36. The total cost of the investigation up to July 1, 1931, was as follows:

Stream gaging, construction, operation, and maintenance	$35, 114. 59
Water-supply studies	11, 117. 14
Surveys	62, 533. 51
Exploratory work (drilling foundations)	60, 873. 93
Geological explorations and reports	6, 575. 00
Land classification	3, 270. 52
Study of markets for power and farm products	14, 275. 20
Office studies, drafting, writing report	122, 681. 56
	316, 441. 45

CHAPTER II. DATA

A. Columbia River Basin

A. GENERAL

37. The Columbia River is approximately 1,210 miles in length, of which the upper 465 miles lies wholly in Canada. Of the portion in the United States, 425.3 miles lies above the mouth of Snake River, and that is the portion with which this section, part 2 of a report in three parts on Columbia River, is particularly concerned. The portion of the river below the mouth of the Snake, 323.5 miles in length, is described in a companion report, part 3, prepared by the district engineer, Portland, Oreg., district.

38. The drainage area of the Columbia above the mouth of Snake River is 103,000 square miles, of which 39,000 square miles are in Canada, and 64,000 square miles are in the United States. The drainage area above the mouth of Snake River is divided between the Province of British Columbia and the three States of Montana, Idaho, and Washington, and comprises about 40 percent of the total drainage area of the Columbia River.

39. Data relating to the main river and its principal tributaries above the Snake are included in tables nos. 1 and 2, with more detailed descriptions following.

Table No. 1.—*Data relating to Columbia River*

Distance above mouth of Snake	Place	Drainage area	Estimated flood discharge of 1894	Average discharge	Elevation of low water above sea level	Distance below British Columbia boundary
Miles		*Square miles*	*Second-feet*	*Second-feet*	*Feet*	*Miles*
0.0	Snake River, mouth:					
	Below	212, 000	1, 100, 000	183, 000	312	425. 3
	Above	103, 000	750, 000	126, 000		
3. 5	Pasco, N. P. Ry. bridge		750, 000	126, 000	314	421. 8
3. 9	Kennewick, highway bridge		750, 000	126, 000	315	421. 4
10	Yakima River, mouth:					
	Below	102, 000	750, 000	126, 000	319	415
	Above	96, 200	740, 000	121, 000		
66	Vernita (Richmond ferry)	95, 500	740, 000	121, 000	389	359
	Priest Rapids:					
72	Foot	95, 400	740, 000	121, 000	400	353
81	Head				469	344
87. 7	Beverly, C. M. St. P. & Pac. R.R. bridge	90, 300	740, 000	121, 000	471	337. 6
96. 9	Vantage, bridge	89, 700	740, 000	121, 000	487	328. 4
98	Vantage dam site	89, 700	740, 000	121, 000	488	327
129	Rock Island dam:					
	Below	88, 700	740, 000	121, 000	544	296
	Above				560	
132. 3	Great Northern Ry. bridge		740, 000	121, 000	563	293
140. 5	Wenatchee, highway bridge	88, 500	740, 000	121, 000	588	284. 8
	Rocky Reach:					
150	Power-house site	87, 200	735, 000	117, 000	604	275
151. 5	Dam					273. 5

TABLE No. 1.—*Data relating to Columbia River*—Continued

Distance above mouth of Snake	Place	Drainage area	Estimated flood discharge of 1894	Average discharge	Elevation of low water above sea level	Distance below British Columbia boundary
Miles		*Square miles*	*Second-feet*	*Second-feet*	*Feet*	*Miles*
179.5	Beebe, highway bridge			115,000	667	245.8
180	Chelan power site	85,500	735,000	115,000	667	245
192	Wells, power site:					
	Below	85,400	730,000	115,000	697	233
	Above				703	
199	Methow River, mouth:					
	Below	85,300	730,000	115,000	716	226
	Above	83,500	728,000	113,000		
205.5	Brewster, highway bridge				728	219.8
209	Okanogan River, mouth:					
	Below	83,300	728,000	112,000	737	216
	Above	75,100	725,000	109,000		
217	Bridgeport, ferry		725,000	109,000	751	208
221	Foster Creek, power site	75,000	725,000	109,000	765	204
235	Gaviota dam site	74,800	725,000	109,000	841	190
274	Grand Coulee	74,100	725,000	109,000	933	151
317	Spokane River, mouth:					
	Below	72,600	725,000	109,000	1,042	108
	Above	66,000	700,000	100,000		
382.9	Kettle Falls, highway bridge			100,000	1,165	42.4
383	Kettle Falls:					
	Below	64,500	700,000	100,000	1,165	42
	Above				1,203	
386	Kettle River, above mouth	60,400			1,206	39
387.3	Great Northern Ry. bridge				1,208	38
	Little Dalles:					
409	Below	59,800	680,000	97,800	1,245	16
410	Above				1,248	15
414.4	Northport, highway bridge				1,265	10.9
425.3	International boundary	[1] 59,700	680,000	97,600	1,292	.0
885	Source					(2)

[1] 39,000 in British Columbia.

[2] Above 460.

TABLE No. 2.—*Data relating to the principal tributaries of the Columbia River*

Stream	Length	Drainage area (square miles)		Average discharge	Elevation mouth, at low water above sea level
	Miles			*Second-feet*	*Feet*
Kootenay	448	British Columbia	14,550	34,000	±1,415
		United States	4,900		
		Total	19,450		
Clark Fork	479	British Columbia	1,190	25,000	1,292
		United States	24,630		
		Total	25,820		
Priest	±70	1,047		1,600	2,050
Flathead		British Columbia	640	±12,000	2,468
		United States	8,500		
		Total	9,140		
Bitterroot		2,813			3,094
Blackfoot		2,311			[1] 3,255 [2] 3,235
Kettle	170	British Columbia	3,160	3,000	1,206
		United States	1,100		
		Total	4,260		
Colville		1,036		±255	1,162
Spokane		6,600		±8,000	1,042
Okanogan		British Columbia	6,000	±2,950	740
		United States	2,200		
		Total	8,200		
Methow		1,850		1,660	716
Chelan		963		2,120	665
Entiat		±420		529	641
Wenatchee	±47	1,327		3,400	598
Yakima		5,970		4,500	320
Snake		109,000		57,460	312

[1] Dam.

[2] Natural.

40. Columbia River rises in Columbia Lake, at elevation 2,650, in British Columbia at latitude 50°15′ N., longitude 115°55′ W. For 195 miles it flows northwest, in the narrow Intermontane Valley of British Columbia, passing through Lake Windermere and Lake Kinbasket. The heavily timbered foothills of the Rocky Mountains parallel its course on the northeast, rising to elevations of from 5,000 to 6,000 feet, while heights of from 8,000 to 10,000 feet obtain on the southwest side of the valley. Just north of the 52d parallel of latitude, after falling 650 feet in its 195 miles of northwesterly course, the Columbia turns abruptly west, then south, cutting its way through the mountains into an adjoining valley. At this point, known to the early fur traders as Boat Encampment, two rivers join the Columbia, one from the north, the Canoe River, and one from the east, the Wood or Portage River. It was up this latter stream that the canoes of the voyagers traveled in the journey from the Pacific Ocean to Hudson Bay.

41. Passing through the water gap at Boat Encampment, the Columbia flows south for 270 miles to the boundary line between the United States and Canada, falling about 700 feet in this distance. The river runs in a narrow valley formed by a complex and irregular mountain system which towers above the river to elevations from 4,000 to 11,000 feet. Heavy forests, numerous glaciers, and extensive snowfields cover these ranges, and many glacier-fed streams add their turbid waters to the Columbia. At places this valley widens, and in one of these openings are two long, narrow lakes. Upper Arrow Lake is 36 miles long and almost uniformly 2 miles wide, with an arm about 10 miles long and 1 mile wide. It is very deep, and navigable throughout. Eighteen miles below this lake the Columbia enters Lower Arrow Lake, 51 miles in length. Steamers run from the northern end of Upper Arrow Lake down through both lakes to the mouth of Kootenay River, and the river is navigable still further down to Little Dalles, 15 miles below the boundary, making a total navigable distance above Little Dalles of 480 miles. Above Upper Arrow Lake the river is navigable at high water to its source for light-draft steamers. Below Lower Arrow Lake the Columbia is joined by the Kootenay at a point 30 miles upstream from the border, and by the Clark Fork just north of the border.

42. Below the Canadian boundary the Columbia flows in a southerly direction for 112.3 miles, receiving the waters of Kettle River on the west side and of Colville and Spokane Rivers on the east side. The river then makes an abrupt turn to the west, and for 108 miles flows in a westerly direction, to the eastern foothills of the Cascade Range. It follows these in a southerly direction for 205 miles, to its confluence with Snake River. Between Spokane River and Snake River, the Columbia receives from the north and west several swift tributary streams rising in the Cascades or their Canadian relatives; but from the south and east no stream of importance flows into the Columbia between Spokane River and Snake River, as in this section the annual run-off is nearly zero from an area of over 9,000 square miles. This great treeless plateau is one of the most arid regions in the basin, rainfall being between 6 inches and 14 inches per annum.

43. The Kootenai (Kootenay in British Columbia) rises in British Columbia in about latitude 51° N., longitude 116° W., its source being about 80 miles north of Columbia Lake and in the next valley

to the east. Just opposite Columbia Lake, this river breaks southwest into the Intermontane Valley of the Columbia, its course separated from Columbia Lake by the tiny 5-foot divide of Canal Flat. This mountain meadow, less than a mile in width, sends the waters of the Columbia northwest up the valley and turns those of the Kootenai southeast down the same narrow trough between the mountains. Flowing down this valley for 180 miles, the Kootenai crosses the international boundary line into Montana in longitude 115°15′ W.; continuing south, it reaches latitude 48°20′ N. at Jennings, Mont., where it breaks sharply west to Troy, Mont., thence northwestward, running into the State of Idaho, again crossing the international boundary line in longitude 116°30′ W., its total course in the United States being about 167 miles.

44. Twenty-three miles below the boundary line, Kootenai River enters Kootenai Lake, which is 66 miles long by some 2 to 3 miles wide, and very deep. About midpoint of the lake, an arm leads off to the westward, whence the river leaves the lake and cutting through the mountains for 23 miles, flows into Columbia River 30 miles north of the border.

45. The Kootenai drains 19,450 square miles of mountainous country, of which 14,550 square miles are in British Columbia; 3,825 square miles are in Montana; and 1,075 square miles are in Idaho. Its principal tributaries in the United States are Tobacco and Yaak Rivers, joining it in Montana, and Moyie River, joining it in Idaho. These tributaries have their sources in mountain lakes from 3,000 to 4,000 feet above sea level. The Moyie and the Yaak rise in British Columbia and flow southwest; the Tobacco rises in Montana near Flathead Lake and flows northwest.

46. The valley of the Kootenai is generally narrow and flanked by mountain ranges rising to altitudes of from 5,000 to 7,000 feet. At Bonners Ferry, Idaho, this valley widens to from 2 to 3 miles and is very rich in agricultural value, but rather swampy in character. The river falls about 4 inches per mile for the stretch of 47 miles between Bonners Ferry and the border. During the maximum flood of record, that of 1894, the water at Bonners Ferry, Idaho, was 35 feet above low-water level. In normal years the range in water levels varies from 25 feet at Bonners Ferry to 19 feet at Kootenai Lake.

47. The Kootenai contributes annually an average of some 34,000 cubic feet per second to the Columbia. Between Kootenai Lake and the Columbia, Kootenai River falls about 330 feet, and this stretch, with Upper and Lower Bonnington Falls partially developed, constitutes one of the best sources of power in British Columbia. Regulation of Kootenai Lake for power purposes will materially affect Columbia River in the United States.

48. Clark Fork of the Columbia rises near Butte, Mont. It flows almost due north for 40 miles to Deer Lodge, then northwest for about 96 miles, where it receives the waters of Blackfoot River. Flowing west for 14 miles, it passes through the city of Missoula, Mont., and meets Bitterroot River at the foot of the mountain range of that name. Following these mountains, Clark Fork turns and flows northwest for 79 miles until it reaches the town of St. Regis, Mont. Here it swings abruptly around a mountain spur and flows 26 miles in a northeasterly direction to its point of confluence with Flathead River. Thence, Clark Fork again turns and flows to the northwest for 104 miles,

crossing into the Panhandle section of Idaho and entering Pend Oreille Lake. Flowing westward 20 miles from the outlet of this lake, Clark Fork is joined by the waters of Priest River; and at a point a short distance below Albany Falls, 6 miles farther to the west, it crosses into the State of Washington. It then heads a little west of north for 71 miles, to the Canadian boundary. This stretch is navigable from Albany Falls to Box Canyon, a distance of 55 miles. The river then plunges over Metaline Falls and into Z Canyon, crossing into Canada and turning west; thence, it flows for 16 miles through the mountains to its confluence with the Columbia, about one half mile above the international boundary. From Metaline Falls to Columbia River is about 27 miles, the Clark Fork falling some 678 feet in this distance, delivering an average annual flow of 25,000 cubic feet of water per second.

49. The drainage basin of Clark Fork and its tributaries covers an area of 25,820 square miles, of which 1,190 square miles are in Canada. It is the most important tributary basin of the Columbia system lying within the area covered by this report. It comprises a region of irregular, mountainous country lying between the main ranges of the Rocky Mountains and the Bitterroot Mountains. These two mountain chains rise from 7,000 to 9,000 feet above sea level and are drained by many small streams.

50. The principal tributaries of Clark Fork are Flathead, Bitterroot, Blackfoot, and Priest Rivers. The Flathead rises in Canada and flows southeast along the west side of the Continental Divide, passing through Flathead Lake and joining Clark Fork 113 miles downstream from Missoula. It receives the overflow from many glacial lakes with altitudes of 3,000 to 4,000 feet. Some of these lakes lie within Glacier National Park.

51. The Blackfoot rises in the Rocky Mountains, and flows almost due west to its confluence with Clark Fork, 7 miles east of Missoula. The Bitterroot, on the other and, rises in the south between the Bitterroot and Sapphire Mountains and flows north, joining Clark Fork 7 miles west of Missoula. Priest River rises close to the corner formed by the Canadian border and the Washington-Idaho line, flows south in Idaho's panhandle, through Priest Lake, and joins Clark Fork 96 miles upstream from its mouth.

52. The flow of the Clark Fork is regulated by natural storage in Pend Oreille, Priest, and Flathead Lakes. Pend Oreille Lake, in Idaho, is on the main stream; its area is 125 square miles, and its low-water elevation about 2,048, United States Coast and Geodetic Survey datum. The only sizable tributary which enters Clark Fork downstream from Pend Oreille Lake is Priest River, regulated in turn by Priest Lake, 19 miles long, with an area of 37 square miles, and a low-water elevation of 2,436, United States Coast and Geodetic Survey datum. Flathead Lake regulates the principal tributary of Clark Fork, the Flathead. It is about 35 miles long and 15 miles wide, with an area of 175 square miles, and a low-water elevation of 2,882 feet, United States Geological Survey datum. These three lakes have great potentialities for storage and river regulation, which are discussed hereafter. (See discussion on stream flow and tributary effects and appendix 2, p. 1112.)

53. The driest section of the Clark Fork basin is near Missoula, the annual precipitation being less than 15 inches. In the mountain

regions the snowfall is heavy, accumulating to great depths during the winters and affording the abundant and perennial flow of water in the streams that have their sources in the mountains.

54. Kettle River rises in Canada, between the Columbia and the Okanogan Rivers, in latitude 50°10′ N., longitude 118½° W., flows in a southerly direction, provides outlet for Christina Lake, crosses the British Columbia-Washington line three times in the last 60 miles of its course, and discharges a mean annual flow of about 3,000 cubic feet per second into the Columbia 39.4 miles south from the boundary. In its basin of 4,260 square miles there are several tracts of irrigable land, mostly along the border. Of this total area, only 1,100 square miles lie in Washington, while 3,160 square miles are in Canada.

55. Spokane River, a minor tributary of the Columbia, having a drainage area of only 6,600 square miles and contributing but 8,000 cubic feet per second mean annual discharge, is important by reason of its numerous falls and the regulating effect of Coeur d'Alene Lake, which factors make power development possible at relatively small cost.

56. Coeur d'Alene Lake receives the important drainage from the western slopes of the Bitterroot Range, through the St. Joe and Coeur d'Alene Rivers. The lake occupies about 42 square miles at low water, and 89 square miles at high water. It is regulated by the dam of the Washington Water Power Co. at Post Falls, Idaho, so that low water is at about elevation 2,117, United States Coast and Geodetic Survey datum. High water has reached elevation 2,134.7. The lake lies in a low, wide valley, whose lands are annually subject to overflow, particularly along the tributaries for 15 to 20 miles above their entry into the lake. The St. Joe is navigable for a distance of 32 miles.

57. From Coeur d'Alene Lake, in Idaho, the Spokane flows west and northwest for 105 miles to join the Columbia at mile 317 above the Snake, at low-water elevation of approximately 1,042, thus falling about 1,075 feet in 105 miles. It receives several tributaries, most of them also having their sources in lakes. Above the city of Spokane the valley is comparatively wide and level and is underlain throughout by a coarse gravel that affords ample ground water storage from which a liberal supply for irrigation can be drawn. Below Spokane the river flows through a deep canyon, flanked by high lands.

58. The upper portion of the drainage basin is heavily forested, and a large portion of it is included in the Coeur d'Alene National Forest, but in the lower portion conditions of semiaridity prevail. The country in the upper portion of the basin is rugged and broken, with steep-sided valleys and peaks rising into the region of perpetual snow.

59. Okanogan River (Okanagan in Canada), like Kettle River, has both its source and most of its drainage area in Canada. The basin of the river has a total area of 8,200 square miles, of which 6,000 square miles are in British Columbia. The river passes through Okanagan Lake in Canada, and through Osoyoos Lake on the boundary. The former is 69 miles long by 2 miles wide, with low-water elevation of 1,125 feet, and a 5-foot rise to high water. Osoyoos Lake is the lowest point in the Columbia Basin in British Columbia, with a low-water elevation of 913 feet.

60. Leaving the boundary and flowing due south for 87 miles, the Okanogan enters Columbia River at elevation 740 feet, mile 208.9

above the mouth of the Snake. Seven and one half miles south of the boundary it is joined from the west by the Similkameen River, which adds double the volume of water to the Okanogan. Their combined average annual flow into the Columbia is about 3,000 cubic feet per second.

61. The valley of the Okanogan is a dry belt, with less than 15 inches of rain a year. It includes an irrigation project, originally developed by the United States Reclamation Service, which project will be discussed later in this report under the head of irrigation. This valley lies in the foothills on the eastern side of the Cascade Mountains, which effectively prevents much rain from falling in the deeper valleys.

62. Rising on the eastern slopes of the Cascade Range, Stehekin River flows southeast for 22 miles until it enters Lake Chelan, whose regulated low-water elevation is 1,079 feet, with high water at 1,100 feet. This lake is 50 miles long and from one half to 2 miles wide, lying in a deep, narrow valley with mountain spurs of from 6,000 to 8,000 feet altitude towering above it on both sides. Three miles from the Columbia this lake empties into the short and tortuous Chelan River, which enters the Columbia at mile 178.7 above the mouth of the Snake, and at elevation about 665. The basin is only about 960 square miles in extent and has many small lakes in its higher portions. Lake Chelan is regulated by the Washington Water Power Co. and, except for wastage over the spillway of this company's dam, Chelan River now has no flow.

63. The Little Wenatchee flows southeast down the eastern side of the Cascade Mountains for 18 miles, entering Wenatchee Lake at elevation 1,879. This lake, 7½ miles long and from 1 to 2 miles wide, feeds Wenatchee River, which runs into the Columbia at Wenatchee, 47 miles to the southeast. The Wenatchee enters the Columbia at mile 143.8 above the mouth of the Snake, and at elevation 600. The drainage basin of the Wenatchee is 1,327 square miles, all in the State of Washington. The river and its many small tributaries are fed by the snows and glaciers of the main heights of the Cascade Range, which, near the headwaters of the river, attain altitudes of over 10,000 feet. The Wenatchee discharges into the Columbia annually an average of about 3,400 cubic feet of water per second.

64. At mile 10.3 above the mouth of Snake River the Yakima enters the Columbia from the west, discharging annually an average of about 4,500 cubic feet per second. This river, from its juncture with Cle Elum River, runs about 160 miles in a southeasterly direction, receiving several tributaries, before it joins the Columbia. Its basin of 5,970 square miles includes the backbone of the Cascade Mountains. Between the Columbia and the Yakima, in the lower portion of its basin, is a low rolling plain, with isolated ranges of hills rising above the plateau by little more than 1,000 feet. As the Yakima gets closer to the Columbia, the southwest side of the valley also opens out into a broad plain. One of the best known irrigation projects of the United States Reclamation Service is located in the valley of the Yakima.

(B) GEOLOGY

65. The following outline of the geological history of the Columbia River, and the adjacent country, from the mouth of Snake River

to the international boundary was prepared by Henry Landes, dean of the college of science, professor of geology and mineralogy at the University of Washington, and consulting geologist for the United States Engineer Department.

1. THE PRINCIPAL GEOLOGICAL FORMATION REPRESENTED FROM THE OLDEST TO THE PLEISTOCENE

66. *a. Pre-Cambrian.*—A series of rocks that are possibly pre-Cambrian in age are found making up the walls of the Columbia from near the mouth of Wenatchee River to the Okanogan, and continue far to the northward along the valley of the latter stream. The formation is primarily one of gneiss and schist, recurring in a very intimate mixture. The rocks are clearly of igneous origin, but they have been considerably altered from their primary conditions. Along the Columbia the gneiss and schist have been pierced at innumerable places by intrusions of granite and basalt. The granite is often in sufficient abundance to form conspicuous masses along the canyon walls. The basalt usually occurs as feeder dikes, indicating the vents to the lava sheets that were outpoured at the surface above.

67. In the valley of the Columbia north of Wenatchee, the gneiss and schist, with the intruded masses, make up the entire west wall of the canyon. On the corresponding east side similar rocks occur at the bases of the cliffs, but the topmost part, or the rim rock, is composed of layers of basalt. In the vicinity of Orondo the contact between the underlying gneiss and schist and the basalt above is at a level about 1,500 feet above the river.

68. The whole extent of this supposed pre-Cambrian area is not known. Similar rocks occur from the Columbia northwestward into the Cascades and are probably identical with certain formations in the Skagit Valley. Rocks with the same lithological characters have been noted at the head of Grand Coulee, in the vicinity of Spokane, and along the Kettle River near Orient.

69. *b. Paleozoic.*—In the general vicinity of the Columbia River, formations of this age are widely distributed from the international boundary to the mouth of Spokane River, in both Stevens and Ferry Counties. Originally the formations were essentially thick beds of shales, sandstones, conglomerates, and limestones. The total thickness of these strata amounted to many thousands of feet. Through the agencies of mountain building, involving folding, faulting, and crushing of the rock, a complete metamorphism has resulted. The shales have been compacted and hardened, and converted into argillites, slates, and schists. The sandstones have been changed into quartzite, and the limestones into marbles. The limestones were not only altered in physical condition but in many instances they were greatly modified chemically. Through the medium of percolating water, bearing magnesia, much of the limestone was changed to dolomite and in extreme instances to magnesite.

70. It is noticeable that in the stretch of the river from the Canadian line to the mouth of the Spokane the valley is broader than it is farther downstream. The bold canyon walls are lacking, and wooded slopes lead from the highlands down to the river. The stream is usually margined by flood plains or terraces upon which farms and small villages are located. It all indicates that the erosion of the Paleozoic

formations has been comparatively readily performed because of the soft nature of the various rocks.

71. *c. Mesozoic.*—The story of the rocks of this age is told chiefly by the great masses of granite that outcrop over extensive areas in Stevens and Ferry Counties. In many places the older Paleozoic rocks have been displaced by batholiths of granite of variable size. In other places the granite appears in the forms of dikes and other types of intrusive masses. The age of the granite is in some doubt. Most writers have regarded it as belonging to Jurassic time, while some believe it to be of Cretaceous age. Its total original extent is also not known. In addition to the localities mentioned above, it is found in the gneiss and schist at the head of Grand Coulee, and in a similar way in the general vicinity of Chelan. It covers a large area along the Wenatchee River, and is especially conspicuous in Tumwater Canyon above Leavenworth.

72. *d. Tertiary—Swauk formation.*—The term Swauk is applied to a formation of Eocene age that covers several hundred square miles in central Washington. The rocks of this formation outcrop along the Columbia in the vicinity of Wenatchee. On the east side of the river the contact between Swauk strata and the older formation of gneiss and schist is near the clay mine about 2 miles north of East Wenatchee. From this point outcrops of Swauk beds may be found downstream as far as Malaga. Here the upper surfaces of the beds pitch to the eastward and disappear under the heavy overburden of basalt. How far to the eastward the Swauk formation originally extended, or now extends under the basalt, no one knows.

73. On both side of the Wenatchee River, from its mouth to Leavenworth, the Swauk rocks form conspicuous outcrops. From Leavenworth one area of these beds extends northward to Lake Wenatchee, and up the Chiwawa Valley for several miles. A second belt continues southward from Leavenworth through the Blewett Pass area to the Yakima River at Cle Elum.

74. The Swauk strata consists of congolomerate sandstone and shale, with occasional dark bands of carbonaceous matter. There are occasional beds of excellent clay, such as occur at the clay mine near East Wenatchee. In one or two places workable beds of coal have been found.

75. The Swauk rocks are lacustrine in origin and were laid down in a lake which once covered several hundred square miles. The sediments were derived largely from granite, gneiss, and schist of earlier ages which outcropped around the margins of the lake. The maximum thickness of the Swauk rocks reached over 5,000 feet. The beds show rapid changes in character along the strike, changing from conglomerates to sandstones, sandstones to shales, or the reverse, in a very short distance. Subsequent to deposition the strata have been folded into rather sharp anticlines and synclines, and they have been intruded by rhyolite and other types of dikes. Because of the nonresistant character of the Swauk beds they have been very heavily eroded by the various streams that cross their general area.

76. *Yakima basalt.*—This conspicuous and well-known formation is regarded as of Middle Tertiary, or more definitely of Mid-Miocene age. Along the Columbia the basalt towers in bold cliffs from the general vicinity of Coyote Rapids as far as Malaga. Above the latter place, the basalt occurs but rarely near the shore line of the

river. It forms the high rim rock on the left or east bank of the Columbia for nearly the entire distance from Orondo to the mouth of Spokane River.

77. Outcrops of Yakima basalt occur continuously and abundantly in Moses, Grand, and other coulees, and over the scablands of central Washington. This rock is found conspicuously along Crab Creek from Beverly eastward for many miles. North of Spokane River, in Stevens County, Yakima basalt occurs at several places as erosion remnants of a once continuous plain. It is also found as disconnected outliers over extensive areas in Ferry and Okanogan Counties, between the upper Columbia and the Okanogan Rivers. It is likewise found west of the Columbia, in the Entiat Mountains; it covers a large area in Kittitas County and northern Yakima County, where it extends almost to the summit of the Cascades.

78. The Yakima basalt represents a series of lava flows that came up through fissures in the earth's crust rather than through tubular openings. The lava appeared through cracks at the surface in a highly liquid condition and flowed so far before cooling that each sheet assumed a position almost completely horizontal. In the outpourings of the basalt, one flow followed upon the heels of another, with a varying time interval between. Sometimes there was a sufficient lapse of time not only for a bed of lava to cool, but for a soil to form upon it, which in turn supported vegetation, often trees of large size. In other instances, streams eroded shallow valleys and then filled these with such sediments as clay, sand, or gravel. In some places basins were found which retained ponds of water. Usually these depressions soon became filled, perhaps by the work of tributary streams in building deltas, or by the fall of ash from distant volcanoes, or by deposits of diatomaceous earth. Succeeding flows of lava covered over such surface aggregations of foreign material and they all became entombed within the great basalt mass.

79. The flows of Yakima basalt probably began near the center of the Columbia Basin in Washington, in a country that was hilly or semimountainous. Naturally the first flows filled the lowlands, until gradually all of the minor elevations, and then substantially all of the higher surfaces of the original area, were covered completely by the lava. The last flows penetrated into the valleys of the mountains which bordered the great basalt plain on the east, north, and west. The total thickness of basalt in the center of the original basin is not less than 5,000 feet, with a gradual thinning to a few feet of depth at the outermost margins. Around the periphery of the area, where the basalt was never thick, much of the rock has been eroded, leaving disconnected outliers resting on the older rocks.

80. The individual flows of basalt varied greatly in thickness when they finally congealed. When observed today, as along the face of a high cliff, most of the beds are relatively thin, but occasionally one is found that approaches 200 feet in thickness. The thinner flows cooled quickly and hence do not have any great lateral extent. The thicker masses of lava traveled many miles before they solidified and came to a position of rest. Contraction or shrinkage cracks are very noticeable in the basalt. They are very irregular in the thinner sheets and at the upper and lower surfaces of the thicker beds. In the latter the central part of the flow contracted in such a way that columns of

rock were formed, usually hexagonal in cross section and vertical or nearly so in position. The general effect of such marked shrinkage in the basalt, following a change from a liquid to a solid condition, was to break up any flow into innumerable fragments of variable sizes.

81. *Ellensburg formation.*—The typical occurrence of rocks of this formation is near the city of Ellensburg, and hence the name. The strata belong in age to the upper Miocene, and their deposition followed soon after the last outpouring of Yakima basalt. The Ellensburg beds consist chiefly of conglomerate, sandstone, and shale, with a large amount of volcanic ash of a grayish white color. The sediments are but little solidified or compacted and offer but scant resistance to erosional agencies.

82. The area of the Ellensburg formation was once a large one, covering several thousand square miles and extending over central Washington on both sides of the present position of the Columbia. The sediments for the most part were laid down in a large lake, and the rocks have all the characteristics of lacustrine beds. In the western part of the general area some of the deposits appear to be of fluviatile origin, and no doubt were laid down by large streams where they came out of the mountains and spread their debris over the plains. The Ellensburg strata as originally laid down were in a horizontal position and attained a maximum thickness of about 2,500 feet.

83. Sometime after the final deposition of the Ellensburg formation the beds were folded along with the underlying layers of Yakima basalt into an extensive series of anticlines and synclines. These folds are intimately connected with the last uplift of the Cascades, and the anticlines may be regarded as spurs which extend diagonally away from those mountains. Some of the conspicuous anticlines, which today are observed as prominent ridges, are the Saddle Mountains, Rattlesnake Hills, Yakima Range, and Gable Mountain. Subsequent to the period of folding just described the Ellensburg strata have been eroded from the tops of the anticlines, and are now found only in the synclines, or part way up the slopes of some of the anticlines.

84. Along the Columbia River the Ellensburg formation outcrops for a number of miles below the foot of Priest Rapids. Along the east shore, opposite the towns of White Bluffs and Hanford, the Ellensburg beds appear above the river bank, where they are overlaid unconformably by the Ringold formation, which is described later. At the present time extensive deposits of the Ellensburg formation occur in the larger basins from Kittitas Valley to the mouth of the Yakima River. The artesian and other wells from which water is secured in the basins of the Yakima Valley are nearly all drilled in the Ellensburg rocks.

85. *e. Pleistocene.*—In the area under discussion, within the Pleistocene period of time, there were two very definite advances and retreats of great ice sheets that left heavy marks upon the surface of the country. The later glacial period corresponds rather closely in time with the Wisconsin of the Mississippi Valley. The earlier ice advance, designated by Bretz as the Spokane glaciation, may have been synchronous with the Iowan as to time.

86. In northeastern Washington the terminal moraine which marks the maximum extension of the ice has been fairly well determined. It enters the State from Idaho directly east of Spokane, but swings in a great loop to the southward of the city, and then con-

tinues northwestward to about the confluence of the Spokane and Columbia Rivers. From the latter locality the moraine arches rather far to the north in southern Ferry County, but comes down to the Columbia again at the head of Grand Coulee. The front of the ice lay above the cliffs along the western margin of the coulee as far as the vicinity of Coulee City. From this point it turned west and then northwest, and finally came down to the Columbia not far below the mouth of the Chelan River. West of the Columbia River, and south of Lake Chelan, glaciers covered the highest mountains and occupied the heads of the largest valleys, but some of the intermediate heights were not glaciated.

87. As far as the Columbia itself is concerned, its valley north of the mouth of the Spokane River, and between the head of Grand Coulee and Chelan River, was entirely filled with ice having a thickness of from 2,000 to 3,000 feet. In addition there was a very prominent tongue of ice which extended down the Columbia from the mouth of the Spokane River to the head of Grand Coulee. This mass of ice was of sufficient height and size to enter and occupy Grand Coulee as far south as Coulee City. This fact is demonstrated by the presence of glacier debris in the forms of moraines and erratics on the floor of the coulee. It is also known that farther down the Columbia, below Chelan River, a great tongue of ice continued to flow through the valley as far as the Potholes, which are located about 6 miles below Trinidad. The presence of this extension from the great ice mass is readily proven by the occurrence of moraines, erratics, and potholes throughout this part of the Columbia Valley.

88. In the Pleistocene period several temporary lakes were formed in central Washington, the evidences of which are readily found today. One of these lakes was very fleeting in time, although it was large in area. It covered much of central Washington up to the present level of 1,250 feet above tide. This basin, produced by a temporary subsidence, was in its prime about the time of the maximum extension of the ice. The glaciers came to the margins of the lake at one or more places, and floating bergs carried away large quantities of debris. This debris is commonly found scattered over hundreds of square miles of country. It is usually recognized by the erratics, light in color, composed mainly of granite and gneiss boulders, that dot the plain. The lake was not in existence long enough for deltas to be made by the tributary streams, nor for the development of shore forms due to erosion by waves. The presence of this lake has been recognized by many observers, and it was Russell who first designated it as Lake Lewis.

89. A second lake, of short duration, was formed in the general area along the Columbia between Coyote Rapids and the mouth of the Yakima River. Due to some warping of the surface, the water was held in a basin long enough for deposits several hundred feet in thickness to accumulate. These are best shown today along the east bank of the Columbia in what are known as the White Bluffs. The latter are about 400 feet in thickness and rest unconformably upon the Ellensburg formation beneath. The materials of the White Bluffs, above the Ellensburg beds, constitute the Ringold formation, which extends along the river for more than 20 miles. This formation consists essentially of horizontal beds of fine sand and silt, with a fairly large proportion of volcanic ash. The Ringold beds today

extend for many miles east of the Columbia, and no doubt were once continuous west of the river as far as the foot of Rattlesnake Mountain.

90. Another lake, also due to deformation of the bedrock, was produced in the Pleistocene time in what is called Quincy Valley. This basin is hemmed in by Badger Mountain and Frenchman Hills, on the north and south, respectively, by Babcock Ridge on the west, and on the east by the rising surface of the basalt plateau. In the Quincy Basin there are very extensive beds of clays and sands, overlain with coarse and fine gravels, and dotted here and there by glacial erratics. The lower beds are rather distinctly stratified and have a thickness known to exceed 300 feet. These beds are truly lacustrine, but the coarser materials above represent the outwash laid down by the glacial streams coming down from the north.

91. The Pleistocene was a time of marked erosion throughout the region affected by the ice invasions. In much of the country not covered by the glaciers, but rather directly influenced by them, both erosion and deposition are much in evidence. In the region south of the terminal moraine the proofs of erosion are more conspicuous than those of deposition. The valleys which had southern courses, and which received glacial water in large quantities, assumed canyonlike outlines. The sizes of the canyons ultimately formed depended primarily upon the volume of water carried, the gradients of the streams, and the corrasive effects of the debris in transit. The most spectacular canyon formed by the glacial flood waters was Grand Coulee, with Moses Coulee second in magnitude. East of Grand Coulee there are several similar canyons, but smaller in size, all with courses from northeast to southwest, that were important spillways from the ice front.

92. Pleistocene time, as today, was marked by the aggressive work of the winds. Hills and dunes of wind origin early began to take form over some of the plains which had been affected by the ice. The dominant winds, coming from the west, carried the finer material farther and farther eastward, often filling the shallow valleys and providing impediments for the streams. A conspicuous example of this was the making of Moses Lake, which occupies a shallow north and south valley that was formed soon after the close of the glacial history. This valley of Crab Creek was crossed by a belt of sand dunes, traveling from the west, and a dam constructed which impounded the water, thereby bringing Moses Lake into existence.

2. SOILS

93. Within the general area now being considered there is a great variety of soils. There is practically no residual soil, that is, soil derived by the disintegration and decay of the bedrock at that particular place. One does not find anywhere a transition from the solid rock beneath, through intermediate stages of broken rock above, to the well defined soil at the surface. Almost uniformly the transported soil rests upon a bedrock that is foreign to it as far as its genesis is concerned.

94. The oldest soils of this part of the Columbia Basin are those upon the uplands that were not influenced by the invasions of the ice. They are found covering the intercoulee areas, the broad mountain tops,

such as Badger Mountain, and the general plateau as it approaches the eastern margin of the State. This upland soil is essentially all Eolian in character, borne by the strong and persistent winds that come from the west and the southwest. Very much of this soil has come from the treeless regions west of the Columbia. A large part has been derived from the extensive exposures of large areas of the Ellensburg formation, which contains a high proportion of silt and fine sand. And through all of the wind-carried soil there is found much volcanic ash, which came from volcanic vents located to the westward.

95. Some of the soils of the region are intimately connected with the events of the Pleistocene period. Over the country crossed by the ice a veneer of debris was often left upon the surface. Sometimes the glacial material was till or hardpan, and again a rather coarse soil of sand or gravel. One of the baneful results of the glacial experience was the removal, over hundreds of square miles of country, of the mantle of soil already there when the ice came. This was due to the erosive character of the great streams produced by the melting ice, which stripped off the soil, and exposed the scabland country which now covers so much of east central Washington.

96. As it stands today, it is safe to say that there is hardly a square yard of area in all the Columbia Basin where the soil at the top at least does not show the work of the winds. This is true in the river valleys as well as out upon the plains and plateaus. Along such valleys as those of the Columbia, Yakima, and Wenatchee Rivers, the top soil is usually from one to several feet in depth, overlying coarse beds of sand, gravel, or boulders, derived under flood conditions of the rivers, or through the activity of glaciers. The veneer of soil at the surface, fine in grain, and productive when moisture is applied, represents fine material blown in from the neighboring country at times of high wind velocities. When one leaves the broken country and goes out upon the plains and uplands the evidence of Eolian soils are everywhere. Regardless of whatever makes up the base or substratum, there is usually a coating of fine wind-blown soil, sometimes many feet in depth. As a rule the topography of the soil covering clearly indicates the influence of the winds and their prevailing direction.

97. In general, the soils along the Columbia are light in color, and because of desert conditions they carry but little humus. In going both east and west from the river the amount of rainfall increases, the vegetation is more abundant, and the soils become darker in color.

98. It may be said that all classes of soil in the Columbia Basin respond well to irrigation. They are sufficiently pervious to allow an easy penetration by water, and have the proper ingredients to grow many varieties of crops. The soils of the uplands are sufficiently retentive of moisture for the growing of wheat. These soils are easily worked, and are adapted to dry-farming practice. The situation is greatly helped because the spring and summer rains usually fall at an opportune time for the developing grain.

3. SUMMARY OF RECENT RIVER HISTORY

99. It is evident that the valley of the Columbia antedates the topography which lies adjacent to it. As far back as the time of the Yakima basalt this stream no doubt was in existence and occupied

one position after another across the laval plains. It is probable that the great bend of the Columbia to the westward was made by the effect of the flows of lava rising higher in the central part of the basin and pushing out in all directions. The river was thereby obliged to encircle a part of the plain and make its way around the margin, instead of taking a more direct line from the mouth of Spokane River to the mouth of Snake River. Because of its pronounced gradient from the international boundary to the sea, and the highland masses that it crosses, it was very natural for the Columbia to carve out a canyon along most of its way. The river was well established in approximately its present position before the last uplift that affected the Cascade area. The secondary folds that come from the west or northwest, away from the main axis of the mountains, extend beyond the Columbia and for some distance out into the basin. The anticlines make up such prominent elevations as Entiat Mountain, Badger Mountain, Frenchman Hills, and Saddle Mountain. The upward movement of these anticlinal arches was at a rate no greater than the normal erosion of the river, and the stream was not dislodged from its earlier position. The anticlines and synclines that are conspicuous on the east side of the Columbia may all be observed on the west side of the stream, and are found to be connected with the larger Cascadian uplift.

100. The effects of the glacial episode upon the valley of the Columbia were very marked. Wherever the stream bed was occupied by the ice, especially when the latter was flowing in the same direction as that of the channel, the bottom was very irregularly deepened, giving quite variable depths to bedrock.

101. One of the primary effects of the ice occupation was the choking of the river valley by enormous quantities of debris. Wherever the ice lay for any considerable time a glacial topography in the form of moraines is now found. On the top of the actual ice-deposited drift there is usually found today a much greater quantity of essentially stratified debris, carried downstream through the long period of time that the ice was waning and eventually disappearing. This process of deposition oftentimes filled the entire valley to the depth of several hundred feet.

102. Since the ice finally disappeared it has been the task of the river to clear away the debris from its channel as rapidly as it can. It is safe to say that up to the present time not more than a third or a half of the original sediment in any cross section has been entirely removed. In most instances the river yet flows upon detritus derived from the ice, and the stream has not reached its original position on bedrock. In the process of the removal of the glacial debris, many terraces have been developed. They often extend up and down stream for several miles, and the topmost ones reach heights of 500 or 600 feet above the present river level.

103. It is evident that in the removal of the debris, starting at an elevation several hundred feet above the preglacial stream bed, the river frequently finds itself today in a channel which does not conform in location to the one it had before the advent of the ice. It occasionally happens that an elbow of the original wall rock of the valley was completely covered by a moraine or the outwash from the ice. The river in its postglacial cutting has sometimes unearthed

these protruding rock spurs, and thereby developed falls and rapids, such as those that occur at Rock Island, below Wenatchee.

104. Downstream, beyond the actual limits of the ice, the Columbia has done considerable lateral cutting in recent times. One of the best instances is to be found in the general vicinity of White Bluffs and Hanford. It is clear, from field evidence, that from the vicinity of Coyote Rapids the river once flowed west of Gable Mountain, or near the eastern foot of Rattlesnake Hills, in a very much more direct line than is true today. The eastward migration of the river has been induced primarily by the soft beds belonging to the Ellenburg and Ringold formations, which do not offer strong barriers to the cutting power of the stream.

4. THE GEOLOGICAL CONDITIONS ALONG THE COLUMBIA THAT AFFECT CERTAIN ENGINEERING PROBLEMS

105. In that portion of the Columbia, from the mouth of Snake River to the international boundary, the principal engineering problems are those that have to do with foundations for dams, bridges, or other large structures, and the making of reservoirs. The topography of the valley floor is always of importance, but usually the position of the bedrock, underneath the overburden, is of much greater consequence. It is noteworthy that at only a few places, and then for short distances only, does the river flow directly upon the bedrock. As a rule the depth to solid rock can be determined only by drilling, but the kind of rock is usually the same as that along the adjacent cliffs.

106. The cutting of the great trench in which the river flows has been very largely due to the erosive power of running water. In a very minor way the excavation was due to the ice which at least twice occupied nearly all of the Columbia Valley now under discussion. While the major cutting was done by the river in preglacial time, many of the present irregularities of the rock floor of the valley are due wholly to the scour of the ice. Due largely to variations in the mass of ice and its rate of flow from place to place, changes in the quality and quantity of the debris which formed its working tools, and to other causes, the moving ice made for itself a very irregular floor of rock upon which it rested.

107. Probably the greatest variation in the level of the underlying rock was made when the course of the main valley conformed to the direction of flow of the ice. At Chelan, where the ice followed the trend of the valley, the drilling disclosed striking differences in the depth to bedrock. At Foster Creek Rapids, where the flow of ice was at right angles to that of the Columbia, the drill found but little change in the position of bedrock from one side of the channel to the other.

108. The debris of the river bed has had four principal methods of origin. The largest portion has been the direct and indirect results of extensive glacial action, as described earlier in this report. A second way for the production of the detritus of the master valley has been the work of the large tributaries in their contribution of sediments, particularly in times of large floods. The third method has been the long weathering of the high cliffs that border the valley, and the consequent production of the talus slopes of unusual size. A

final part of the debris is that due to the constant action of the winds, in bringing in the finer soil from the neighboring plateaus.

109. The contributions of each of the four causes just mentioned vary greatly from place to place. The glacial contribution depended upon the position and size of the ice mass. The sediments brought in by the tributaries are usually of most importance immediately below their mouths. The bulk of the talus slopes vary with the height and perpendicular character of the canyon walls, and whether or not streams are at work in removing the debris as it falls from the cliffs. In some stretches of the valley of the Columbia, the wind-blown soil lies many feet deep and in other places it is very shallow.

110. The variation in the kind and amount of debris within the valley of the Columbia has caused many shifts in the position of the stream. The river has been able to meander within rather narrow limits, and this has caused a more or less constant migration of the channel from one side of the valley to the other. It is safe to say that the present bed of the stream crosses and recrosses almost everywhere its positions in earlier episodes of river history.

111. In any cross section of the Columbia it is not easy to forecast where the bedrock surface will be the lowest as regards sea level. It may be along the central axis of the valley, but often is toward one side or the other. Sometimes the curving walls of the canyon, when traced up and down stream, afford strong suggestion as to the longitudinal line of greatest depth to solid rock. Whether the original cutting away of the rock was done by river action alone, or was modified by glacial scouring, enters into the problem.

112. In some places the river has recently swung far toward one side of its valley and now flows close by the foot of the adjacent cliff. Under these circumstances the chances are that rock in place forms one bank of the stream and may extend part way across the bottom. The place of deepest drilling will then be somewhere between the opposite side of the channel, and the distant canyon wall.

(c) TOPOGRAPHY

1. GENERAL

113. The drainage basin of the upper Columbia lies between the Continental Divide on the east and the Cascade Mountains on the west. Between these two main ridges of the North American Cordillera lies a broad belt of mountainous country characterized by parallel series of broad, rugged plateaus, separated one from another by deep, narrow valleys. In general, these valleys and plateaus, together with the Cascades, have a prevailing trend north and south, while the main divide of the Rockies runs more to the northwest, giving a roughly triangular shape to the basin of Columbia River above the Snake.

114. On the west of this basin, the Cascade Mountains trace a sinuos course to the north, with summits from 6,000 to 8,000 feet above sea level. The long spurs and valleys of the eastern escarpment of this range strike off to the southeast from the crest line, terminating in most instances at the Columbia itself.

115. The main divide of the Rockies, which is about 450 miles to the east of the Cascade Range, extends generally to the northwest with altitudes between 7,000 and 12,000 feet above sea level, but there are

several short ranges of less Majestic proportions on the western side of this divide and generally parallel to it. The Bitterroots branch west from the main divide about 60 miles southwest of Butte, Mont., and describe a great curve to the northwest, terminating just southeast of Pend Oreille Lake. These mountains are between 7,000 and 9,000 feet high at their point of juncture with the Rockies, but gradually decrease to approximately 5,000 feet altitude near Pend Oreille Lake. The northeast side of this range is very abrupt, but the more gently sloping southwest side sends down many long valleys and spurs to merge almost imperceptibly with the higher portions of the Columbia Plateau.

116. The Selkirk Mountains are the most easterly and the highest of a series of parallel ranges which close in on the north of this region. They rise north of Spokane and run due north, their summits frequently attaining altitudes in excess of 7,000 feet. The Clark Fork and Kootenai have cut deep canyons through these ranges to the Columbia. The successive ridges comprising the Okanogan highlands run parallel to the Selkirk Mountains to the north, from the northern bank of the westerly course of the Columbia. These ranges, while comparatively low near the Columbia, eventually reach elevations in excess of 5,000 feet, meeting and mingling with the spurs and secondaries of the two main mountain systems and thus completing the northern inclosure of the basin.

117. Although many benches and flats exist throughout this basin, the largest area of open country is the Columbia Plateau. This tableland is bordered on the west by the Columbia, on the north by the Columbia and Spokane Rivers, on the east by the foothills of the Bitterroot Mountains, and on the south by the divide of Snake River. Generally, the rolling prairies of this plateau slope from the northeast to the southwest. Two parallel ridges, Frenchman Hills and Saddle Mountains, run eastward for a few miles from Columbia River, in the vicinity of Beverly. Many dry stream gorges indent the rolling prairies of the northern and eastern portions of this plateau, Grand Coulee being the most important. It leaves the Columbia and runs south-southwestward through a canyon 1 to 2 miles wide, with walls 400 or more feet high, for a distance of 33 miles, where the valley floor drops 400 feet. From this point south to Frenchman Hills, the coulee is less deep and gradually merges with the plateau.

118. Around the northern and western edges of this plateau, the Columbia flows in a gorgelike depression from 300 to 2,000 feet below the surface of the plain. Glacial action and weathering have in many places modified the canyon form of this valley, and the actual rock walls of the gorge are mantled by terraces rising one above another along the course of the river. These deposits of glacial origin also underlie the river itself, and in many instances the Columbia is now cutting its channel down through gravel and boulders, with bedrock at unknown depths below.

2. PROFILE

119. Profiles were obtained by leveling from a line of bench marks run in connection with a topographic survey of the river and its valley. Several parties were used so that the work would be done in the shortest time possible and thus avoid making corrections for change in stage. It is difficult to obtain an extreme low-water profile,

as this condition obtains only during times when ice is running, which frequently jams and changes the natural river slope. (See plate no. 2.)

120. The profile of the Columbia is a succession of steep slopes connected by lines of much less grade, and further concentrations of drop at Priest Rapids, Rock Island, Grand Rapids, and Kettle Falls.

121. (*a*) *Medium low-water profile.*—At medium low-water stage with a discharge 50,750 second-feet at Vernita, 46,300 second-feet at Grand Coulee, and 41,400 second-feet at Kettle Falls, the profile is as follows:

From Snake River to foot of Priest Rapids, a distance of 72.6 miles, the average slope is 1.16 feet per mile, with one stretch of 3 miles where the slope is 3 feet per mile and another place where the slope is 2 feet per mile for 11 miles.

Priest Rapids has a drop of 73 feet in 11 miles, or 6.63 feet per mile. Within the rapids there is one place where the slope is 11 feet in 1 mile, one with 12 feet in 1 mile, and a third with 16 feet in 1 mile.

From Priest Rapids to Rock Island Rapids the distance is 46 miles and the average slope 1.67 feet per mile. In Island Rapids the slope is 5 feet per mile, and at Cabinet Rapids 10 feet in 1 mile.

At Rock Island the river drops 17.3 feet in 1½ miles, or at the rate of 11.5 feet per mile.

From Rock Island to Bridgeport the distance is 90 miles, and the average slope 2.12 feet per mile. At Orondo Bar and Entiat Rapids, however, the river has a fall of 6 feet per mile over a distance of 4 miles; and at Methow Rapids the river falls 7 feet in 1 mile. At one place in this stretch the river runs 3 miles with a drop of only 1.5 feet.

From Bridgeport to Grand Coulee, 55.5 miles, the slope is 3.42 feet per mile. In Long Rapids the slope is 14 feet per mile for 1.3 miles; and from the foot of Foster Creek Rapids to the head of Long Rapids, a distance of 14 miles, the fall is at the rate of 6 feet per mile.

From Grand Coulee to Grand Rapids the river falls at the rate of 2 feet per mile, the distance being 103 miles. Some stretches within this section have a slope of from 6 to 9 feet per mile for distances from 1 to 3 miles. Above Spokane Rapids the river drops only 1 foot in 3 miles.

Grand Rapids has a drop of 20 feet in less than 1 mile.

Between Grand Rapids and Kettle Falls the slope is 0.7 of a foot per mile; the distance being 5 miles.

Kettle Falls has a drop of 37 feet in 1 mile.

Above Kettle Falls to the international boundary the average slope is 2.16 feet per mile for the 41 miles. The average slope for the entire 425.3 miles from the boundary to Snake River is 2.3 feet per mile.

Over short distances the river has steeper slopes than given above.

122. (*b*) *High-water profile.*—No complete high-water profile of the river is available. Isolated elevations of a flood which occurred in 1894, and of the 1928 high water, are available; and the following information is based on these records.

Between the mouth of Snake River and foot of Priest Rapids the slope is but little affected by change in stage. Records at Pasco and at Wahluke, 48 miles apart, give a drop of 4 feet less at high water (1928) than during a medium low stage. The drop in Priest Rapids varies only a few feet with change in stages between low and high, while at Rock Island the drop is greatly reduced with increased stage and is only a few feet at extreme high water.