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

WATER-SUPPLY PAPER 316

GEOLOGY AND WATER RESOURCES

OF A PORTION OF

SOUTH-CENTRAL WASHINGTON

BY

GERALD A. WARING

WASHINGTON
GOVERNMENT PRINTING OFFICE
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GEOLOGY AND WATER RESOURCES OF A PORTION OF SOUTH-CENTRAL WASHINGTON.

By GERALD A. WARING.

INTRODUCTION.

EXTENT OF AREA.

The area considered in this report comprises about 5,000 square miles in south-central Washington, including Benton County, the eastern parts of Yakima and Klickitat counties, and the western

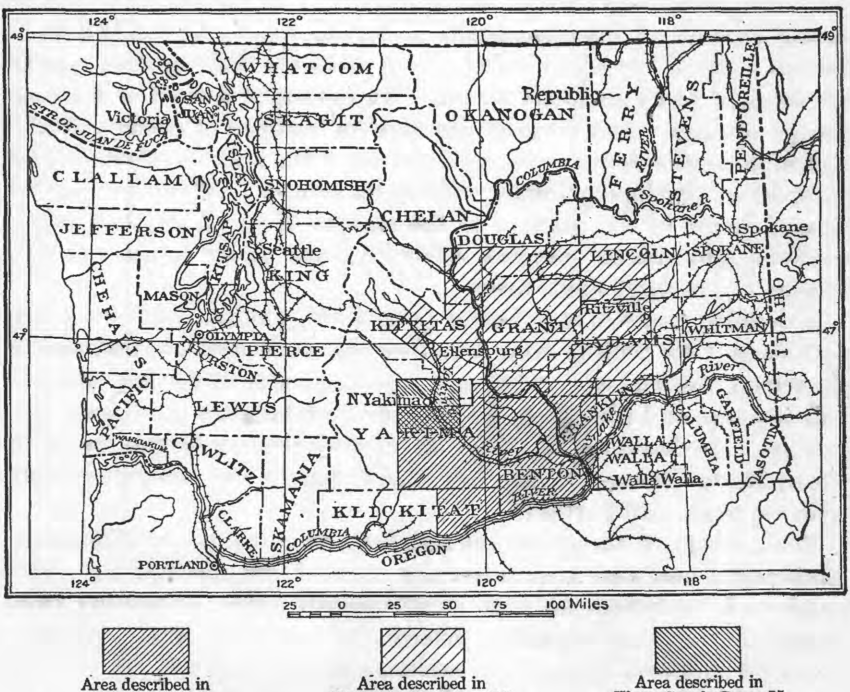

FIGURE 1.—Index map of Washington showing location of area discussed.

part of Franklin County. (See Pl. I and fig. 1.) Columbia River flows southward through its eastern portion and then turns and flows westward, forming the southern boundary of its western portion.

OBJECTS OF THE EXAMINATION.

Until within the last few years the greater part of the region was sparsely settled and was used only as a stock range; recently, however, much of it has been filed upon under the homestead and desert-land laws and is now being rapidly settled and cultivated. Except in the bottoms near the major streams, water is scarce, even for domestic use. In order to study the supply at present in use and the possibility of increasing it by sinking deep wells, the author spent several weeks in reconnaissance during the fall of 1907. The time available permitted only a hurried inquiry into the present utilization of surface and underground water by canals and by wells and a general study of rock characters and structural conditions in their relation to further development of the underground sources.

EARLIER INVESTIGATIONS.

In the summer of 1892 I. C. Russell made a preliminary examination of central and southern Washington with special regard to its water resources, and though more detailed work has led to a modification of some of his conclusions as to the structural conditions in certain parts of the area his deductions as to the underground supply are thought to be generally sound.[1] In his paper Russell states that though shallow water is easily obtained in portions of eastern Washington the region is not a generally artesian area, and that there is little prospect of developing flowing wells in its valleys. In another paper [2] Russell treats of the country to the east, in Walla Walla, Columbia, Garfield, and Asotin counties, describing the wheat lands and discussing the underground water.

A detailed study of the district near North Yakima has been made by George Otis Smith,[3] who describes the main geologic features of the region, the general conditions affecting ground water, and the several streams, and discusses a number of available sites for storage reservoirs. He describes in greater detail the Atanum-Moxee basin, in which North Yakima is situated, and discusses the flowing artesian wells in its eastern portion.

The geology of the area that has been mapped as the Ellensburg quadrangle has also been carefully worked out by Smith.[4] This quadrangle embraces an area of 820 square miles, extending from Atanum Ridge northward to Ellensburg and from North Yakima about 23 miles westward. In addition to treating the rock formations and their structure in detail, Smith discusses the ground waters and the artesian waters.

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[1] Russell, I. C., A geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893.

[2] Russell, I. C., A reconnaissance in southeastern Washington: Water-Supply Paper U. S. Geol. Survey No. 4, 1897.

[3] Geology and water resources of a portion of Yakima County, Wash.: Water-Supply Paper U. S. Geol. Survey No. 55, 1901.

[4] Smith, George Otis, Ellensburg folio (No. 86), Geol. Atlas U. S., U. S. Geol. Survey, 1903.

A general study of the region immediately north of that covered by the present report has been made by Calkins,[1] who gives lists of deep wells in the area around Moses Lake and the cost of drilling them and discusses the possibility of obtaining flowing wells in the several districts. The areas described by Smith and by Calkins are shown on the index map (fig. 1).

As all these publications treat of areas adjacent to that considered in the present report, and as all of them describe regions in which the climatic, geologic, and hydrologic conditions are similar, they have been freely drawn upon. Frequent references have also been made to a recent bulletin of the Department of Agriculture[2] concerning a number of irrigation canals along the lower Yakima River, and to an earlier publication of the same Department on the soils of the Sunnyside Valley.[3]

GEOGRAPHY.

SETTLEMENTS.

The principal towns in the south-central part of Washington are North Yakima, the county seat of Yakima County; Sunnyside, about 35 miles southeast of North Yakima; Prosser, the county seat of Benton County; Kennewick, an agricultural settlement on the western side of the Columbia; and Pasco, a railroad town on the opposite side of the river. By the census of 1910 North Yakima had a population of 14,082, Prosser 1,298, Kennewick 1,219, and Pasco 2,083.

Most portions of the region are easily accessible by rail. The Oregon-Washington Railroad & Navigation Co.'s line follows the south bank of Columbia River from Portland to Wallula, Wash., and there branches eastward to Walla Walla and northeastward to Spokane. From Pasco one branch of the Northern Pacific Railway system follows Yakima River and continues westward to the Puget Sound cities, and another extends northeastward to Spokane. A third line, the Spokane, Portland & Seattle Railway, has been built along the north side of Columbia River into the southern part of the region. Small steamers ply daily along the Columbia, going as far upstream as Priest Rapids, but there is room for much improvement in their facilities.

Along the railroad line that follows Yakima River there are shipping depots every few miles and in addition numerous small towns that depend for trade on the grain-raising portion of the Horse

[1] Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper U. S. Geol. Survey No. 118, 1905.

[2] Jayne, S. O., Irrigation in the Yakima Valley, Wash.: Bull. Office Exper. Sta. No. 188, U. S. Dept. Agr., 1906.

[3] Jensen, C. A., and Olshausen, B. A., Soil survey of the Yakima area, Wash.: Rept. Field Operations Bur. Soils for 1901, U. S. Dept. Agr., 1902.

Heaven country or on the fruit-raising and dairying settlements farther north. The railroad towns east of Columbia River are mainly centers of supply and shipping points for the surrounding grain-producing sections; the interior towns are mail and trading stations for the neighboring ranches.

CLIMATE AND VEGETATION.

The Cascade Range crosses the State in such a way that it shuts off its eastern part from the rain-bearing clouds of the Pacific Ocean and thus divides the State into two distinct climatic provinces. The western province receives abundant and in some places excessive rainfall and has cool summers and mild winters; the eastern province is arid and has hot summers and severe winters.

The precipitation in the eastern province differs greatly from place to place. Its record shows variation with elevation and with distance from the mountains and exhibits also the wide annual variation common to all arid regions. At Moxee Wells, in the Moxee Valley, the mean annual precipitation for the 11 years from 1893 to 1903, inclusive, was 8.9 inches and the mean annual temperature for the same period was 50° F.[1] At three other stations—North Yakima, Sunnyside, and Kennewick—the precipitation in 1905 was respectively 9.06, 6.48, and 2.88 inches, showing a marked decrease of rain and snow southeastward from the mountains. In the western part of the area examined, which includes the country around Bickleton and that at the head of Reservation Valley, the precipitation is greater than at North Yakima, but no records of the rain and snowfall in this western region are available.

Although most of this area is north of latitude 46° the winter is not severe in the valley lands, for they lie at elevations below 1,200 feet and are to some extent protected by the ridges that separate them. Some snow falls on them, but it usually remains only a short time, so that the winter is "open" most years. Although frost may be expected early in the fall and late in the spring it is seldom so severe as to injure the hardy crops.

Pine and other native trees grow on the higher western slopes and scrub oaks on the lower hills at the west end of Reservation Valley, but sagebrush and smaller desert shrubs form the main natural vegetation of the plains. Along Yakima River and the streams that enter it from the west there are cottonwoods, willows, and alders. The banks of the Columbia along that portion of the river that flows through the area here considered are not lined with trees, though in places they bear clumps of willows.

[1] Henry, A. J., Climatology of the United States: Bull. Q, Weather Bureau, U. S. Dept. Agr., 1906, p. 942.

AGRICULTURE.

The irrigated valley lands yield bountiful crops. Forage plants, especially alfalfa, timothy, and clover, are extensively grown; hops and garden vegetables make valuable crops; and the apples, pears, and other fruits raised are noted for their size and quality.

The supply of stream water easily available for irrigating much of the valley land, and the accessibility of the fruit-growing districts to market by rail, eastward to Spokane and other cities and westward to the cities on the Puget Sound, have greatly aided in bringing the country rapidly to the front. Much of the land that lies above irrigation canals has proved valuable for raising wheat by dry farming.

For the last 40 or 50 years some settlement has been in progress along Yakima River and its tributaries, and water from these streams was early diverted to some extent for irrigation, but active development has taken place mainly since the completion of the Northern Pacific Railway through this region in 1883, and the greatest development has taken place within the last 10 years.

GRAZING.

In early days nearly all this region was used as range for cattle and horses. The settlement of much of the valley land has reduced the area available for grazing, but the higher and more rocky portions of the region will probably never be valuable for other purposes, and many head of cattle still range over them. In summer the cattle graze over the higher western lands, but in winter they are usually brought down to the plains and are fed during stormy periods. Considerable open range remains in the west end of Reservation Valley and to the north, on Selah Ridge.

Many sheep are herded in the mountains during the summer and fall and taken into the cultivated valleys and fed from alfalfa stacks in severe weather during the winter. Some farmers allow the sheep to graze on their alfalfa fields for a short time each day, but the pasturage fee received scarcely seems to compensate for the injury done to the fields by the sharp-hoofed animals.

GEOGRAPHIC PROVINCES.

For purposes of examination and description the area may be conveniently divided into four geographic provinces, namely, Sunnyside Valley, which lies between Rattlesnake Ridge and Yakima River;[1] Reservation Valley, which lies west of Yakima River and between

[1] The Zillah sheet of the Topographic Atlas of the United States, issued by the U. S. Geological Survey, covers parts of the Sunnyside and Reservations valleys, on a scale of about 2 miles to the inch. It maps an area 30 minutes in extent in each direction, most of it in Yakima County.

Atanum and Toppenish ridges; Horse Heaven Plateau, which is in the southern part of the area; and Columbia River Plains, which is in the northeastern part of the area.

SUNNYSIDE VALLEY.

Extent.—On the northeast side of Yakima River, below Union Gap, a wide area of cultivable land, known as the Sunnyside Valley, stretches northward to Rattlesnake Ridge and southeastward from Zillah nearly to Prosser. From the river the land rises toward the crest of Rattlesnake Ridge, its grade increasing near the ridge. Although some portions of the otherwise even surface are hummocky or are cut by small drainage channels, the only important feature of relief is Snipes Mountain, a low ridge on the west-central border of the area.

Development.—The greatest development has taken place in the central part of the valley. In the early nineties nearly all of this land was unsettled and covered with sagebrush, but since that time a great part of it has been brought under irrigation and is now in a high state of cultivation. In 1910 Sunnyside, the largest town in the valley, had a population of 1,379; Outlook, Granger, and Grandview are newer and smaller. A branch line of the Northern Pacific Railway extends from Toppenish to Grandview, furnishing a ready outlet for produce.

This section has been developed very rapidly since water from Yakima River was made available for its irrigation by the construction of the Sunnyside Canal. One who enters the cultivated fields and orchards around Sunnyside after riding from Mabton northward across desert land, covered with sagebrush and sandy hummocks, is strikingly impressed with the results of irrigation.

Soils.—Most of the valley is bottomed by the Ellensburg formation, consisting of gravel, sand, and silt, which is overlain in part by alluvium washed from the higher slopes. From the Ellensburg formation and this latter alluvium a fertile soil has been formed.

In 1909 the gullied slopes north of Sunnyside, above the irrigating canal, were but little cultivated, but the slopes of Rattlesnake Ridge, farther east, had been extensively cleared and devoted to wheat raising. Between Sunnyside and Mabton the land, though cultivable, is more uneven and in places more sandy; most of it, however, will probably be brought under cultivation when ditch laterals have been extended through it. On the south side of the river, between Mabton and Prosser, the soil is thinner than it is in the Sunnyside region and is in places absent, basalt forming the surface, so that not all of the lowland in this locality is suitable for tillage.

In 1901 a soil survey of the Yakima and Sunnyside areas was made by the United States Department of Agriculture, and the classes of soils and their alkaline contents were determined and mapped.[1] The determination showed that alkali was present in objectionable amount at the surface in only a few places. Beneath the low lands, however, alkalies were found in considerable amount, but as they consisted mainly of sulphates they would probably not become troublesome if proper drainage were provided. Since this examination was made, however, alkaline and swampy tracts have been developed in some of the lower parts of the area through saturation of the ground by overirrigation and by seepage from canals, for nearly all the main canals and laterals are unlined. It is manifest that this rise of alkali can be overcome by drainage canals, and in 1907 work was accordingly begun on the construction of a canal extending from a point near Sunnyside southward to Yakima River.

In this region much alfalfa, clover, and timothy hay is grown, which finds a ready market in the cities of Puget Sound. Hops and garden vegetables are also extensively cultivated, and apples, peaches, and other orchard fruits raised in this section are becoming well known throughout the country.

RESERVATION VALLEY.

Extent and character.—West of the Sunnyside Valley, across Yakima River, the wide, nearly level valley land continues in an area between Atanum and Toppenish ridges known as the Reservation Valley. Its western border is marked by hilly slopes cut by ravines into nearly parallel ridges that rise to form higher portions of the Cascade Range. The valley floor is more nearly flat and is less diversified than that of the Sunnyside region, and the ridges on each side rise more abruptly, so that the boundary between valley and slope is more sharply defined. Like the Sunnyside area, it is floored with deposits of the Ellensburg formation, but these do not extend far up the sidehills. Several branches of Toppenish Creek, which drain the slopes west of the valley, unite at its west end and flow along its southern border, joining Yakima River near Alfalfa. As the branches of this creek rise on wooded mountains its flow is fairly constant, but during the summer much of its water is diverted for irrigation in the southern portion of the valley.

Deposits of coarse gravel in different parts of the valley, especially a gravel terrace that extends from north to south through its central part, indicate that Toppenish Creek has shifted its course over the lowland and in places has left deposits of stream wash on the Ellensburg formation.

Development.—Most of the land of the Reservation Valley lies within the Yakima Indian Reservation and has been allotted to the

[1] Jensen, C. A., and Olshausen, B. A., Soil survey of the Yakima area, Wash.; Rept. Field Operations Bur. Soils for 1901, U. S. Dept. Agr., 1902.

Indians in 80-acre tracts. Prior to about 1905 they were not allowed to sell their holdings; many of them, however, leased their land to whites who cared only to get as much as possible from the soil with a minimum expenditure, and who made few improvements, such as fences and buildings. In 1907, however, a ruling permitted each Indian to sell three-quarters of his land in order to obtain funds with which to improve the remainder, so that within a few years the valley will probably become largely settled by whites.

Farming has been carried on mainly along the south side of the valley and in its eastern portion, near Toppenish. Within the drainage basin of the Reservation Valley, but in its northwestern part, above the valley lands, several orchards and hop yards lie along the upper branches of creeks. The soil here is thin, however, being mainly a dark-red residual material derived from the decay of the basalt, and large parts of it are too rocky to be cultivated.

HORSE HEAVEN PLATEAU.

Surface features.—In the southern part of the area examined, between Yakima and Columbia rivers, lies a region known as the Horse Heaven Plateau, from the luxuriant growth of bunch grass that covered its eastern part in early days, before excessive grazing had made the term inappropriate. From the sagebrush slopes of its eastern portion the surface gradually rises northward to the wooded mountains of the Cascade Range. A few main drainage channels trend southward across it to Columbia River, but it contains no perennial streams. The upper courses of Alder and Cottonwood creeks, however, usually carry water throughout the year.

Settlement.—The higher, western portion of the Horse Heaven Plateau, known as the Bickleton region, has been settled longest, the town of Bickleton having been established over 30 years ago. The more hilly slopes back of this town, which stands at an elevation of nearly 3,000 feet, are timbered. The land south and east of Bickleton has for a number of years yielded crops of grain, but it is only since about 1900 that the lower eastern parts of the plateau have been cultivated, and only since 1905 that homesteading has gone on with much rapidity.

Agriculture.—Wheat is the staple crop of the Horse Heaven Plateau. Hardy winter wheats, chiefly the varieties known as Jones's Five and Fortyfold, are those most raised; though Turkey Red and other spring wheats yield well under favorable conditions.

On account of the deficiency in rainfall it is customary to summer fallow half of the land each year, sowing it only in alternate seasons, for by this means a greater amount of moisture is obtained for the crop. In years of plentiful rainfall, however, some farmers plant all their land.

A number of roads lead from the plateau down to the railroad stations at Mabton, Prosser, Kiona, and Badger. During the summer and fall these roads are marked by trailing clouds of dust raised by teams hauling the wheat for 15 miles or more to the railroad for shipment. This long haul adds considerably to the cost of production.

Soils.—The origin of the soil of the Columbia Plains has been the subject of more or less discussion. Some writers have claimed that it is essentially a residual formation;[1] others have held that it is a wind-borne deposit.[2] It seems probable that the soil of some parts of southern Washington is of one origin and that of other parts is of the other or both. The evidence that has been advanced by writers in favor of each mode of formation seems to apply well to the two classes of soil observed in the Horse Heaven region. The soil of the lower lands is a loose, light-brown, sandy loam, seemingly brought by the winds from the Columbia River lowlands and resting on comparatively unaltered basalt; whereas the soil of the higher slopes seems to be residual in origin and to be a product of decay of the immediately underlying rock.

The thickness of the transported soil on the Horse Heaven Plateau is shown in several places were wells have penetrated it, notably in sec. 29, T. 7. N., R. 30 E., where a well drilled by A. H. Richards passed through 117 feet of the material before reaching solid rock. In areas farther west the soil is much thinner, and in many fields near Bickleton it is only a foot or two deep. It also changes from the light-brown loam to a dark-red heavier soil, having in many places a hummocky, "hog wallow" surface, and lies on partly decomposed basalt.

Granitic bowlders scattered over a band of quartz pebbles that crosses the region from northeast to southwest, near Bickleton, suggest either that at one time the Ellensburg formation may have covered portions of the now uplifted region or that glacial action has extended this far east from the summit of the Cascades. The Ellensburg formation outcrops in a comparatively large area on the lower bluffs near Mabton, where it is the source of the light soil that in summer renders the road so dusty.

COLUMBIA RIVER PLAINS.

GENERAL FEATURES.

The wide expanse of country known as the Columbia River Plains lies north of Snake River, extending in part west of Columbia River but lying mainly east of that stream. On the west low plains lie but

[1] Russell, I. C., A reconnaissance in southeastern Washington: Water-Supply Paper U. S. Geol. Survey No. 4, 1897, pp. 57-64.

[2] Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper U. S. Geol. Survey No. 118, 1905, pp. 45-49.

little above the level of the river, but on the east bluffs appear along the stream and the land rises to form a plateau. In the main the surface of both the higher and the lower plains is only gently undulating, though a few prominent hills and ridges rise above the general level and wide coulees mark the courses of flood-water channels. Perennial streams do not flow in these channels, but the larger ones in the northeastern part of the plains contain a number of lakes.

The greater portion of these plains is used only as a cattle range, but many homesteaders have come into the region since about 1905 and have cleared the land for grain raising.

AREA EAST OF COLUMBIA RIVER.

East of Columbia River parts of the Columbia River Plains are rocky and untillable, but most of the portion lying within a few miles of the river is covered with the Ellensburg formation, which has decomposed to a soil that is fine grained, light, and easily tilled and that yields well when the rainfall is sufficient. Though no analysis of it is at hand it is known to be a limy soil, as calcareous nodules are scattered over its surface.

On the portion of the plateau covered with soil derived from the Ellensburg formation much work has been done in clearing and fencing the land and in raising grain. The season of 1907 was a favorable one in this section as well as in the Horse Heaven country, and the large crop of wheat and the good price received for it gave impetus to the settlement of these more arid plains.

AREA WEST OF COLUMBIA RIVER.

GENERAL CHARACTER.

The eastern portion of the part of the plains region lying between Rattlesnake Ridge and Columbia River is a nearly level sagebrush-covered plain, much of which is susceptible of irrigation by water pumped less than 200 feet from the Columbia. Near the river a part of the land is covered with cobbles and river gravel and is too stony to be cultivable, though a great part of the river wash is overlain by a loose sandy soil. Farther west this soil is finer in texture and grades into the soil along the base of Rattlesnake Ridge and into that derived from the Ellensburg formation near the mouth of the canyon of Cold Creek.

RATTLESNAKE VALLEY.

A narrow east-west valley, lying west of Columbia River on the western edge of the plains region, is known as the Rattlesnake Valley. On the south it is limited by Rattlesnake Ridge and on the north gentler slopes rise to Selah Ridge. A low divide separates it from the Moxee Valley, but to the east it opens on the plains bordering Columbia River. The west end of this valley has been occupied by a few settlers for a number of years, but, as in most of the plains region, lack of water has kept it mainly a wheat-raising section. During 1907 the land in the eastern, wider part of the valley, which is known as Spring Valley, was filed on and much of it was sown to grain.

COLD CREEK REGION.

During the two or three years prior to 1907 many settlers took up claims along the lower course of Cold Creek, a few miles north of the Rattlesnake Valley, being apparently induced to do so chiefly by the fact that similar land in the Yakima and Sunnyside areas had become very valuable when brought under irrigation. In this area, which is covered mainly by fine-grained deposits of the Ellensburg formation, there is much tillable but arid land, and the newcomers apparently intended to rely on grain raising for several years at least.

PHYSIOGRAPHY.

RELATION OF SURFACE FEATURES AND STRUCTURE.

Two distinct types of surface features exist in south-central Washington; in one the surface conforms to the structure and in the other it is independent. The broad ridges and the wide, flat plains and valleys constitute the first type. Beneath the plains the rock beds lie nearly horizontal, conforming closely to the present surface except that in the valleys the surface has been made more nearly level by deposits of alluvium. On the ridges the steepness of the slopes is determined by the attitude of the rock layers composing them, many slopes conforming closely to the dip of the underlying rocks.

The gorges that have been cut by the streams directly across several of the ridges constitute the second physiographic type, the most striking example being the gorge cut by Yakima River through Atanum Ridge at Union Gap. Farther north, beyond the limits of the area (Pl. I), the Yakima crosses Selah and Umptanum ridges in a similar manner. Another great gorge has been cut through basaltic layers by Columbia River at Sentinel Bluffs, and a much smaller one near the mouth of Alder Creek, on the southern border of the Horse Heaven Plateau. The cutting of these gorges is most satisfactorily explained on the assumption that the courses of the streams were determined before the uplift of the ridges began, and were maintained as the ridges rose. This assumption is further corroborated by the fact that in a number of places the main drainage lines cross the major topographic depressions, instead of following them, as would be expected.

RELIEF.

The northeastern part of the area shown on the reconnaissance map (Pl. I) lies within the wide, rolling, sagebrush-covered region known as the Great Plains of the Columbia. These plains extend northward and eastward to the Okanogan Highlands, a hilly region in the northeastern part of the State, and westward, as an area of gradually rising ridges and valleys, to the Cascade Range. This range extends from north to south through the State somewhat west of its center, rising in the main to elevations of 4,000 to 7,000 feet, though several volcanic peaks attain heights exceeding 10,000 feet. The two most prominent summits, Mounts Rainier and Adams, are visible from nearly all parts of the plains region. In the southern part of the country between Yakima and Columbia rivers lies the higher region known as the Horse Heaven Plateau. This plateau is bounded on the north by a prominent bluff from which the surface slopes gently southward to lower bluffs along Columbia River, on its southern border. On the west its altitude, like that of the lower plains, gradually increases to the timbered slopes of the Cascades. On the south, across Columbia River, the country also rises to a greater height than the plains and it continues as a rolling plateau dissected by deep canyons far southward to the base of the Blue Mountains.

In the western portion of the area two ridges extend from the slopes of the Cascades eastward into the plains. Atanum Ridge, the northern ridge, rises 1,000 or 1,500 feet above the valley land on each side. Its continuity is interrupted by Union Gap, through which Yakima River passes southward, and about 5 miles to the east by a depression that leaves it only about 100 feet above the valley land on the north. Farther east, however, it rises to join a higher and broader ridge, over 3,000 feet high, known as Rattlesnake Ridge.

About 15 miles south of Atanum Ridge a similar long elevation, known as Toppenish Ridge, terminates before it reaches Yakima River, but it apparently reappears on the east side of the stream as a lower ridge known as Snipes Mountain.

DRAINAGE.

COLUMBIA RIVER.

Columbia River, the master stream of the State, flows through the eastern and southern parts of the area. Although its grade in some parts of its course is only 8 inches to the mile, the great volume of water that it carries gives it a considerable current. At Coyote Rapids and at Priest Rapids outcropping basalt beds give it a much steeper grade and a swifter flow, though not enough to prevent river steamers from ascending Coyote Rapids and proceeding to the foot of Priest Rapids. The annual change in the level of the river is said to be about 17 feet at White Bluffs. Gage readings at Pasco during 1906 showed a change in level of 13.8 feet at that station, the river being highest in the middle of June and lowest about the middle of January.[1] Its principal tributaries are Snake River, which joins it from the east, and Yakima River, which enters it from the west, a few miles above the mouth of the Snake. Along its south side it receives Walla Walla, Umatilla, and Greys rivers, three smaller streams that drain portions of the country south and southeast of the area considered in this paper.

YAKIMA RIVER.

The most useful stream in this region for irrigation is Yakima River, which flows in a general southeasterly course along the western border of the plains. Unlike many streams of arid regions, the Yakima is not subject to many serious floods, for its flow is to a large extent regulated by lakes near its source and by the well-timbered slopes of the Cascade Mountains. Its flow varies between wide limits, however, the maximum discharge at Union Gap having been about 26,250 second-feet in June, 1903, and 14,700 second-feet in June, 1905; and the minimum 820 and 795 second-feet in August to September of the same two years, which were years of unusually high and low stages. Highest water occurs usually during May and June and lowest during September. Much of the summer flow is utilized in irrigation, and during the irrigation season the normal discharge is greatly diminished below the intakes of the ditches.

The principal tributaries along the lower course of Yakima River are Toppenish Creek, which enters it from the Reservation Valley, and Satus Creek, which flows from the gently rising rocky slopes south of Toppenish Ridge. Toppenish Creek has its source in the wooded slopes west of Fort Simcoe and flows for most of its course in a gravelly channel through the flat valley eastward to the Yakima. Satus Creek also rises in the higher western area, but its several branches flow for the greater part of their courses in rocky gorges in the basaltic slope that rises southwestward toward the Cascades. Nearly all the other streams shown on the reconnaissance map (Pl. I) are intermittent and even in winter carry little water. Several of these watercourses are in wide canyons known as coulees, which are considered to be channels that were cut by streams of considerable size during an earlier period of greater stream flow.

[1] Stevens, J. C., Follansbee, Robert, and La Rue, E. C., Surface water supply of the north Pacific coast drainage for 1906: Water-Supply Paper U. S. Geol. Survey No. 214, 1908, p. 19.

GEOLOGY.

STRATIGRAPHY.

The stratigraphy of the region is simple, the entire area being underlain by the Yakima basalt, more than 2,500 feet thick, overlying which in places is the Ellensburg formation. Except for surficial alluvium, wind-borne soil, etc., all the deposits of the region belong to one or the other of these two formations.

YAKIMA BASALT.

All the country traversed during the field work for this report is underlain by basalt that forms a part of the vast series of effusive materials known as the Columbia River basalt. These lavas cover a great part of southern Washington, eastern Oregon, and adjacent parts of Idaho, Nevada, and California. Basalt that belongs to this series underlies nearly all of the southern part of Washington and constitutes the surface material over much of it. In the area covered by the present report it is known as the Yakima basalt, this name having been adopted [1] in preference to the more general name Columbia River basalt,[2] which includes rhyolites, andesites, and basalts of earlier and also of later periods of effusion than the main flows to which the Yakima basalt belongs. The latter has been determined to be of early and middle Miocene age by fossils that have been found in sedimentary beds interbedded with the lavas and exposed along the canyons of Columbia and Snake rivers and in a few other localities. Of the character of this rock, Smith [3] says:

> As seen in Yakima County, the basalt is a black rock, compact and heavy. On the weathered surface it is often of a brownish color, but wherever exposed it is dark, and the appearance of the ridges is dull and somber, unrelieved by even the desert vegetation. In a few places, where the residual soil can be found unmixed with alluvial or other foreign matter, it is of a bright-red color.
>
> The most noticeable feature of the black rock is the columnar parting by which the black sheets of lava are broken up into long colonnades. In some localities these columns are prismatic, with sharp edges and even sides, the prisms being often so regular as to suggest the work of human hands. This parting is the result of contraction or shrinkage of the solidified lava as the rock mass gradually cooled. The presence of these joint cracks is important, because they afford passages for water in a rock relatively impervious. It therefore is interesting to note the presence or absence of the jointing of the basalt where it is exposed, and such observations have their bearing upon the discussion of the course of the underground waters.
>
> The basalt of certain flows has extremely rough and scoriaceous surfaces due to small cellular cavities which were formed by the steam in the molten rock and which greatly alter its appearance. These varieties, which tell so graphically the story of the lava eruptions, are less common than the compact basalt. Fine and coarse tuffs, or so-called ash beds, are found at a few horizons in the basalt series, but such beds are insignificant when compared with the thicker and more common lava sheets.

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[1] Smith, George Otis, Ellensburg folio (No. 86), Geol. Atlas U. S., U. S. Geol. Survey, 1903, p. 3.

[2] Smith, George Otis, Geology and water resources of a portion of Yakima County, Wash.: Water-Supply Paper U. S. Geol. Survey No. 55, 1901, p. 15.

[3] Idem, p. 16.

MAP OF SOUTH-CENTRAL WASHINGTON

SHOWING LOCATIONS OF WELLS AND SPRINGS AND APPROXIMATE EXTENT OF GEOLOGIC FORMATIONS

Base from reconnaissance map, Northern Transcontinental Survey, by R. W. Gordon
Detail maps by U. S. Geological Survey and U. S. Reclamation Service

MAP OF SOUTH-CENTRAL WASHINGTON

SHOWING LOCATIONS OF WELLS AND SPRINGS AND APPROXIMATE EXTENT OF GEOLOGIC FORMATIONS

ELLENSBURG FORMATION.

Over a considerable part of the area sedimentary beds of Miocene age were deposited directly upon the basalt in formerly existing lakes. These beds consist of soft shales, sandstones, and conglomerates, together with unconsolidated sand and gravel. The material formerly covered a greater area than it now does, but it has been washed away from much of the higher lands so that on many slopes only thin patches or scattered pebbles remain. On the lower lands this formation is mostly hidden by stream wash, beneath which it is exposed in a few places along streams and irrigation canals. One of its most extensive exposures is in White Bluffs, along the east side of Columbia River, where nearly 600 feet of sediments is to be seen. At the north end of these bluffs Calkins [1] measured a section 225 feet in thickness, consisting of alternating sandstones, sands, and clays. Another extensive exposure of this material along Naches River, measured by Calkins,[2] shows a thickness of 1,569.5 feet. The deposits are of coarser texture than those at White Bluffs, layers of conglomerate being common and a greater amount of tuffaceous material being present. This difference is doubtless due to the fact that the Naches River locality is much nearer to the original source of the material than the White Bluffs locality.

In many localities outside of the main areas now covered by these bedded materials remnants of them persist, and in some places within those areas the sediments are very thin or are in large part obscured by alluvium. Near Kiona River gravel and wind-blown sand conceal the Ellensburg sediments, if any are present. Farther east, in the vicinity of Kennewick and Pasco, the margin of the formation is obscured by the gravel wash of Columbia River. The extent of territory now covered by the Ellensburg formation is therefore indefinite and can be shown only approximately on the map (Pl. I).

The only definite exposure of the Ellensburg seen in the southeastern part of the region is about 2 miles east of Prosser, where a quarry has been opened in a thick-bedded gray pumiceous sandstone. The record of a well at Pasco, given by Russell,[3] shows 72 feet of sand, 200 feet of Ellensburg formation, and 330 feet of lava to the bottom of the well.

The following section of the rocks exposed in sec. 1, T. 9 N., R. 19 E., was measured by Max A. Pishel, who gathered some additional data on the stratigraphy and structure of the rocks in the

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[1] Calkins, F. C., Geology and water resources of a portion of east-central Washington: Water-Supply Paper U. S. Geol. Survey No. 118, 1905, pp. 35-36.

[2] Water-Supply Paper U. S. Geol. Survey No. 55, 1901, pp. 17-21; Ellensburg folio (No. 86), Geol. Atlas U. S., U. S. Geol. Survey, 1903.

[3] Russell, I. C., A geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, p. 39.

Yakima Indian Reservation in 1912 and made some observations that are incorporated in this report:

Section of rocks exposed in sec. 1, T. 9 N., R. 19 E.

	Feet.
Conglomerate; the upper half consists of an equal amount of coarse sand and gravel, the pebbles of which are largely andesites, porphyries, and quartzites; the lower half is largely conglomerate	86
Volcanic ash, in appearance resembling chalk	5
Shale	45±
Basalt	10–15
Shale, sandy near top, with fossil bones; lower part has the appearance of fuller's earth	200
Basalt	2,000+

In a general way this columnar section resembles the one measured in the Naches Valley by F. C. Calkins,[1] but it exhibits marked differences in detail. On the whole, that part of the formation below the basalt sheet and the conglomerate above it appear to increase in thickness toward the south.

The beds of volcanic ash and shale, 200 feet thick, just above the heavy body of basalt compose the lower member of the Ellensburg formation. This member was measured by Mr. Pishel in sec. 26, T. 8 N., R. 20 E., where he found it to be about 175 feet thick, although the contact above and below was somewhat obscured. Good exposures were found in sec. 22, T. 12 N., R. 18 E., and along the Toppenish Ridge from sec. 1, T. 9 N., R. 19 E., eastward, where it almost completely overlaps the ridge and forms its highest points. Thick beds were traced westward from the last-named locality for about 10 miles along the north flank of the ridge, where they outcrop about 700 feet above the valley floor. To the south they can be traced across the Satus Valley to the north flank of Horse Heaven Ridge. The road running from the mouth of Logy Creek south to Bickleton forms practically the western boundary of this lower member of the Ellensburg formation. The sheet of basalt at the top of this member, the outcrops of which have just been discussed, can not be traced into nor connected with the Wenas basalt described in the Ellensburg folio. Nevertheless the conviction remains strong that it is one and the same sheet and is as persistent in its continuity as the shale and volcanic-ash member underneath. In fact, it is this layer which protects these softer sediments from erosion, and wherever one is found the other as a rule is also present. The conglomerate bed above this basalt is fairly persistent, but was measured only in sec. 1, T. 9 N., R. 19 E., where it attains a thickness of 86 feet, inclusive of the irregularly bedded layers of sand and seams of tuff. Good exposures, 20 feet or more in thickness, were noted in

[1] Op. cit, pp. 35–36.

sec. 30, T. 12 N., R. 18 E.; sec. 6, T. 9 N., R. 21 E.; and sec. 18, T. 8 N., R. 22 E. At these outcrops the bed had not the appearance of a local deposit but rather that of an extended bed. Scattered pebbles of the conglomerate were found in a number of places over the east half of the Yakima Indian Reservation. It is Mr. Pishel's opinion that the red quartzite pebbles, so numerous in the neighborhood of Bickleton and 4 miles to the east and west of that place, are remnants of this conglomerate bed, and that this member originally extended over the ridge a few miles to the north. The exposures in this particular field do not reveal the type of rock that lies immediately above the conglomerate, as the outcrops of that part of the Ellensburg formation are rare in the Reservation Valley, but according to the log of a well sunk very near the middle of the valley the beds above this conglomerate consist largely of shale and sandstone. There is very little doubt, therefore, that the rocks discussed above underlie that part of the Reservation Valley extending from White Swan eastward and also the western part of Sunnyside Valley.

SURFICIAL DEPOSITS.

Besides the wide areas of alluvial valley land belts of gravelly land and of fine-grained alluvial deposits lie along the streams. Yakima River for much of its course between Union Gap and Prosser and also near its mouth flows in a wide gravelly channel that in summer is mainly a cobble-covered waste. Along Columbia River similar wide gravelly lowlands are overflowed during high water but are dry and barren for much of the year. On the west side of the Columbia, above the town of White Bluffs, this gravelly flat has a width of a mile or more. Terraces of similar coarse gravel lie farther southwest toward the Gable Hills.

A few bowlders of granitic rock are scattered over the valley alluvium and also over some parts of the higher lands. These bowlders appear to be erratics brought down during the glacial epoch from the mountains that lie to the northwest.

WATER IN FORMATIONS.

The basalt of this region will not yield much water except where it is jointed or porous. Its principal alkali constituents, such as sodium, potassium, and magnesium, are so combined with silicates as to make them almost insoluble. Therefore water encountered in this rock, unless it has percolated through strata from which it derived soluble minerals before it entered the basalt, will probably be comparatively free from alkali. In general, it can be said that neither basalt nor any other igneous rock is a good water carrier.

Shale and similar sediments found at several horizons in the Ellensburg formation consist of more or less consolidated mud. Such shale is very impervious and does not permit the ready passage of water. Sand, on the other hand, will absorb water readily and permit its free percolation and is therefore an excellent water carrier. When a flowing well with heavy pressure ends in fine loose sand, however, much of it will be carried through the pipe and is likely to cut out the well casing in a comparatively short time. The shale and sandstone in the Ellensburg formation consist largely of volcanic material which is easily disintegrated and attacked by solutions, so that water seeping through a sandy shale or fine sandy volcanic ash will leach out the soluble potassium, sodium, and magnesium compounds and thus become alkaline. For that reason the water obtained from wells, especially shallow dug wells, in the Ellensburg formation is more or less alkaline.

Conglomerate or gravel will transmit water freely and consists largely of almost insoluble material which will not contribute much mineral matter to the water.

GEOLOGIC STRUCTURE.

DEFORMATION.

The sheets of lava that cover southern Washington and thousands of square miles to the east and south originally flowed out as nearly horizontal layers. Upon them were deposited the sediments of the Ellensburg formation also in nearly horizontal layers. Since the deposition of the sediments geologic forces have deformed the whole series of rocks, so that they now constitute mountain ridges separated by wide, flat valleys. In southern Washington these ridges for the most part extend eastward from the higher slopes of the Cascade Range.

There are two such long ridges in the area examined—Atanum Ridge and its eastern continuation Rattlesnake Ridge and Toppenish Ridge and its prolongation Snipes Mountain. Southeast of Toppenish Ridge a third and wider uplifted mass forms the Horse Heaven Plateau.

Russell made several trips through southern Oregon, where the rocks are also of effusive origin, belonging to the Columbia River basalt. In that region they have been broken and tilted to form great blocklike ridges with a steep slope on one side and a gentle slope on the other, having what is known as basin-range structure. In his reconnaissance through central Washington, Russell [1] considered that the ridges of that area also had been produced in large part by the faulting and tilting of great blocks. Detailed study in the Ellensburg

[1] Russell, I. C., A reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, pp. 28, 38, 40, 43.

quadrangle,[1] however, has led to the belief that sharp folding into unsymmetrical anticlines, rather than faulting, has produced the form of structure common in southern Washington.

ATANUM AND RATTLESNAKE RIDGES.

The structure of Atanum Ridge has been described by Smith,[2] who speaks of it as a broad arch with a gentle southern slope and a steep northern front. On its north side the dip is nearly vertical, and near Yakima River the beds are overturned for short distances. About 5 miles east of the river the ridge pitches downward to an elevation only about 100 feet above the floor of the Moxee Valley; but farther east it rises again and forms Rattlesnake Ridge. This mountain was considered by Russell to be an uplifted block, faulted along its north side. It seems, however, like the other ridges of this region, to be more probably an unsymmetrical anticline that has a much steeper dip on its north side than on its south side. Its east end swings farther to the southeast, descends to the level of the plains, and affords a low place for the passage of Yakima River a few miles above its mouth; but on the other side of the river the structural feature continues southeastward in low hills that parallel the lower course of the Yakima at the distance of a few miles. North of Rattlesnake Ridge four low isolated ridges, known as the Gable Hills, rise from the level plain. The basalt layers that compose these ridges dip northward at an angle of about 10°. These ridges appear to be the eastern extension of those which form the bluffs near Priest Rapids and to be remnants of a minor fold between Rattlesnake Ridge and Saddle Mountain, which lies north of Columbia River.

TOPPENISH RIDGE AND SNIPES MOUNTAIN.

Toppenish Ridge, called Satas Ridge by Russell,[3] seems also to be an unsymmetrical anticline or, as he terms it, a monoclinal fold. On its north side the steep attitude of the rocks has aided in causing great landslides. Two of these, named by Russell the Simcoe and Toppenish slides, are conspicuous. At the base of the former, which is about 25 miles west of Alfalfa, the débris has been piled up on the plain below and forms typical hummocky landslide topography, in which there are three small lakes. The Toppenish slide, which is near the east end of Toppenish Ridge and is plainly visible from the railroad, has left a great scar on the hillside, but the material has not been piled up at the foot of the slope so conspicuously as at the larger slide.

Snipes Mountain lies on the east side of Yakima River, in line with Toppenish Ridge, and is very probably a continuation of that struc-

[1] Smith, George Otis, Ellensburg folio (No. 86), Geol. Atlas U. S., U. S. Geol. Survey, 1903.
[2] Idem, p. 5.
[3] Russell, I. C., A reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, p. 45.

tural feature. It is almost entirely covered with gravel of the Ellensburg formation, which in a quarry near its southeast side dips about 10° S. In places along its crest basalt bowlders indicate the composition of the core of the mountain, and near its west end a slight depression exposes the basaltic core.

HORSE HEAVEN PLATEAU.

The Horse Heaven Plateau, which lies south of Yakima River, between the Columbia and the Yakima, and extends westward to the Cascade Mountains, has the characteristics of a great unsymmetrical anticline, with gentle south and steep northern slope. Along its northern border its edge is in some places slightly upturned, like the edge of a saucer, and in its northwestern part the bluffs on its north face are so steep as to suggest faulting. However, although no reliable northward dips were seen, owing largely perhaps to the covering of soil and talus, the structure as a whole appears to be due to sharp folding rather than to faulting. Still, in hard, much-fractured rock like the basalt of this region, it is often difficult to distinguish between these two types of deformation, and it may be that actual breaking and slipping has taken place along the steeper portions of the scarp in the vicinity of Prosser. The structure as interpreted is shown in the geologic cross section through this plateau and the plains to the north. (See Pl. I.)

Within the Horse Heaven Plateau there are several minor folds, of which perhaps the most important is the shallow syncline that probably determined the course of Glade Creek, a wide coulee-like drainage channel that is dry during the summer throughout most of its length. Cove Creek, in the southwestern part of the plateau, is a similar wide drainage channel that also probably occupies a shallow structural trough. Other dry channels join these two major drainage lines, but most of them seem to be of erosional and not of structural origin and to be the work of streams during an earlier period of greater precipitation and run-off.

Along the right bank of Columbia River, for several miles west of Carley, on the south edge of the plateau, an anticlinal ridge has been uplifted, across which Alder Creek has cut a gorge to the river. A few other minor irregularities mark the surface of the Horse Heaven region, but in the main it is a plateau surface that forms the southern slope of a great unsymmetrical anticline.

COLUMBIA RIVER PLAINS.

West of Columbia River, between the mouth of Yakima River and Priest Rapids, the basalt layers are in general deeply buried beneath the Ellensburg formation, so that the surface presents few features of relief. The only notable feature of structural origin is the line of ridges west of White Bluffs known as the Gable Hills, which are probably remnants of a minor fold between the anticlinal Rattlesnake Ridge and Saddle Mountain. East of the Columbia the surface rises to a plateau 600 or 800 feet higher than the plains west of the river, but the attitude of the basalts, where they lie beneath the Ellensburg sediments, indicates only slight folding.

GEOLOGIC HISTORY.

During the Tertiary period great outpourings of lava spread over many thousands of square miles in eastern Oregon and Washington and adjacent areas in Idaho and California. These lava flows changed the pre-existing surface, which was probably one of much irregularity, into a great undulating plain. Upon this plain, in undrained depressions, lakes came into existence into which thick deposits of sand and mud, together with volcanic dust and fragmental material, were washed by streams or blown by wind from the surrounding area and were laid down directly upon the lava surface. A period of deformation followed, during which the rocks were more or less folded along lines running in general from east to west by forces that were subsidiary to those which uplifted the Cascade Range. Later the early lakes were drained and the present major features of relief were given to the country. Still later, during the glacial epoch, ice lobes or perhaps drift ice floating in the glacial lakes strewed the region with bowlders of foreign material brought down from the lands to the northwest. That the glacial lakes were not of great extent nor of long duration seems to be shown by the fact that little lacustrine material of later date was deposited upon the earlier lake beds, the glacial bowlders lying directly upon the earlier deposits. Since glacial time, however, the streams have brought down alluvium from the higher lands and have covered much of the earlier sediment in the valleys.

WATER RESOURCES.

SUNNYSIDE VALLEY.

IRRIGATION.

Sunnyside canal.—The Sunnyside canal, by which the Sunnyside Valley is irrigated, is the largest in the State, having a capacity of over 600 second-feet. Under it lie about 64,000 acres of land, about 40,000 of which were irrigated in 1907. The intake of the canal is on the east bank of Yakima River, just below Union Gap. In 1907 the total length of the main trunk canal was about 63 miles and of the Snipes Mountain, Rocky Ford, and other main laterals 210 miles.

The construction of the canal was undertaken in the early nineties by the Northern Pacific, Yakima & Kittitas Irrigation Co. Owing to financial difficulties the canal was purchased by the Washington Irrigation Co., which operated it until it was taken over by the Reclamation Service in 1906. The Government land under the canal is subject to entry under the terms of the homestead act, modified by the reclamation law. Some lands under the canal were in 1907 still controlled by the Washington Irrigation Co. Of the cost of this deeded land S. O. Jayne,[1] of the Department of Agriculture, says:

The Washington Irrigation Co. formerly owned the odd sections of land under the canal. The land has been sold with water rights for from $35 to $90 per acre. For a number of years, however, the price of most of the land has been $60, while only that near Prosser was held at $90.

Water rights for several years past have sold for $30 per acre, and considerable water has been rented for nonwater-right land at $2.50 per acre per year. There has been a uniform maintenance fee of $1 per acre on nearly all water-right lands, but a few sales were made in the early days of the company with a 50-cent maintenance fee.

Regarding the distribution of water [2] the same author states:

One hundred and fifty to two hundred diversions are made from the canal. These diversions range in amount from 1 cubic foot per second or less up to 15 or 20 cubic feet per second and supply laterals from a quarter of a mile to 10 or 12 miles long. These laterals in general follow crests or ridges or elevations, roughly at right angles to the main canal. The farms average about 20 acres, and in most instances each farm receives from the laterals an individual delivery of water, for the measurement of which in most cases weir boxes with adjustable gates have been supplied at the company's expense. Many of the laterals in this way supply water to from five to thirty different farms. The Snipes Mountain lateral, over 12 miles in length, with a number of large sublaterals, constitutes a system larger than that of many independent canals of the valley.

Reclamation project.—In the irrigation of the cultivable land in this part of southern Washington the Sunnyside district is a unit in the general plan of the United States Reclamation Service known as the Yakima project. Ample water supply is assured by storage reservoirs on the headwaters of Yakima River and its tributaries, and the Sunnyside canal and its laterals are being improved and extended so as to supply a total area of about 100,000 acres in this subproject. The irrigation of some 10,000 acres of land that lies on the south side of Yakima River, in the neighborhood of Mabton and Prosser, involves the use of an inverted siphon across this stream.

A higher canal has been considered, which would be able to supply much land that lies along the base of Rattlesnake Ridge above the level of the present canal. Later plans, however, have contemplated the establishment of pumping stations that will lift water from the main canal to these higher lands.

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[1] Jayne, S. O., Irrigation in the Yakima Valley, Wash.: Bull. Office Exper. Sta. No. 188, U. S. Dept. Agr., 1907, p. 32.

[2] Idem, p. 45.

UNDERGROUND WATER.

Shallow wells.—Water for domestic use is obtained throughout the Sunnyside district from wells sunk in the Ellensburg formation to a depth usually of only 50 to 60 feet. Water is found at shallower depths, but as it is alkaline the upper water-bearing strata are cased off in the better wells and the deeper water of better quality is tapped. As irrigating water is supplied by the canal, these wells are drawn on only for domestic use.

The remarkable rise in the ground-water level caused by irrigation is shown by the following table showing the level in wells near Sunnyside:

Water level in wells near Sunnyside, Wash.[a]

Well.	Date of digging.	Depth to water when dug.	Depth to water in 1902.
		Feet.	*Feet.*
No. 1	1890	80	5.0
No. 2	1900	90	20.0
No. 3	1899	42	0.0
No. 4	1892	54	4.0
No. 5	1894	50	3.5
No. 6	1893	53	0.0
No. 7	1900	15	1.0
No. 8	1899	40	6.0
No. 9	1898	53	15.0

[a] Jayne, S. O., op. cit., p. 86.

It is said that between 1900 and 1908 the water plane rose in general about 25 feet throughout the Sunnyside Valley.

Artesian conditions.—The possibility of obtaining flowing wells in Sunnyside Valley in lands above the Sunnyside canal has been much discussed locally, and a few attempts have been made to raise funds to sink a test well. In its general features the Sunnyside region resembles the Moxee Valley, which lies about 25 miles northwest of Sunnyside, beyond Rattlesnake Ridge. In the Moxee Valley a number of flowing wells have been obtained in the sedimentary beds of the Ellensburg formation, and have proved of great value for irrigating high lands, and it is argued that flows should also be obtainable in the Sunnyside Valley.

There are, however, a number of important differences between the Moxee and Sunnyside valleys. The Moxee basin has been shown by Smith [1] to have the trough shape essential to artesian structure,[2] and along its sides the beds of the Ellensburg formation seem to have

[1] Smith, George Otis, Geology and water resources of a portion of Yakima County, Wash.: Water-Supply Paper U. S. Geol. Survey No. 55, 1901, pp. 40–42.

[2] Many years ago the term "artesian" was applied only to water under sufficient pressure to yield flowing wells when properly tapped; but of late the word has come to be applied to wells in which the water rises appreciably, whether it flows or not, the term "flowing" being used to designate those wells in which water rises to the surface and overflows.

been so compressed by the uplift of the bordering ridges as to have become nearly impervious to leakage, and hence to prevent the drainage of the underground basin where the edges of the beds are cut by Yakima River. The Ellensburg formation is 1,000 feet or more thick in the locality in which the successful wells have been obtained, but to the east it thins out rapidly. The flowing wells have been obtained where the surface is at an elevation of less than 1,200 feet, and deep borings on the higher slopes of the Moxee basin have not been successful in obtaining artesian flows. The Sunnyside Valley, on the other hand, although a structural basin, is comparatively shallow, and the lower part of the Ellensburg formation, containing the best water-carrying strata, is probably not buried deeply enough to confine the water effectually over the largest part of this valley. Structurally, the portions of the Yakima Valley between Rattlesnake Ridge and the northern border of Horse Heaven Plateau form a great unsymmetrical syncline with a cross fold—Snipes Mountain—a continuation of the Toppenish Ridge anticline, crossing it from east to west just south of Sunnyside. The Toppenish Ridge anticline pitches eastward until it reaches Yakima River, then rises again in the neighborhood of Snipes Mountain. Eastward from that locality it flattens and is lost in the broad bottom of this great unsymmetrical syncline. The rise of this subordinate anticlinal axis in the neighborhood of Snipes Mountain probably means a corresponding rise of the synclinal fold to the north of it. If this is true, a structural basin forming favorable artesian conditions exists from Granger westward. Thus it may be that small flows of artesian water will be obtained in the neighborhood of Outlook. Farther west these conditions apparently become more favorable, so that the part of the Sunnyside Valley in which wells that may possibly flow can be obtained is roughly bounded by straight lines joining the towns of Granger, Zillah, and Outlook. Flowing wells would be of value as a source of pure domestic water in this locality, and as the cost of a test well would be comparatively small, the attempt to obtain better drinking water by such means is thought to be well worth trying.

The Ellensburg formation in the area lying north of the Sunnyside canal is very shallow and dips gently southward, so that it is highly improbable that flowing wells will ever be obtained here. As the water-bearing strata are comparatively thin from Outlook eastward and the rock basin is probably not closed in that direction, it is not to be expected that artesian flows can be obtained there.

South of Snipes Mountain lies the southernmost of the two troughs into which that mountain and Toppenish Ridge divide the main syncline which extends from Rattlesnake Mountain to the Horse Heaven rim. The axis of this fold extends southeastward from the vicinity of Satus, practically paralleling Yakima River. It is not closed toward the east, but the bottom of the basin rises until above Prosser the basalt emerges from beneath the Ellensburg sediments. Although these conditions are not favorable to the confinement of the deep waters under the pressure necessary to maintain artesian flows, the basin is worth prospecting, as in some parts of the United States local conditions are such that flowing wells are obtained even in open synclinal basins of this character, and it is possible that similar conditions exist here. The possibility of obtaining artesian water is greatest along the bottom of the basin and decreases toward the sides. It is therefore more probable that flowing wells will be struck in a strip of land a mile wide just north of Satus and running southeastward along the north side of Yakima River than elsewhere in this basin.

Thus far flowing water has been found in south-central Washington only in the sands and gravels of the Ellensburg formation; but the question has been raised whether flowing wells might not be obtained from the basaltic rock that underlies these unconsolidated deposits. Few tuffaceous layers that might act as water-bearing beds seem to be interbedded with the basalts, and though it is probably true that water exists in the more porous "honeycombed" portions of the basalt, these more porous beds are believed to be irregular and of uncertain occurrence. Even if water-bearing beds were known to be associated with the basalts that underlie the Sunnyside basin, it is doubtful if flowing wells could be obtained from them, for the syncline is open toward the east, and so probably permits the escape of the deep-seated water in this direction.

Several springs break forth along the slopes of Rattlesnake Ridge and these have led to a popular belief that an abundant supply of water underlies the upper lands. Some of these springs are of surface origin and rise in ravines where seepage water from the surface soil collects. Others are probably supplied by water that collects in local structural folds or in remnants of the Ellensburg formation and breaks out farther down the slopes, wherever escape is possible. A spring that was opened by Mr. Nicolai in November, 1907, near the summit of the ridge, about 10 miles north of Sunnyside, is believed to be of such character. This spring was said to have discharged three-fourths of a second-foot of water at a temperature of 66° F. during the first few weeks after it was opened.

RESERVATION VALLEY.

IRRIGATION.

Toppenish Creek furnished water for some irrigation along its lower course, and three Government canals, constructed by the Indian Office, divert water from Yakima River below Union Gap and irrigated about 40,000 acres on the Yakima Indian Reservation in 1911.

The adequate irrigation of the Reservation Valley, like that of the Sunnyside region, is provided for by a unit in the reclamation project that covers this part of southern Washington, the unit watering the Reservation Valley being known as the Wapato subproject.

UNDERGROUND WATER.

Good water can be obtained at shallow depths throughout Reservation Valley, though as the present settlement lies almost wholly along Toppenish Creek, the domestic supply is obtained directly from this stream. At the only well (No. 18) noted in the valley the water stood 16 feet below the surface in November, 1907.

ARTESIAN WATER.

Water derived from the collecting grounds in the mountains to the west saturates to a large extent the deposits of the Ellensburg formation in the Reservation Valley. This fact is recognized clearly by the ranchers in the western part of the basin, who have attempted to irrigate the area lying along the outcrop of the gravels of the lower part of the Ellensburg formation with water taken out of Toppenish Creek. Here they find it almost impossible to keep water on the land, as it drains away as fast as it is applied.

The Reservation Valley occupies an unsymmetrical synclinal basin whose steep side lies along the Toppenish Ridge. The axis or deepest part of the trough extends from Granger westward and runs about 1½ miles north of and almost parallel with the south edge of the valley. About 15 miles west of Granger it gradually swings northwestward and passes White Swan about a mile to the north. Dips and strikes of the Ellensburg strata observed along the south side of the basin—that is, along the north flank of Toppenish Ridge—vary from 40° to 90°, whereas the steepest dip noted along the south side of Atanum Ridge is 35°. The dips decrease toward the center of the basin and the bottom of the syncline is comparatively flat but has a slight inclination toward the south, so that the water-bearing gravels in the lowest part of the Ellensburg formation are possibly a thousand feet or more below the surface along the south branch of Toppenish Creek in the lower 19 miles of its course.

The area that is most favorable for flowing wells is bounded about as follows: From Granger northwestward almost parallel to Yakima River to the township line 2 miles north of Wapato, thence westward about 5 miles, thence gradually swinging southwestward to a point about 2 miles north of White Swan, thence curving south and southeast toward the center of T. 10 N., R. 17 E., thence east along the south branch of Toppenish Creek past Alfalfa to Yakima River. The limits in the western part of the basin are more uncertain.

In drilling within the area thus described it would be well to drill down to the Yakima basalt. The only way to be sure of reaching the basalt is to continue drilling until 50 feet or more of the igneous rock has been penetrated. This operation may not necessarily be without compensation, as it is possible to obtain flowing water even in basalt. So far as the writer knows, none of the wells heretofore drilled in this area have reached the gravels at the base of the Ellensburg formation, and it would be well for those who obtain only a small flow in the upper part of the Ellensburg to drill deeper, at least far enough to penetrate these coarse basal beds.

The region lying outside of the area above outlined must probably obtain its water supply from nonflowing wells or from irrigation ditches. Water can be reached in shallow wells at less depth along the stream courses than at a distance from them. As the shale of the Ellensburg formation lies very near the surface along the south side of Atanum Ridge north of the basin described, and as recent stream gravels are entirely absent, it is necessary for those who are attempting to develop local supplies in that area to sink wells deep enough to reach the water-carrying stratum of the Ellensburg formation. Some who have tried in vain to get water along this belt and have abandoned the attempt might well resume work with the expectation of striking such a stratum. At any rate, there is a probability of finding water in the gravel immediately above the Yakima basalt.

It may be argued that as Yakima River crosses the rim of the basin just west of Snipes Mountain at points approximating 670 feet above sea level, the artesian basin should be drained at about this level, and that therefore no flowing wells will be possible in the Reservation Valley. However, as the rocks along the side of the fold are very highly inclined, it is not impossible that here, as in the Atanum-Moxee basin, they are so compressed as to be relatively impervious along the south rim of the basin and thus prevent leakage. Another element that may favorably affect the chances of procuring artesian flows in the Reservation Valley is the probability that the porous beds of the Ellensburg formation become finer and less pervious toward the east away from their source in the mountains, so that water which enters freely along upper Toppenish Creek can escape eastward only with difficulty. Under these conditions of decreasing porosity of the aquifers and resulting increasing frictional resistance to percolation, pressures sufficient to give rise to artesian flows will exist, even though the artesian basin is not closed.

According to a report made by J. W. Martin, superintendent of irrigation at the Yakima Indian Reservation, two 4-inch wells sunk during the winter of 1911–12, in secs. 9 and 16, T. 11 N., R. 18 E., to a depth of about 200 feet struck a water stratum which produced small flows under very slight pressure, and an 8-inch well sunk in June, 1912, in sec. 34 of the same township, to a depth of 512 feet, struck a strong flow. The water from the well in sec. 34 is reported to have a slight taste of sulphur and to have a temperature of 68° F. The log of this well is as follows:

Log of flowing well in sec. 34, T. 11 N., R. 18 E.

	Feet.
Top soil	3
Coarse gravel	123
Bowlders	6
Clay	4
Sandstone	15
Bowlders and clay	14
Sandstone	90
Sand	4
Clay	50
Clay and sand	43
Sand	5
Loose shale (soft)	50
Yellow clay	15
Blue shale	40
Hard sandstone	6
Gravel	9
Shale	15
Sand; first small flow	5
Sand rock	6
Sand; second flow, heavier than first	4
Sand rock; gusher	5
	512

HORSE HEAVEN PLATEAU.

IRRIGATION.

Some years ago preliminary surveys were made for a canal that would take water from the upper part of Klickitat River and bring it to the Horse Heaven Plateau. In 1910 the construction of this canal was again being considered, but its excessive cost, owing to the distance which water would have to be brought and to the difficult character of the country to be traversed, and the lack of knowledge concerning the available water supply combine to render it improbable that it will be built. Many settlers who have anticipated the advent of irrigation by filing on land under the proposed canal hope to make a living by grain farming until water is brought in and orchards can be planted. If water can be obtained and applied to the Horse Heaven lands, the climate and soil will make this an excellent fruit-growing region.

DOMESTIC WATER SUPPLY.

General sources.—In the country near Bickleton water is obtained from dug wells, most of which are less than 50 feet in depth, and from deeper drilled wells. Along the ravines and canyons a few springs issue and in the coulees water is found within a few feet of the surface. Farther east water is much scarcer and less accessible. A few wells that have been drilled in the eastern portion of the plateau obtain a good supply at depths of 300 or 400 feet, but the cost of such a well, with pumping plant and storage tank, is so great that few ranchers can afford the expense.

A few springs rise along the course of Glade Creek and in other main drainage channels, from which many of the new settlers obtain water, but a number of them are obliged to go 15 miles or more to Yakima or Columbia River for their supply. Tank wagons holding 500 or 600 gallons are used almost exclusively in hauling the water. On a few ranches cisterns have been built, in which rain and snow are collected during the winter and stored to help out on the summer requirements. If a rancher has no cistern or other reservoir, he must either buy water from some neighbor who has one, the rate charged being about 75 cents for 1,000 gallons, or must usually go after a tankful every few days. During the harvest season, when many horses must be watered, the hauling of water is a large item of expense.

Springs.—The following springs (see Pl. I) in the Horse Heaven region are deserving of special mention:

At the house of Mr. B. Beckner, about 4 miles northeast of Bickleton, a spring of clear cold water (No. 8, Pl. I), which is essentially of surface origin, yields perhaps 9 or 10 gallons a minute. Its surplus flow forms a duck pond about 25 yards square. It has been bricked around and inclosed in a small spring house.

Cold Spring (No. 12), west of Dot post office, issues from the steep southern bank of the main drainage channel of the locality and flows between 50 and 100 gallons a minute. It has been used mainly as a watering place for cattle and sheep. Like the Beckner spring it seems to be of surface origin and it issues where a water-bearing bed is intersected by the side of the ravine.

McKinley Spring (No. 10) is an important source of supply to a number of the surrounding ranches. It consists of a pit dug and boarded in against a low bank in the wide drainage course of Glade Creek close to the channel. In the fall of 1907 no water was flowing from the reservoir or well thus formed, though a few pools stood in the stream channel near by. The amount collected from the underflow, however, is sufficient to furnish several barrels a day.

Badger Spring (No. 7), on the northeastern edge of the Horse Heaven Plateau, is similar to McKinley Spring in being a place where the underground flow in a ravine is reached. The water is collected in a rock-walled pit about 10 feet deep. The amount supplied during the summer is small.

Wells.—Most of the wells put down in this area are drilled with portable rigs. Although these outfits are not as powerful as the heavy standard drilling rigs and although they work very slowly in the hard basaltic rock, they are capable of drilling to depths of 1,500 feet or more. The usual diameter of the wells drilled is 6 inches. One or two feet a day is the best progress that can be made in some of the harder portions of the rock.

The following wells, which were the best known at the time of examination, are worthy of special mention:

The Hayden well (No. 31, Pl. I) is one of the wells of largest yield on the plateau. From it a 14-horsepower gasoline engine has pumped between 20,000 and 30,000 gallons a day during the summer, supplying water to most of the surrounding settlers. The well is 6 inches in diameter and was drilled to a depth of 496 feet. Water was struck at about 200 feet, but the main supply is found near the bottom of the well. This lower supply is said to have risen 200 feet above the depth at which it was struck, so that the pumping lift is about 300 feet. Basalt of different degrees of hardness was encountered below the surface layer of soil, the water coming from a honeycombed phase of the rock.

About 1½ miles southeast of the Hayden well there is a well (No. 30) that was drilled at the joint expense of Yakima County and the State to a depth of 630 feet. The water in it stands about 300 feet below the surface. During the summer a 12-horsepower gasoline engine has lifted an average of about 5,000 gallons a day from it.

A third important well (No. 43), which has supplied several ranchers, is that of Louis Anderson, at Horse Heaven post office. The first water was struck at 225 feet in this well, but the yield amounted to only about a barrel an hour. The main supply comes from a depth of 335 feet, and drilling was stopped 15 feet below this depth. During the harvest season fifteen to twenty 500-gallon tanks have been filled from it each day. The water has been pumped by a 5-horsepower engine and by a large windmill.

The Frances well (No. 32), which is 150 feet deep, struck water at about 100 feet. Its yield is greater than a 2-horsepower gasoline engine can exhaust, and it has supplied a few neighbors in addition to the ranch on which it is located, filling seven or eight 500-gallon tanks a day during the summer.

At the east end of the plateau A. H. Richards has drilled a 6-inch well (No. 50) to a depth of 1,100 feet. At 700 feet a small amount of water, estimated at 125 gallons an hour, was struck, but this was lost at 1,100 feet in shell rock (probably laminated basalt). Below the soil layer, which is 117 feet deep at this place, the material penetrated consisted of alternate layers of basalt 40 to 50 feet thick and softer material, possibly tuff.

In F. W. Sanderson's well (No. 54), about 6 miles east of Bickleton, a number of water-bearing layers or seams were encountered in drilling to a depth of 309 feet. Water was first struck at 45 feet, but a strong supply was not obtained, as a windmill has been able to pump it out. The red honeycombed rock from which the main water supply of this well is thought to come is exposed along the eastern wall of Spring Canyon, about a mile to the west. Water that was struck at a depth of 65 feet in this well is said to have risen within 15 feet of the surface. The well is situated a short distance south of a swale that seems to lie along the axis of a small syncline, and this structural feature possibly accounts for the pressure of the water in the underlying rocks and its consequent rise in the Sanderson well.

None of these wells are cased, as they penetrate solid rock for most of their depth, though in each one layers of "blue clay," probably tuffaceous beds, are said to have been penetrated. In nearly every well water was found in honeycombed basalt.

About 2 miles north of Bluelight a small flowing well (No. 37) is situated on the slope of a small drainage course on the ranch of L. Spencer, some distance above the bottom of Glade Creek coulee. Its depth is 96 feet; between 12 and 93 feet hard rock was penetrated, but the last 3 feet, from which the water comes, is softer. This well has a fountain head of nearly 6 feet, but yields only about 1½ gallons a minute. Little seasonal variation has been noted in its flow. The anomaly of this flowing artesian well on an upland slope seems best accounted for by the facts that to the south the surface rises 200 feet and that the underlying rocks dip toward the well, so that the pressure developed is sufficient to bring the water to the surface at this point. The small flow in comparison to the head of the well suggests that the supply is small or, what is more probable, that most of the water of the rock layer that has been tapped finds its way on downward to the underground drainage of Glade Creek.

Two flowing artesian wells near Carley, close to the border of the Horse Heaven Plateau, perhaps owe their existence to its structure. These wells are situated north of Columbia River, in Artesian Coulee (Carley's coulee), which seems at one time to have been a channel of the Columbia but is apparently silted up, so that the river now flows in a channel just south of a rocky hill. The eastern well (No. 65) was drilled 162 feet deep and 6 inches in diameter and is said to have a fountain head of 90 feet. In 1907 its water was conducted 45 yards through a galvanized pipe to a ditch 6 feet higher than the well. Into this ditch is discharged nearly a cubic foot of water each second, at a temperature of 74° F. This flow was led eastward and irrigated several fields of alfalfa in the coulee.

M. E. Carley has a similar well (No. 66) on his ranch. In it the main flow comes from a depth of 142 feet, though a smaller flow was struck at 128 feet. This well yielded 1½ second-feet during the first four weeks after it was sunk, but the flow lessened to about 1 second-foot. Its fountain head is said to be only about 5 feet.

Both of these flowing wells penetrate only loose gravel, sand, and clay. About halfway between them a well was drilled to a depth of more than 300 feet without striking an artesian flow. Bedrock was not reached even at this depth, but at about 200 feet mud was encountered of so fluid a character that it produced sufficient pressure to crush heavy casing.

About 3 miles east of Mr. Carley's well another unsuccessful well was drilled 420 feet, mainly through rock. Two other wells of less depth have been drilled on the northeastern edge of the coulee; but up to 1907 artesian flows had been obtained in Artesian Coulee only from the two wells first named.

The slopes of the Horse Heaven Plateau are the most evident source for the pressure of the water in Artesian Coulee. It is possible that water seeping down from this region collects in the silted-up river channel under the head requisite to yield the flowing wells. That only two wells have been successful in tapping such a supply indicates that the water-bearing beds are not continuous, but probably exist as lens-shaped masses of sand and gravel, interbedded with mud and clay.

Of the shallow wells in the Horse Heaven region two (Nos. 27 and 48) may be mentioned as typical. The former, the Amond well, dug in a small ravine, supplies only about 400 gallons a day in summer, at which season the water stands about 15 feet below the surface; in winter, however, it rises nearly to the surface. The other well, that of Don Creswell (No. 48), is also in a drainage channel, at a place formerly known as Cottonwood Spring. The group of trees from which the spring received its name still remains, but the well, 35 feet in depth, has seemingly appropriated the water supply. In 1906 this well went dry, but in the fall of 1907 it contained 15 feet of water and supplied 30 horses. Other shallow wells yielding small supplies of seepage ground water have been dug along the same drainage line, both above and below Cottonwood Spring.

Artesian conditions.—The conditions under which flowing artesian water is usually found have been fully discussed in several publications of the Geological Survey,[1] so the subject is not taken up here. The existence of water under sufficient pressure to yield flowing wells in areas that do not contain typical structural artesian basins nor alluvial artesian slopes has been discussed by Fuller,[2] who has cited examples of flowing wells in areas that do not have the usual structure of artesian basins. It is therefore evident that, although the Horse Heaven Plateau is not similar in character to areas in which the best flowing wells are obtained, the existence beneath it of water under

[1] Fuller, M. L., Water-Supply Papers No. 54, pp. 101–104; No. 78, pp. 10–14; No. 118, pp. 61–67; and Bull. No. 319.

[2] Fuller, M. L., Summary of the controlling factors of artesian flows: Bull. U. S. Geol. Survey No. 319, 1908.

sufficient artesian pressure to flow is not impossible; in fact, in nearly all the deep wells drilled in this region the water rose notably above the level at which it was struck. The question has therefore often been raised whether flowing artesian wells can not be obtained by drilling to greater depths. In partial answer to this question it may be said that although water in the underlying vesicular and tuffaceous phases of the basalt is under considerable pressure and rises in deep wells so as to reduce the cost of pumping very materially, in none of the wells does it rise close to the surface. Moreover, a sufficient number of wells have been drilled to show that it is very probable that flowing wells can not be obtained on the plateau. Any that may be developed, like that of Mr. Spencer (No. 37), will be due to an unusual combination of favorable conditions.

COLUMBIA RIVER PLAINS.

AREA EAST OF COLUMBIA RIVER.

The water conditions in the eastern part of the Columbia River Plains are similar to those in the Horse Heaven country. A few springs furnish small supplies, a few deep wells have been drilled in the higher lands, and shallow wells have been successful in obtaining water along the coulees, but a number of settlers haul their supply from Columbia River.

IRRIGATION.

During the fall of 1903 and the spring of 1904 a careful reconnaissance of the southern and eastern parts of Franklin County was made by the United States Reclamation Service in order to determine the feasibility of irrigating the area by water taken from Palouse River. This project contemplated the irrigation of lands between Columbia and Snake rivers and between Connell and Pasco. In 1910 no work beyond the reconnaissance had been done on this project, because of the doubtful feasibility of the construction of the main storage reservoir and the probable high cost per acre of the project, even if it could be successfully completed.

Only one small pumping plant along the Columbia was noticed. This was on a farm on the east bank of the stream a few miles below the mouth of the Yakima, where an engine and centrifugal pump lifted water to irrigate a few acres of alfalfa and garden.

UNDERGROUND WATERS.

On the plateau surrounding Eltopia a number of drilled wells draw domestic water supplies from seams or from honeycombed portions of the underlying basalt. Little ground water is found in the unconsolidated deposits of the Ellensburg formation.

In H. Wysong's well (No. 5) water was struck at a depth of about 340 feet and rose within 100 feet of the surface. About a mile farther east, in the well belonging to H. Meentz (No. 4), water was struck at 375 feet and rose about 50 feet. About a mile to the west, in Mrs. M. P. Jordan's well (No. 7), the water level is nearly 400 feet below the surface. Near the eastern base of the portion of the plateau which terminates in White Bluffs Joe Allen obtained an abundant supply of water in a well (No. 3) 42 feet deep, sunk into the basalt underlying the gravel of a flood-water channel. In the fall of 1907 Mr. Allen had a 3-horsepower gasoline engine and 3,000-gallon storage tank and supplied several neighbors.

In the lower lands north of Snake River wells dug in the deep gravel of coulees find a small supply of water. The porous character of the dry gravel in these old stream channels tends to produce breathing or blowing wells such as are found in a number of other places in the United States.[1] One such well that was visited (No. 26) is about 4 feet in diameter and 100 feet deep, in the bed of a shallow coulee. Nearly all the material passed through appeared to consist of rather loosely packed subangular pebbles, ranging from 1 to 3 inches in diameter. At the time the well was visited the barometer was falling and a strong current of air was rushing outward through the cracks of the board cover; this outrush continued with apparently undiminished force during the half hour spent at the place.

AREA WEST OF COLUMBIA RIVER.

RATTLESNAKE VALLEY.

Wells.—Several of the earlier settlers in the western part of Rattlesnake Valley put down drilled wells from which they pump water by windmills for irrigating small gardens as well as for domestic use. Information concerning the principal wells is given in the table on pages 44–45. Over most of the valley the soil is thin, as only remnants of the Ellensburg formation are left, and in drilling most of the material passed through is basalt.

Springs.—In the Rattlesnake Valley, as elsewhere through the plains region, the water supply is still derived largely from springs. The principal source of supply is Trough Spring (No. 3), which is situated in a small ravine where apparently an outcropping basalt layer brings ground water to the surface. A covered reservoir has been built in the ravine in which the flow of perhaps 8 or 10 gallons a minute is collected. From this reservoir water is hauled by the settlers in the usual tank wagons.

Several other surface springs issue along the higher slopes on the north side of the valley. In connection with their occurrence it is

[1] Condra, G. E., Geology and water resources of a portion of the Missouri River valley in northeastern Nebraska: Water-Supply Paper U. S. Geol. Survey No. 215, 1908, pp. 31–32.

interesting to note a dug well (No. 10), also on the north side, in which water was reached at a depth of 17 feet. The slope was sufficient to permit the owner to tunnel in from a point 40 or 50 yards down hill from the curb and lay a pipe to the bottom of the well. Thus he obtained flowing water, virtually a surface spring, in his barnyard. Water for the house has been obtained from the same well by wheel and bucket.

Barrel Spring (No. 2), on the northwest edge of Spring Valley, was the main source of supply for the settlers in the locality in the fall of 1907. At this spring, which issues at the base of a low bluff, a barrel had been sunk and the flow of about 5 gallons a minute was piped into two troughs. The overflow filled a small earthen reservoir that was used as a watering place for sheep. During the early part of 1908 O. G. Steward ran a tunnel into the hillside about 200 yards east of this spring and developed a small but constant flow of water. It is probable that in several other places along the sides of the valley water may be obtained from similar tunnels, but it is not likely that springs that will yield enough water for irrigation can be developed.

In the middle part of the course of Rattlesnake Creek, at the edge of the plains, Rattlesnake Spring (No. 1) issues along a steep-sided gully in the alluvium that floors the valley. It forms a stream having a fairly constant flow of 500 or 600 gallons a minute. The spring water is led through a ditch for about 2 miles southeastward to the ranch of E. F. Benson, where it is used to irrigate about 75 acres of alfalfa and 25 acres of potatoes and other garden vegetables. It also supplies domestic and stock needs, for a well is said to have been sunk to a depth of 105 feet at the ranch without striking water.

Two or three other springs that issue along the northern slope of Rattlesnake Ridge are used for irrigating small areas of alfalfa and vegetables.

The existence of these springs has been considered by the residents to indicate artesian conditions. They seem, however, to be more probably of surface origin and to be supplied by the rain and snow that collects on the slopes above. This water seeps down the hillsides and issues at places where fissures in the rocks and the attitude of the beds and their relation to the soil covering furnish favorable conditions. The rocks on the sides of Rattlesnake Valley have been folded and also probably much fractured in the process of uplift, so that many opportunities are given for ground water to reappear along the lower slopes.

COLD CREEK REGION.

Irrigation.—Among the recent settlers in the lands west of the Columbia there has been much talk of the projected Government high-line canal, which is expected to water nearly all of the land lying above the present irrigation works. It is possible to bring water to most of this arable land by a gravity canal, and in connection with the Yakima project of the Reclamation Service surveys for canals to supply this area have been made. Chiefly on account of the fact that a sufficient water supply is not available from the proposed source, however, the irrigation of these higher and more remote lands has been, at least for the present, abandoned, and attention has been given to the lower areas in Atanum, Reservation, and Sunnyside valleys, along Yakima River, and below Kiona, all of which can be more easily supplied.

The Benton subproject of the Reclamation Service originally contemplated the irrigation of about 210,000 acres in Benton County, of which 180,000 acres lies north of lower Yakima River and 30,000 acres south of that stream. The land south of the river can be reached by siphon. Water is to be diverted from Yakima River near Prosser and conducted by canal around the south end of Rattlesnake Ridge and along its eastern base.

During 1907 two private irrigation companies began the construction of works to irrigate land in the northwestern part of the plains along the Columbia by water pumped from the river into canals. These systems were intended to irrigate about 33,000 acres, cutting down by that amount the original area that was to be covered by the Benton subproject.

It is the intention to make this land along the Columbia mainly a fruit-growing district, as its mild climate and long frostless season are well adapted to this branch of farming.

Underground waters.—Few tests have yet been made for underground water in the plains area west of the Columbia. It is probable, however, that ground water can be obtained at relatively slight depths beneath most of it. In the gravelly land within a few miles of the river abundant water is reported near the surface. At the Hanford Hotel a dug well (No. 2, Pl. I) reached water at 43 feet. The depth of water in this well changes with the height of the river, at about whose level water was reached, and it is probable that seepage from the river supplies the well. About 2 miles south of White Bluffs two dug wells obtained water at a depth of about 90 feet. Near them a drilled well (No. 1) was sunk a few years ago, in search of flowing artesian water, to a depth reported to be about 400 feet. Water was reached at 67 feet, at about the level of the river, but no strata carrying water under pressure were found. The material penetrated below the river gravel was probably the Ellensburg formation, as hard rock was not encountered.

The Ellensburg formation probably underlies much of the gravel that covers the low-lying land west of the river, but there is little chance of finding flowing water in it; for although Rattlesnake Valley and the valley of upper Cold Creek are of synclinal structure and contain deposits of the Ellensburg formation, they are not so deeply nor so completely filled with this material as is the Moxee basin, in which flowing wells have been obtained. These valleys also open eastward to the broad plains region, beneath which the Ellensburg strata lie nearly horizontal, so that the collection of water in these beds under sufficient pressure to rise to the surface is rendered very improbable.

IRRIGATION ALONG LOWER YAKIMA RIVER.

Besides a number of small canals in the Moxee Valley, the canals of Reservation Valley, and the Sunnyside canal, a number of canals take water from the lower course of Yakima River. The following statements concerning these canals are condensed from a publication of the United States Department of Agriculture.[1]

The uppermost canal receives its supply from the river at Prosser, where the Prosser Falls Land & Irrigation Co. has built a concrete dam across the stream, raising the water level about 10 feet and giving a power head of nearly 12 feet. By means of turbines and cylinder pumps, water is lifted into a canal with two branches, one of which extends 8 miles southwestward along the bench land bordering the river; the other extends 3 miles in the opposite direction; together they supply about 1,300 acres. Water and electric light are also furnished to the town by this plant.

About 4 miles above Kiona, on the north bank of the river, is the intake of a canal that was formerly owned by the Northern Pacific Irrigation Co. In 1907 ownership was transferred to the Kiona Development Co. The canal is 9 or 10 miles long, and between April 1 and November 1 the amount of water carried by it is about 25 second-feet. It irrigates from 1,400 to 1,800 acres, but if it were extended it could be made to supply about 26,000 acres.

A smaller canal, only about 2 miles long, irrigates a few acres across the river from Kiona. This canal is several feet below the level of the fields it irrigates, and water is lifted from it by current wheels. In summer it carries 15 to 20 second-feet, but only a fraction of this amount is available for irrigation.

The Grosscup canal, about 5½ miles in length, takes water from the north bank of Yakima River about 10 miles below Kiona and irrigates a small area on the Grosscup farm.

Just across the river from the heading of the Grosscup canal is the intake of the Kennewick canal, which was constructed in 1894 with a length of over 20 miles. After two years' use it was abandoned, owing to financial difficulties, but later the property was acquired by the present company, the canal was enlarged and reconstructed, and

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[1] Jayne, S. O., Irrigation in the Yakima Valley, Wash.: Bull. Office Exper. Sta. No. 188, U. S. Dept. Agr., 1907.

in 1907 it had been in use for five seasons. The main canal is about 35 miles long and carries during the irrigation season between 125 and 150 second-feet. Under it there is about 12,400 acres, about a third of which was irrigated in 1906.

The lowest canal to take water from Yakima River is the Amon canal, owned by the Benton Water Co., which has its intake on the north bank of the river, about 5 miles below the Kennewick and Grosscup canals. It irrigates land near the town of Richland, between Yakima and Columbia rivers. About 2,500 acres of land under the canal and its branches was originally owned by the company.

SUMMARY.

In Sunnyside Valley water for domestic purposes is obtained in part from wells dug to the ground-water level and in part, of a better quality, from bored wells cased to the deeper water-bearing strata. There is a possibility that artesian flows will be obtained north of Snipe Mountain in a triangular area bounded approximately by straight lines joining the towns of Outlook, Granger, and Zillah, this area being a part of the favorable belt that extends westward across the Yakima and occupies a part of the Reservation Valley. Throughout most of the area the Ellensburg formation is so thick that few wells penetrate below it. On the eastern border, where the formation is thinner or entirely lacking, wells must be drilled to considerable depths into the basalt, but they obtain water of good quality. A notable rise of the ground-water level in the lower areas has taken place since the introduction of irrigation.

For irrigation the Sunnyside canal furnishes ample water to the land below it, but there is need of water to irrigate the land above this supply. The possibility of obtaining artesian flows for this purpose is remote. It is probable, however, that before many years a higher canal or pumping stations will be constructed that will bring under irrigation a great part of this cultivable but as yet unwatered land.

In the Reservation Valley the conditions are similar to those in the Sunnyside Valley. Ground water for domestic use is in most places easily obtained from shallow wells, and as it comes from the near-by slopes of the Cascade Mountains it is generally of good quality. The rock structure underlying this valley is such as to form a partly inclosed basin, and it is probable that flowing wells can be obtained in that part of the valley which lies within the following boundaries: From Granger northwestward almost parallel to Yakima River to the township line, 2 miles north of Wapato; thence westward about 5 miles; thence gradually swinging southwestward to a point about 2 miles north of White Swan; thence swerving south and southeastward toward the center of T. 10 N., R. 17 E.; thence eastward along the south branch of Toppenish Creek past Alfalfa to Yakima River.

Irrigation has not been developed in this valley to the extent that it has across Yakima River, chiefly because the land has been owned by the Indians. The ruling that allows the Indians to dispose of three-quarters of their holdings will probably cause rapid settlement by whites. As most of the land is low-lying, it will nearly all be brought under easy irrigation by the construction of the Reservation canal.

In the southern part of the Columbia River Plains, in the region that lies between Snake and Columbia rivers, the underground water supply has been but slightly developed. In the settled portions near the Columbia this stream is the main source of domestic supply; in sections more remote water is obtained from small springs or wells dug in coulees, and in the higher plateau portion it has been necessary to drill wells to considerable depths.

Irrigation is practiced in a number of areas along lower Yakima and Columbia rivers, but much of the land, though fertile, will probably remain unwatered and be used mainly for raising grain for a number of years to come. Gravity canals from the Columbia seem impracticable, and pumping plants are expensive and are most economically installed in large units. This means that irrigation of these portions of the plains region can not be efficiently undertaken by each farmer for himself but must be undertaken by the State or National Government or by development companies.

The region is, however, endowed with a great supply of water in Yakima and Columbia rivers. Development has already taxed the supply of the Yakima, but proposed storage reservoirs on its headwaters will render available for irrigation much of the winter as well as the summer flow and enable it to supply much more land than it can at present. Along the master stream, the Columbia, development has hardly begun. The river carries an almost limitless supply of water, but its utilization presents serious engineering and economic difficulties. The grade of the river is so slight that long and expensive canals will be required in order to obtain gravity supplies from it, and pumping projects involve expensive machinery and heavy lifts.

Although some of the higher lands will remain grain-raising districts for many years to come, it seems probable that before long the greater part of the lower-lying areas will be brought under canal lines and rendered as productive as similar lands in the Yakima and other highly developed districts.

WELLS AND SPRINGS.

The wells and springs listed in the following tables were visited in the course of the examination of the region. Reference has been made to many of them in the text, but the data are here assembled, together with those on others not previously mentioned, for more convenient use with the map (Pl. I), on which the wells and springs are shown by symbols whose numbering corresponds with that in the lists.

Wells in south-central Washington.

No.[a]	Owner.	Location.			Class of well.	Depth.	Depth to water.	Remarks (depth in feet).
		Sec.	T. N.	R. E.				
						Feet.	*Feet.*	
1	....	4	13	27	Drilled..	[b] 400	67	Through soft materials.
2	Hanford Hotel......	25	13	27	Dug.....	45	43	Water at river level.
3	Joe Allen...........	28	13	29	...do....	42	40	In basalt underlying gravel of coulee.
4	H. Meentz..........	25	12	29	Drilled..	407	325	Water at 375.
5	H. Wysong.........	26	12	29	...do....	473	100	Water at about 340. Strata passed through: Sand, 0–20; clay, 20–150; sand 150–160; shale, 160–325; porous rock, harder at bottom, 325–403; clay, 403–413; mud, 413–420; basalt, 420–473. Well not completed in November, 1907.
6	J. Agzel............	23	12	29	...do....	456	100	Water at 450; basalt at 370.
7	Mrs. M. P. Jordan...	22	12	29	...do....	450	400	Water at 430. Strata passed through: Soil, 0–130; quicksand, 130–170; blue clay, 170–425; basalt, 425–450.
8	Peter Kalkwauf.....	3	12	29	...do....	395	[b] 300	
9	W. B. Chamberlain.	.....	12	24	Dug and drilled.	140	100	Soil, 0–8; loose gravel, 8–16; cement gravel, 16–70; clay, 70–105; quicksand, 105–140. Completed June, 1910.
10	....	17	12	23	Dug....	[b] 20	17	
11	G. Meeboer.........	24	12	22	Drilled..	204	172	Water at 187. Strata passed through: Gravel, 0–65; basalt, 65–204.
12	Abram van der Linde.	24	12	22	...do....	96	55	Water at 72.
13	John Cudhie........	29	12	22	Drilled..	186	....	No water; through decomposed basalt to fresh basalt.
14	J. Merriam Smith...	.....	10	30	Drilled..	[c] 327	....	Water at about 180.
15	Northern Pacific Ry.	11	11	30	Dug.....	151	115	In gravel of Eltopia Coulee.
16	....	4	10	31	Dug.....	[b] 50	....	No water; through basaltic gravel to solid basalt.
17	Mr. Hillard.........	.....	10	23	Drilled..	75	....	No water at 75; drilling in December, 1907.
18	....	2	10	18	Dug.....	....	16	In valley filling.
19	Grandview school district.	.....	9	24	Drilled..	62	....	Ellensburg formation, 0–35; basalt, 35–62.
20	Town of Grandview.	23	9	24	Drilled..	132	[b] 60	Water at 60 and at 130.
21	George Houghmaster.	33	9	24	Drilled..	113	8	Water at 57; 100 feet of basalt; white sandstone at bottom.
22	Northern Pacific Ry.	30	9	27	....	[b] 50	....	Water at about river level.
23	Mr. McCauzland.....	.....	9	27	Drilled..	233	80	Water under artesian head.
24	B. B. Swearingen...	12	9	27	Drilled..	300	135	Drilling in June, 1908. Water at 165, 200, and 250. Tested 100 gallons a minute.
25	A. E. Burroughs....	24	9	30	Dug.....	50	48	In gravel of coulee.
26	Foster Bros.........	.....	9	30	Dug.....	110	106	In gravel of coulee.
27	Mr. Amond.........	30	8	29	Dug.....	16	14	In ravine.
28	Kelso Bros..........	16	8	27	Drilled..	800	....	A little water; not completed in November, 1907.
29	Adolph Perrault....	33	8	26	Drilled..	132	30	Supplies neighbors; 3-horsepower engine.
30	Yakima County.....	16	8	26	Drilled..	832	300	Supplies neighbors; 12-horsepower engine; yields 5,000 gallons a day during summer

[a] Numbers correspond to numbers on the map (Pl. I).
[b] Approximate.
[c] Reported.

Wells in south-central Washington—Continued.

No.	Owner.	Location.			Class of well.	Depth.	Depth to water.	Remarks (depths in feet).
		Sec.	T. N.	R. E.				
						Feet.	*Feet.*	
31	W. H. Hayden	8	8	26	Drilled	496	300	Supplies neighbors; 14-horse-power engine; yields 20,000 to 30,000 gallons a day during summer. A little water at 200; main supply at 496.
32	Mr. Frances	35	8	25	Drilled	[a] 150	100	Supplies neighbors; 2-horse-power engine; yields 4,000 to 5,000 gallons a day during summer.
33	I. W. Carter	21	8	25	Drilled	423	200	Soil, 0–12; basalt (?), 12–100; white clay, 100–200.
34			8	23	Dug		45	Through basaltic gravel.
35	Town of Mabton	1	8	22	Drilled	1,161		Not used. Wood at 850 and 1,090. Below 850 a succession of water-bearing strata.
36	A. F. Wattenberger	28	7	21	Drilled	202	166	Water at 196.
37	L. Spencer	27	7	21	Drilled	96	Flows.	Water at 94½.
38	Arthur King		7	22	Drilled	239	200	
39	Will Yeckel		7	22	Drilled	225		Drilling in November, 1907. A little water at 187 and 206.
40	J. V. Rhydholm		7	24	Drilled	110	[b] 100	
41	Mr. Buckingham		7	24	Drilled	404		Windmill pumps out in 8 hours.
42	William Markham		7	25	Drilled	504		Engine and windmill.
43	Louis Anderson	14	7	26	Drilled	350	225	Supplies neighbors; 5-horse-power engine and windmill; yields 10,000 gallons a day during summer; a little water at 225, main flow at 335.
44	Mr. Baker		7	27	Drilled	250		Engine.
45			7	28	Dug	20	18	Small seepage in canyon.
46	John Rose		7	29	Dug	66	60	Water at 60; soil 0–26, basalt 26–66.
47	Mr. Boofer		7	29	Dug	20	15	Seepage supply, about 1,000 gallons a day.
48	Don Creswell		7	29	Dug	35	20	Formerly Cottonwood Spring.
49	Will Richards		7	29	Dug	[b] 15	12	Seepage supply, about 500 gallons a day.
50	A. H. Richards	29	7	30	Drilled	1,100	700	Small supply, not used; about 125 gallons an hour at 700, lost on drilling deeper.
51	S. E. Walker	2	6	28	Dug	14	12	Small seepage.
52	Joe Slaybough	24	6	23	Drilled	124	50	Water at about 90.
53	John Doosey	14	6	21	Drilled	146	100	
54	F. W. Sanderson		6	21	Drilled	309	45	Small supply; water at 65 rose within 15 feet of surface.
55	J. Martinet		6	21	Drilled	131	70	Water at 131.
56	Town of Bickleton	16	6	20	Dug		20	
57	J. G. Gateburg		5	20	Drilled	170	124	
58	John Lund	30	5	20	Dug	20	15	In swale; water at 8 in well 50 yards west.
59	Samuel Sinclair	31	5	20	Dug	40	35	
60		3	5	23	Dug	30	30	In dry drainage channel.
61	H. P. Hansen	10	5	23	Drilled	112		No water; not completed in October, 1907; soil, 0–20; basalt, 20–100.
62	C. M. Jensen		5	23	Drilled	130	128	Water at 111.
63	Nels Sturgard		5	23	Dug	17	14	Seepage in canyon.
64		14	5	24	Drilled	185	120	Soil, 0–100; basalt, 100–185.
65	W. F. Crow		4	24	Drilled	162	Flows.	Yields about 1 second-foot; through unconsolidated material.
66	M. E. Carley	7	4	24	Drilled	176	Flows.	Yields about ¾ second-foot; small flow at 128, main flow from 142.

[a] Reported. [b] Approximate.

Springs in south-central Washington.

No.[a]	Name.	Location.			Flow.	Date.	Remarks.
		Sec.	T. N.	R. E.			
					Miner's inches.[b]	1907.	
1	Rattlesnake	21	12	25	60–70	Nov. 29	
2	Barrel	13	12	23	½	Nov. 29	
3	Trough	15	12	22	½	Nov. 18	
4	Nicolai's	15	11	23	30–40	Nov. 29	
5	Unnamed	8	11	25	....	....	
6	Cliff	......	9	25	....	Oct. 3	Yield said to be a barrel an hour.
7	Badger	......	8	28	....	Oct. 4	Yields less than a barrel an hour.
8	Beckner	36	7	20	[c]1	Oct. 12	
9	Unnamed	......	7	22	....	....	Small yield; in coulee.
10	McKinley	......	6	24	....	Oct. 9	Yields several barrels a day.
11	Unnamed	21	5	25	....	Oct. 8	Small seepage.
12	Cold	7	4	20	5–10	Oct. 11	

[a] Numbers correspond to numbers on the map (Pl. I).
[b] A miner's inch is equivalent to about 9 gallons a minute.
[c] Approximate.

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