspicuously jointed. The few fractures are tight and widely spaced. Upstream, near the contact with the overlying volcanics, the sediments are conspicuously fractured by a well-defined system of tight, closely spaced joints. Near locality 1 (pl. 4) about one-fourth of a mile south of section A–A′, the stream beds are closely jointed and apparently faulted. The fault zone dips about 80° E. and seems to parallel the north-trending lineament plotted on the geologic map of the Fishhawk Creek damsite (pl. 4).

Many springs and points of seepage occur in the damsite area, mainly at the base of the Columbia River Basalt. Abutment slopes are largely obscured by vegetation, slope rubble, and some landsliding.

RESERVOIR SITE

The Fishhawk Creek reservoir site (pl. 3, and also Fishhawk Creek and vicinity, pl. 4) is largely covered by brush and cutover land. The floor of the reservoir site consists mostly of tuffaceous beds like those at the damsite, but includes some very finely laminated carbonaceous clayey siltstone or lacustrine sediments and less extensive areas of basalt and pyroclastic material. Very thick exposures of silty clay and fine-grained sandstone underlie agglomeratic basalt along the abandoned railroad grade on the west slope of the North Fork Fishhawk Creek. Volcanic boulders are exposed locally in the upper part of some thick tuffaceous clay tuff beds. Much of the basalt is highly fractured, locally faulted, and decomposed by weathering. Reservoir slopes are evidently subject to extensive slumping and landsliding.

TUNNEL RIDGE

Tunnel Ridge, between the Fishhawk Creek reservoir site and the Columbia River valley, is composed of sediments representative of the Scappoose Formation. Bedrock exposures along Tunnel Road and at localities 7–12 (pl. 4) along the abandoned railroad grade exhibit very thick massive beds of very fine- to medium- and coarse-grained friable, locally crossbedded micaceous sandstones composed of angular quartz grains, muscovite, biotite, some feldspar, and igneous rock fragments. Thin layers of claystone and conglomeratic lenses of igneous pebbles occur locally in these beds (fig. 11). The beds grade upward into fine silty sand and clay containing boulders of basalt.

At localities 15–19 (pl. 4) on the Columbia River slope, similar arenaceous sediments include lenses of coarse-grained carbonaceous pumiceous sandstone and finely laminated silty clay. At locality 13 and west along the abandoned railroad grade from locality 14, numerous exposures of massive siltstone and conglomeratic sandstone occur. The beds are either slumped or faulted near localities 15 and 16 along the lineament plotted here.

FIGURE 11.—Friable sandstone (Tps) overlain by basalt near crest of Tunnel Ridge (loc. 12, pl. 4). Photograph by D. L. Gaskill, 1957.

At intermediate altitudes along the north slope of Tunnel Ridge, between Eilertsen and Tandy Creeks, a topographic bench or terrace is capped with basalt. Sedimentary beds of Pittsburg Bluff lithology outcrop locally below the basalt and along the Columbia River Highway (U.S. 30) near Marshland.

CONCLUSIONS

The thick tuffaceous sedimentary bed flooring Fishhawk Creek at the damsite seems to have little or no intergranular cementation and probably owes most of its strength to compaction. After partial drying, such rocks tend to slake and disaggregate when acted upon by water and may be subject to slow plastic deformation under loads below their shearing strength (Meade, 1937). These rocks might be susceptible to differential settlement and rebound, but also may be relatively impervious and plastic enough to prevent formation of open joints. The basalt and interbedded pyroclastic flows are porous where decomposed by weathering. In the damsite and reservoir area, these rocks are fractured and weakened by physical disintegration between breccia fragments or alteration zones in agglomerate. Interbedded lenses of tuff and flow contacts also constitute potential zones of weakness and permeability.

The erosional contact between the basaltic rocks and underlying sediments is probably the most critical zone of leakage and instability in the damsite area. On the west abutment, this erosional contact is infered to dip east at a moderately steep angle toward the damsite. On both abutments the basalt tends to fracture, slump, and landslide along this contact.

The bearing power and perviousness of both abutments seems to be vulnerable to reservoir pressure. The ridge between the reservoir area in sec. 30 and the creek in sec. 31, T. 7 N., R. 5 W. (Fishhawk Creek and vicinity, pl. 4) and the narrow spur forming the spillway site ridge (Fishhawk Creek damsite, pl. 4) should be explored for pervious zones, possibly along sandy beds, flow contacts, joints, or shear zones.

Topography limits the height of a dam at section *A–A′* (pl. 4) to about 200 feet. A cutoff wall might be required in foundation rocks and along the top of the east abutment.

A diversion tunnel under the Nehalem-Columbia divide at Tunnel Ridge would be largely in sedimentary rocks below the water table. The behavior of these rocks will vary greatly in respect to their porosity, permeability, water content, stratification, and structural deformation. The costs of tunnel construction depend mainly on the stand-up time of the material penetrated (Trask, 1950, p. 193). The physical properties of these sedimentary beds indicate conditions requiring continuous support and lining of a tunnel as excavation proceeds.

Impervious concrete aggregate and rockfill construction materials are probably available in the general area.

Foundation and abutment rocks at the Fishhawk Creek damsite are unsuitable for a concrete structure, but are adaptable to a flexible wide-base earth or rockfill dam.

POTENTIAL WATERPOWER OF THE DIVERSION PLAN

If diversion to the Columbia River is made, water probably will be raised in the Vernonia reservoir site to an altitude of 540 to 600 feet by constructing a dam at Squaw Creek, Tideport, or Elsie. Other damsites as far downstream as the Salmonberry River possibly could support dams to the 600-foot level; however, the three listed here are thought to be the best suited to the purpose. The volume of the dam, the area flooded, and the storage capacity desired would have considerable importance in the selection of the damsite.

Plate 3 shows tunnel routes at altitudes 540 and 800 feet and a section (*A–A′*) through Tunnel Ridge. The section illustrates a gravity surface-to-surface diversion at altitude 540 feet and also pumped-storage alternatives. The penstock could be on the surface or underground. If pumped storage is to be developed, pressure tunnels and an underground drop to the powerhouse site may be desirable in order to utilize head from the reservoirs. This pressurization could be done by connecting the tunnel at altitude 540 feet to the reservoir through a shaft or by pumping from the low reservoir into the high reservoir through a short tunnel or surface conduit and connecting the high reservoir with the Columbia River side of the divide by a tunnel at an altitude of 800 feet.

Alternative tunnel and conduit routes have been selected for illustrative purposes and are shown on the plan map in plate 3. One is at altitude 540 feet and begins in the NE¼ sec. 1, T. 6 N., R. 6 W., on Fishhawk Creek, passes under the deep part of Fishhawk reservoir site, and ends in the SW¼ sec. 8, T. 7 N., R. 5 W., on the south valley wall above the Columbia River near Woodson. This route is about 4.7 miles long. The other alternative is at altitude 800 feet and would conduct water from the Fishhawk reservoir through Tunnel Ridge to a point above Marshland. This route has been shown because the topography on the valley wall south of Marshland appears better suited for conduit and penstock routes. The penstock would be shorter and the powerhouse would be nearer the surge tanks. Tunnel routes at altitude 800 feet are shorter as the outlet end is moved toward section *A–A′* where it is only 1.8 miles from the intake as shown on the section in plate 3.

If pumped storage is added to the diversion scheme and the tunnel is at altitude 540 feet, water could be pumped into and discharged from the Fishhawk reservoir through a shaft connecting the tunnel and reservoir. The lift would range from 70 to 360 feet. An advantage of this plan is that it could operate directly from the Vernonia reservoir as a gravity unit when desired and thereby keep pumping to a minimum.

A purely pumped-storage development might also be effected by pumping water through a tunnel or surface conduit from the Vernonia reservoir to the Fishhawk reservoir. The lift would be between 200 and 360 feet because water below an altitude of 800 feet would be dead storage.

The amount of water available for diversion would depend upon the damsite chosen for the Vernonia reservoir. Some pertinent data on the various possibilities are shown in table 13.

Of the five sites, the Squaw Creek dam would give the most water per acre flooded by the reservoir. The Tideport site would give the most water per cubic yard of dam volume. If dam volume and area flooded are considered together, Tideport still gives the greatest unit volume of water, Elsie the second largest, and Squaw Creek the third largest. The Elsie site might be chosen because it would make more water available, and further examination may confirm its apparent geological superiority. The Elsie site is the most downstream point

TABLE 13.—*Water available for diversion from Nehalem River to Columbia River via Fishhawk Creek and Tunnel Ridge from Veronia reservoir with the dam at various sites*

Damsite	Dam		Reservoir		Divertible water (cfs) [2]	
	Height (feet)	Volume (cu yds)	Area (acres)	Capacity [1] (acre-feet)	Continuous	Nov.-Mar.
Squaw Creek	150	1,500,000	14,000	570,000	870	2,190
Tideport	163	1,500,000	19,600	800,000	1,185	2,900
Elsie	205	1,800,000	24,000	1,000,000	1,310	3,250
Spruce Run	295	5,200,000	29,000	1,270,000	1,550	4,065
Salmonberry	395	8,400,000	31,000	1,420,000	1,730	4,275

[1] Capacity of reservoir between altitudes 540 and 600 ft.
[2] Net water after conservation release and losses.

where a dam is considered to be feasible to raise the water to the 600-foot altitude. Squaw Creek would be chosen only if keeping the area flooded by the Vernonia reservoir to a minimum is desired. Because of the great volume of the embankments, high dams at Spruce Run and at damsites farther downstream probably are out of the question. Their value in storing a large quantity of water for use during disastrously dry periods seems to justify their inclusion in this report even though they are judged to be too costly to be feasible. Diversions from reservoirs behind dams at the Tideport or the Squaw Creek site would give proportionally less power than the reservoir and dam at Elsie; nevertheless, their peaking capacities would be very great.

Sample operations of a diversion plan using the amounts of water available for diversion from the Vernonia reservoir and a dam built at the Elsie site follow.

The active storage capacity of the Vernonia reservoir behind a dam at the Elsie site is 1,000,000 acre-feet (the capacity between altitudes of 540 and 600 ft.). Assuming a full reservoir on June 1, 1940, the amount of water which could have been diverted for various time periods and the corresponding power in kilowatts and energy in kilowatt-hours which could have been produced by an all-gravity diversion are shown in the following table. Computations are based on an efficiency of 80 percent. The average head is considered to be 575

Time of use	Net water (cfs)	Power	
		Kw	Kwhr
Continuous	1,300	50,800	445,000,000
Combination:			
April-October	470	18,400	95,000,000
November-March	2,645	103,000	373,000,000
Total combination			468,000,000
November-March only	3,280	128,000	465,000,000

feet, the approximate elevation of the Vernonia reservoir when 500,000 acre-feet have been drawn out.

For comparison with the gravity diversion, the following table presents the corresponding data for the all-pumped-storage scheme. The average head is considered to be 860 feet, which is the water-surface elevation the Fishhawk reservoir would have when half of the 38,000 acre-feet stored above the 800-feet level is drawn out. Computations are for an efficiency of 80 percent.

In total kilowatt-hours, the continuous generation plan produces 95 percent of the highest (the combination plan), but all three plans are very nearly equal in total output.

The discharge rates in the table are continuous during the specified period. If operated for peaking purposes, concentration of daily generation into one or two periods of several hours each would be desirable. For this type of operation the water available and the kilowatt output vary inversely with the length of the daily operating periods. The kilowatt-hour output would remain the same as long as all the water is used. For example, 6,560 cfs combined with appropriate installations in the powerhouse could produce 384,000 kw for 12 hours per day on the November–March only plan, or for 9½ hours per day from November–March on the combination plan. Use of 13,120 cfs together with an appropriate powerhouse could produce 768,000 kw for 6 hours per day on the November–March only plan, or for 4¾ hours per day from November–March on the combination plan. Capacities and operating schedules could thus be varied to fit many situations.

Time of use	Net water (cfs)	Power	
		Kw	Kwhr
Continuous	1,300	76,000	666,000,000
Combination:			
April-October	470	27,500	141,000,000
November-March	2,645	155,000	562,000,000
Total combination			703,000,000
November-March only	3,280	192,000	696,000,000

Modern pumped-storage plants expend about 1.4 kw of offpeak power for every kilowatt of peaking power when pumping head is equal to power head (Hammond, 1958). The Ffestiniog pumped-storage station recently constructed in North Wales is designed to operate at about this efficiency. It contains four pumps, each rated to deliver 745 cfs under a head of 1,000 feet at the expenditure of 93,600 hp (Water Power, 1961). If returned at the same rate, the water will produce 68,000 hp at 80 percent efficiency, or 1 hp for every 1.38 hp used in pumping.

The power head is sufficiently greater than the pumping head in the Fishhawk scheme to make at least 2 kw of peaking power available for each kilowatt used for offpeak pumping. This feature of the site is attractive.

Whether development of a pumped-storage diversion at this site would be economical is beyond the scope of this report, as is the determination of the economical size of tunnels and installation capacities. The economic feasibility of pumped-storage additions to power systems is well established, however, and this one should be investigated upon its individual merits by companies or agencies concerned with develpment of waterpower in the area.

OTHER PUMPED-STORAGE POSSIBILITIES

The Nehalem River from Humbug Creek to Nehalem Falls flows in a narrow canyon where bluffs as high as 2,000 feet above sea level are nearby. There are small lakes and reservoir sites into which water could be pumped for production of peaking power. Auxiliary pumped-storage plants could be added to any of the power developments discussed in this report. Table 14 presents the potentialities of several of these pumped-storage sites. The data of the table have been chosen to bring out characteristics of the sites such as reservoir capacities, head, quantities of water to be handled by pumps and conduits, and generating capacities. The reservoir capacities were estimated from measurements of area and depth shown on the 1 : 62,500-scale USGS topographic maps.

DIVERSION TO TUALATIN RIVER BASIN

The Tualatin River basin, especially in the growing Portland suburban area, is approaching the point at which it will need additional water. The Nehalem, Wilson, and Trask Rivers are possible sources for this water and there are several sites in the headwaters of each where diversions to the Tualatin might be made. Diversion of an average of about 700,000 acre-feet annually from the three streams combined seems possible. As much as 280,000 acre-feet

TABLE 14.—*Sites for pumped-storage developments in Nehalem River basin*

Site	Reservoir					Operating 9 hours per day [1]		
	Location			Capacity (acre-feet)	Head (feet)	Cfs	Kw [2]	Kwhr
	Sec.	T.N.	R.W.					
Lost Lake	17	4	7	900	1,170	1,210	96,000	864,000
Spruce Run Lake	17	4	7	1,000	640	1,345	59,000	531,000
Little Falls	30	4	7	800	1,220	1,075	89,000	801,000
Helloff Creek	11	3	9	1,500	950	2,017	130,000	1,170,000
Lost Creek	25	3	9	9,000	300	12,100	247,000	2,223,000
Fall Creek	16	3	9	1,500	560	2,017	77,000	693,000

[1] Filling and emptying the reservoir every 24 hours by pumping 15 off-peak hours and generating 9 hours.
[2] Computed at approximately 80 percent efficiency.

(the entire yield above the diversion points) could be diverted annually from the Nehalem River if reservoirs were built to regulate the river and to store the water from the November–March rainy period until mid-summer and early fall when its value is highest.

Some of the possible diversion routes from the Nehalem River, to the Tualatin River, all originating within the Rocky Point reservoir site, are shown on plate 3. The Rocky Point reservoir should be larger for a diversion plan than for providing water for use only within the basin. It is estimated that an active capacity of 200,000 acre-feet would be necessary to divert the entire yield and that some water would be diverted from Rock Creek, a downstream Nehalem River tributary.

The Rocky Point reservoir site has a capacity of about 240,000 acre-feet below altitude 845 feet and would contain about 210,000 acre-feet between altitudes 750 and 845 feet. The reservoir would be exceptionally valuable for recreation and conservation and therefore the amount of unused water below altitude 750 feet would be justified.

The diversion to Rocky Point reservoir from Rock Creek might best be accomplished by means of a dam on Rock Creek in sec. 14, T. 4 N., R. 6 W. (Camp McGregor), and a 1.2-mile tunnel at altitude 1,120 feet to Clear Creek. Clear Creek would carry the diverted water to the Rocky Point reservoir.

Drainage area above the diversion point on Rock Creek is about 32 square miles and 84 percent of that area is above the Keasey gage. Unit runoff would be higher at Camp McGregor and an additional 5 percent has been allowed for this. Calculations from table 1 indicate an average annual runoff of 109,000 acre-feet for water years 1940–54. Adding this to the annual average for Rocky Point (171,000 acre-ft) brings the total yield of the two areas to 280,000 acre-feet. An average of 387 cfs, less losses and necessary conservation releases, would have been available for diversion from the Rocky Point reservoir had it been in operation for that purpose during the 1940–54 water-year period. The median year is 1947 with an average discharge of 393 cfs. Range is from 230 cfs (1941) to 510 cfs (1950).

Diversion could be made at altitude 750 feet to West Fork Dairy Creek (Manning tunnel route) or to Gales Creek by way of Beaver Creek (Glenwood tunnel route). The tunnels would be 3.7 and 3.6 miles long, respectively. Shorter tunnels would be needed if the water were pumped to a higher altitude. At altitude 1,040 feet the tunnel length could be as short as 0.5 mile to West Fork Dairy Creek. The tunnel would go under the divide near the present railroad tunnel but at a lower altitude than the railway. An even shorter tunnel at altitude 1,040 feet would put the water into Beaver Creek. Several alternative routes which would have similar tunneling requirements exist but are not shown. Conduits can be extended from the tunnels to power drops if it is found desirable to develop power for pumping of water or for other uses. At West Fork Dairy Creek, an extension of about 1 mile would connect the tunnel at altitude 750 feet with a point where the water could be dropped 400 feet into Manning reservoir site. An extension of about 2 miles would connect the tunnel at altitude 1,040 feet to a 700-foot drop site into the same reservoir site. The possible power drops into Beaver Creek would be 120 and 420 feet, respectively, from the 750- and 1,040-foot altitude tunnels to the Glenwood reservoir site. These heads are the difference between the estimated conduit terminal altitudes of 720 and 1,020 feet and the estimated full reservoir altitudes of 320 feet for the Manning site and 600 feet for the Glenwood site. If the Beaver Creek balancing reservoir is constructed there would be no drop from the low-level tunnel and only 300 feet of head from the high-level tunnel.

Provision of equalizing storage on the Tualatin River basin side of the divide would be desirable, and there are sites for doing this. The choice of whether to bring the water into West Fork Dairy Creek or divert it by way of Beaver Creek into Gales Creek might depend on the area of use. Both streams pass near Forest Grove, but if it were desired to deliver the water to the area around North Plains, the West Fork Dairy Creek Diversion might be preferred. Gales Creek appears to offer an advantage insofar as damsites and cultural developments in the reservoir site are concerned. The reach of Gales Creek between Glenwood and the open valley possesses damsites that appear to be relatively good. A site in sec. 23, T. 2 N., R. 5 W., about half a mile downstream from the settlement of Glenwood (Glenwood site) may be the best. On West Fork Dairy Creek the dam would probably have to be constructed in sec. 10, T. 2 N., R. 4 W., at the settlement of Manning (Manning site). The Manning reservoir site appears larger than the Glenwood site, but existing improvements in it are considerably greater. Relocation requirements in the Manning reservoir site would include parts of highways U.S. 26 and State 47, several miles of the Spokane, Portland and Seattle Railway line, and the settlement of Buxton. The Beaver Creek reservoir site shown on plate 3 probably should be regarded as an alternative to the Glenwood site rather than a possible addition to it.

Existing maps are not suitable for determining the capacities of these reservoirs. The capacity is roughly estimated as 75,000 acre-feet for Manning and 30,000 acre-feet for Glenwood. No estimate was made of the Beaver Creek site.

Table 15 shows the potential power of the average dependable divertible water. The losses from the Camp McGregor and Rocky Point reservoirs would total about 30 cfs, continuously. By adding a 10-cfs conservation release to this 30 cfs and subtracting the total estimated loss from 387 cfs (the indicated gross annual average divertible water) a dependable average discharge of 347 cfs is obtained.

TABLE 15.—*Potential power and energy of 347 cfs for several Nehalem River to Tualatin River diversion routes*

[Computations at 80 percent efficiency]

Site	Head (feet)	Power (kw)	Energy (kwh per yr)
Tunnel at 750 ft:			
Manning	400	9,440	82,700,000
Glenwood	120	2,830	24,800,000
Tunnel at 1,040 ft:[1]			
Manning	700	16,500	[2] 145,000,000
Glenwood	420	9,910	[2] 87,000,000

[1] Pump-conduit diversion.
[2] Includes about 48,000,000 kwh per yr that would be required to pump the water from Rocky Point reservoir to altitude 1,040 ft.

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