Geology and Ground-Water Characteristics of the Hanford Reservation of the U.S. Atomic Energy Commission, Washington

GEOLOGICAL SURVEY PROFESSIONAL PAPER 717

Prepared in cooperation with the U.S. Atomic Energy Commission

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By R. C. NEWCOMB, J. R. STRAND, *and* F. J. FRANK

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UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, *Secretary*

GEOLOGICAL SURVEY

V. E. McKelvey, *Director*

Library of Congress catalog-card No. 72-600205

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 Stock Number 2401–00241

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By R. C. Newcomb, J. R. Strand, and F. J. Frank

ABSTRACT

The Hanford Reservation is located on the broad sandy terraces along the Columbia River in the semiarid Pasco Basin of south-central Washington. Altitudes range from 340 to about 800 feet on the terraces, reach 3,524 feet in the mountains adjacent on the west, and extend above 1,000 feet on a few bedrock knobs which rise prominently above the surrounding terraces.

The thick basalt of the Columbia River Group is the bedrock of the region. Its top lies within about 200 feet of sea level below broad areas of terrace lands built on sedimentary deposits. The basalt is warped and locally is severely deformed. The Ringold Formation, of middle or late Pleistocene age, overlies the basalt; it consists of up to 1,200 feet of bedded silts and fine sands containing some gravel and one prominent gravel train. This extensive formation has been partly eroded from the southwestern part of the Pasco Basin. Over its erosional surface have been laid glaciofluviatile and fluviatile deposits which underlie the wind-scarred terraces. The glaciofluviatile and fluviatile deposits consist of gravel and sand containing some lenses of silt, except for the Touchet Beds of Flint (1938), which is largely silt and fine sand. The thickness of the glaciofluviatile and fluviatile deposits is as great as 200 feet locally and as much as 100 feet over large areas.

Under natural conditions, which are now altered by artificial recharge, the water table sloped eastward and northward at an average of 5 to 10 feet per mile from where Cold Creek and Dry Creek flowed onto the terrace lands and where the Yakima River flowed along the higher side of the southern part of the terrace lands. This water-table slope continued to within about 2 miles of the Columbia River, where it flattened. The flatter gradient of the water table near the river continues to be present, but the water table there fluctuates most widely with the annual flood stages of the river. Some bank-stored ground water in the northern part of the reservation is diverted across the large river bend and returns to the river farther south and east. Natural recharge to the ground water was limited to infiltration from the two creek valleys, infiltration from the Yakima River at the southern extremity of the reservation area, and infiltration from the zone of bank storage along the Columbia River.

Artificial recharge from ordinary industrial-plant operations and from radioactive waste disposal has built two rudely conical ground-water "mounds" beneath the high terraces. The western ground-water mound in 1961 was nearly 60 feet high at the apex, had a base area of about 15 square miles, and was entirely in the Ringold Formation. The eastern one was less than half as high and had been elongated by growth to the southeast, in the more permeable glaciofluviatile and fluviatile deposits. Lesser mounds and minor changes in the water-table configuration have been produced elsewhere. Even the two large mounds, constructed by recharge of about 8,000 acre-feet of waste water per year during 1944–66, occupy only a small part of the water-storage space available above the water table in materials of relatively low permeability beneath the terrace lands.

The principal water-bearing units are the basalt of the Columbia River Group, the conglomerate of the Ringold Formation, and the glaciofluviatile and fluviatile deposits. The water table lies mainly in the Ringold Formation, and only locally does the saturated zone extend into the post-Ringold deposits. Permeability and transmissivity of the Ringold conglomerate are about 450 gallons per day per square foot and 50,000 gallons per day per foot, respectively, and those of the glaciofluviatile and fluviatile deposits are about 46,000 and 1 to 3 million, respectively. The effective porosity of the Ringold conglomerate is about 11 percent, and that of the younger deposits is about twice as much. The artificially accelerated rate of lateral movement of ground water within the Ringold Formation in the larger recharge mound, as derived for one condition in 1953, ranged from 0 to about 1,400 feet per year and averaged 240 feet per year. Permeability of the glaciofluviatile and fluviatile deposits is about 100 times that of the Ringold conglomerate, and proportionally greater ground-water velocities can be expected in these deposits for equivalent hydraulic gradients.

The Hanford Reservation contains the major emplacement of radioactive industrial wastes that the Atomic Energy Commission has made to the geologic environment. Wastes containing a large variety of radionuclides are disposed to the subsurface. The most highly radioactive wastes are held beneath the high terraces, where metallic wastes are stored underground in tanks and where fluids have been disposed to the geologic materials by means of infiltration cribs. Most of the disposed radioactive materials are located above the water table. Much of the ground water beneath the disposal areas contains only slight amounts of radioactivity, distributed spottily. A great concentration of radioactivity occurs in the geologic materials which underlie crib-disposal sites. Ruthenium-106 and tritium have moved from one large recharge mound for a distance of 14 miles to the bank of the Columbia River through the basal part of the glaciofluviatile and fluviatile deposits. The rapid (about 10,000 feet per year) movement of these radionuclides to the riverbank resulted from the rise of saturation of a disposal mound above the top of the Ringold Formation and into the overlying more permeable glaciofluviatile and fluviatile deposits.

Disposal of radioactive materials beneath the low terraces along the Columbia River has created some potential hazards, should the river become diverted and cut new channels through such disposal sites.

INTRODUCTION

PURPOSE

The investigation was made to obtain general information on the geologic and hydrologic situations that control many of the operations on the Hanford Reservation of the U.S. Atomic Energy Commission. (See fig. 1.) Important aspects of the investigations were the conditions that govern disposal of radioactive waste to the geologic environment, the general geologic conditions at the plant site, and the availability of ground water for various industrial and domestic water supplies.

The period of this work spanned the formation of the prime contractor's staff section of about 12 earth scientists. That staff section has continued investigations on the geophysical aspects of the disposal of chemical effluents at the Hanford plant and carries on the responsibility of the prime contractor for knowing why, how, and where the plant's radioactive wastes are disposed or stored. Such factors as selective adsorption of radioactive isotopes by different components of the earth materials, natural and induced shape of the water table, ground-water flow characteristics (Raymond and Bierschenk, 1957), and other factors of direct application to waste disposal and plant management are part of the continuing studies of the prime contractor's staff section.

Some of the hydrologic measurements, exploratory testing, and geologic investigation conducted by the U.S. Geological Survey were taken over, continued, and enlarged by the prime contractor's staff after 1953. Some of the Survey's general geologic and hydrologic information has been enlarged or added to by publications of the personnel of the Atomic Energy Commission and the successive prime contractors. For example, the Survey's information on the top of the bedrock beneath the sedimentary deposits was from sites too widely scattered to warrant drawing a bedrock contour map, so the bedrock altitudes were lettered on plate 1. A tentative map has since been compiled and the data kept current by the staff of Battelle-Northwest Laboratories.

PREVIOUS INVESTIGATIONS

The general background knowledge of geology and ground-water characteristics prior to this investigation included the bulletin on the agricultural water supplies of The White Bluffs–Hanford district (Jenkins, 1922), the reports and correspondence prior to and during the existence of the Hanford Engineering Works on the Manhattan Project (A. S. Cary, written commun., 1943, and letter reports of A. M. Piper, 1944), and later investigations after the plant became the responsibility of the Atomic Energy Commission (Brown and Rupert, 1948, 1950; Parker and Piper, 1949).

SCOPE AND METHODS OF INVESTIGATION

The work reported herein consisted of geologic mapping of the reservation, determining the composition and interrelations of the stratigraphic units, and deriving the characteristics of the ground water. After the start of the work in 1950, a second project, involving mostly drilling and sampling work around disposal sites, was undertaken and carried on after the completion of the original project in 1953. The drilling was continued until 1958; some of the data obtained in that work are included in this paper.

DRILLING OF OBSERVATION WELLS

Thirteen new wells previously planned as necessary to complete the 2- to 3-mile observation net on the reservation were constructed in 1950 and 1951 by drilling contractors. During all the drilling, the system of clean-hole drilling and sampling was followed.

GEOLOGIC WORK

MAPPING

The units underlying the surface of the reservation and adjacent areas are shown on plate 1.

The basaltic ridges on and adjacent to the reservation were mapped in some detail not only to record the stratigraphic features that continue beneath the reservation but also to determine the dominant types of tectonic structures that resulted from the deformation of the basalt. This information gave clues to the stratigraphy and tectonic structure of the basalt where it is covered by the unconsolidated materials.

PETROGRAPHIC STUDIES

Drill cuttings from the 13 observation wells and samples taken from outcroppings of the Ringold Formation and the glaciofluviatile deposits were examined in detail in the laboratory. Also examined were most of the samples from critical depths in wells drilled elsewhere on the reservation after use of the clean-hole well-sampling technique was begun in 1948. The mineral composition and the individual grain characteristics (such as roundness and weathering) of the sample materials were studied. One of the main efforts was centered on the recognition of criteria by which the geologic units, and in particular the Ringold Formation, could be distinguished positively in samples of drill cuttings.

STRATIGRAPHIC INVESTIGATIONS

The character and continuity of the strata that make up the basalt, the Ringold Formation, and the glaciofluviatile and fluviatile deposits were deter-

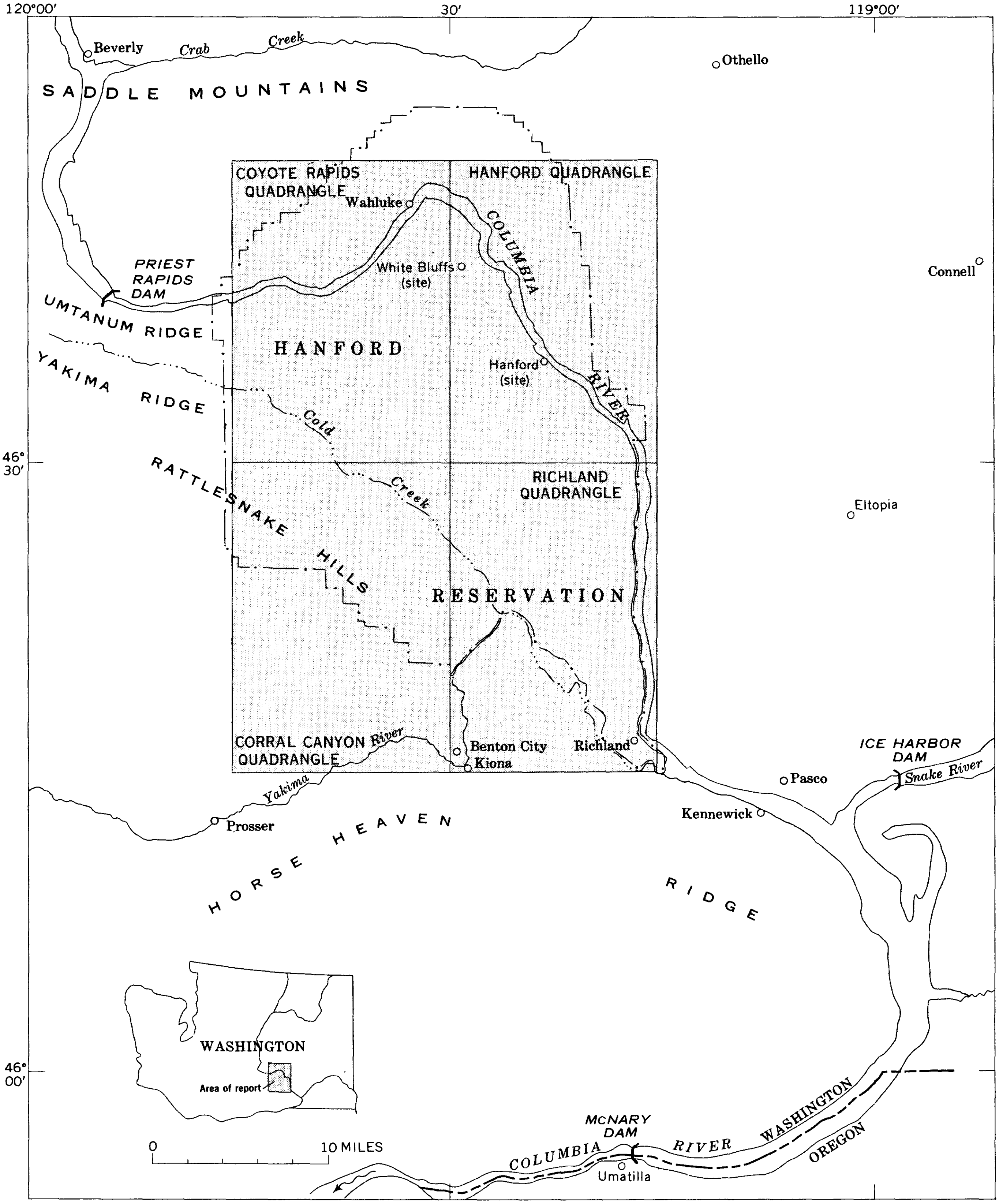

FIGURE 1. — Location of the Hanford Reservation and the area covered by plate 1.

mined by study of systematic sections cut across the outcrops and by study of information derived from samples of drill cuttings. The summary determinations are described in the text and incorporated in the geologic sections. The geologic sections on plate 1 and the logs of representative wells in table 2 give examples of the stratigraphic distinctions. The lateral extent of some geologic units, such as the conglomerate member of the Ringold Formation, is particularly vital to ground-water and waste-disposal situations on the reservation.

Vertebrate fossils were collected from, and age determinations obtained on, the Ringold Formation of The White Bluffs (Strand and Hough, 1952) in order to get better information on the relative ages of the geologic events.

GROUND-WATER INFORMATION

Many of the ground-water facts are in the section on hydrology, and many of the basic data on the ground water of the reservation and of the pertinent adjacent lands are condensed in the tables for representative wells shown on plate 1. The information on wells was obtained from data in the files of the U.S. Geological Survey; from the files of the Hanford Engineering Works and its successor, the Hanford Operations Offices of the Atomic Energy Commission; from the prime contractors, E. I. du Pont de Nemours & Co., General Electric Co., and Battelle-Northwest Laboratories; and from field observations made during this investigation. Configurations of the water table for 1944, May 16–20, 1953, and June 26–30, 1961, are shown on plates 1, 2, and 3, respectively. Other fluctuations of the water table are shown in figures 3 to 9, and the generalized position of the water table is given on the geologic sections. (See pl. 1.) Most of the water-level observations were obtained from the General Electric Co.

Some data on the chemical quality of ground water still in near-native condition are included as background information to help indicate any later quality changes.

WELL DATA

Pertinent information on a condensed list of representative wells is given in table 1. About 1,000 wells have been drilled or dug in the area of the reservation. These include old farm wells, foundation and water-supply explorations of the atomic facilities, ground-water observation wells, and waste-disposal monitoring wells. The monitoring wells represent about half of the total. The 175 wells described in table 1 condense most of the representative data obtained from the entire number of wells.

Details of the materials penetrated by some of the representative wells are given by the logs in table 2, and comprehensive chemical analyses of water from 27 wells and one spring sampled during this investigation are given in table 3.

The Geological Survey well numbers used in this report were derived by the following system: Wells are designated by symbols that indicate their locations according to the official rectangular survey of public lands. For example, in the symbol for well 9/27–4N1, the part written as a fraction and preceding the hyphen indicates township and range; because all parts of the county are in the northeast quadrant of the Willamette base line and meridian, this part of the symbol is specific and indicates T. 9 N., R. 27 E. The number following the hyphen indicates the section (sec. 4); the letter denotes the 40-acre subdivision of the section, according to figure 2; and the final digit is a serial number among wells and springs in that particular 40-acre tract. Thus, well 9/27–4N1 is in the SW¼SW¼ sec. 4, T. 9 N., R. 27 E., and is the first well in that tract to be listed.

PERSONNEL

The senior author supervised the work, and Jesse R. Strand was resident geologist until 1954. Frederick D. Trauger helped with the geologic work and compiled many of the ground-water data from which those in the tables were taken. Paul B. Carter and Victor T. McCauley served as drilling inspectors and ran level lines to the wells drilled under this program. George W. Mason assisted in some of the geologic mapping. Donald H. Hart made some of the quantitative determinations on the ground water. Florian J. Frank aided in the collection and preparation of the data for tables and charts and was in charge of the drilling and sampling work from 1954 to 1958.

GEOGRAPHIC FEATURES OF THE RESERVATION

The reservation contains and is centered on about 350 square miles of terrace lands along the Columbia River within the semiarid Pasco Basin of south-central Washington (fig. 1). The wind-scarred terrace plains rise gradually north and west from an altitude of about 340 feet at Richland to 700 and 800 feet in the northwestern part of the reservation. From these high terraces the surface descends more abruptly to the 450-foot terraces along the river in the northern part of the reservation.

In much of its course through and around the reservation, the Columbia River flows between the lowest terrace and the 600-foot escarpment, known as The White Bluffs. The Yakima River enters the Columbia River just south of Richland. Downstream

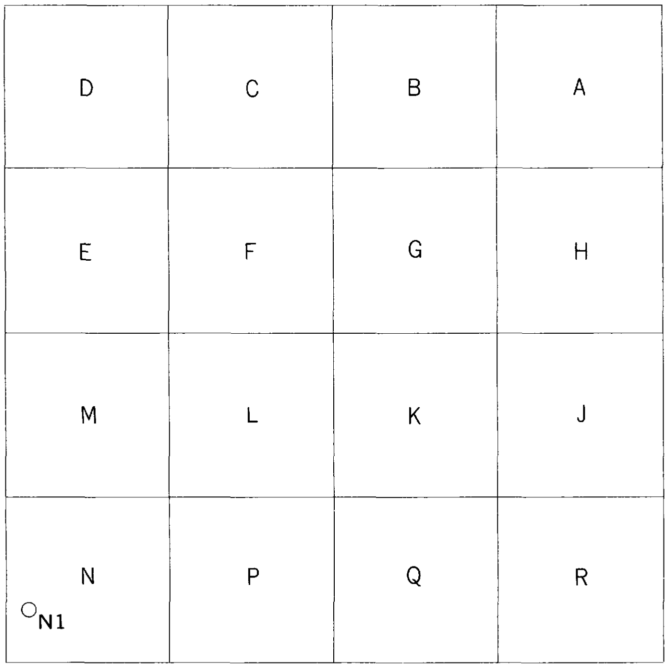

FIGURE 2. — Well-numbering system.

from Richland the Columbia River is impounded in the 55-mile-long reservoir behind McNary Dam.

The terrace lands of the reservation terminate on the west against the slopes and interridge valleys of low linear mountains known collectively as the Yakima Ridges. Rattlesnake Mountain, at the southwest edge of the reservation, rises to an altitude of 3,500 feet. A few bedrock outliers, such as Gable Mountain, protrude above the terraces of the reservation.

Richland and the cities of Pasco and Kennewick, which lie on opposite sides of the river 8 miles downstream from Richland, form the commercially important Tri-Cities area, which had a population of about 80,000 in 1960.

GEOLOGY

GENERAL DESCRIPTION OF THE GEOLOGIC UNITS

BEDROCK

The main body of the basalt of the Columbia River Group extends from the Cascade Range eastward to the Rocky Mountains and from the Okanogan Highlands southward into the mountains of central Oregon. The Pasco Basin, a main structural and physiographic unit, lies near the center of that vast area.

Beneath the terrace lands the basalt has a general saucer-shaped structure; this broad syncline forms the bedrock frame of the Pasco Basin, of which the terrace lands form the southwestern part.

From test drilling for oil at Union Gap and at the Frenchman Hills, respectively 35 miles west and 20 miles north of the reservation, the basalt is known to be more than 4,500 feet thick. Basaltic lavas and pyroclastic rocks were drilled to a depth of more than 10,000 feet in a recent oil test on Rattlesnake Mountain just west of the reservation; however, the electrical log of this Rattlesnake Mountain well indicates that strata penetrated by the well change at a depth of about 5,000 feet from what seems to be basalt of the Columbia River Group above to what may be volcanic sedimentary rocks and lava below. However, so many unknowns are involved that all that can be concluded now is that the basalt of the Columbia River Group forms the top 5,000 feet.

The basalt was drilled to a depth of 3,660 feet in the old Rattlesnake gas field near the southwestern edge of the reservation. (See log of well 11/26–29B1 in table 2.)

The basalt is an accordantly layered sequence of flows which were extruded as highly fluid lava in Miocene and early Pliocene time. It crops out around the sides of the Pasco Basin. In a few places on the reservation, the basalt protrudes through the sedimentary materials that underlie the terraces.

At depth beneath the terraced plains of the reservation the top of the basalt lies within 100–200 feet of sea level except near the lines of deformation that bound the adjacent upland areas. The basalt forms Gable Mountain and Gable Butte as well as several smaller knobs within the reservation. The outcrop extent is shown on plate 1, and the general geologic relations beneath the reservation are shown on cross sections on plate 1.

The basalt is a gray-black coarsely fractured rock that differs a little in color, texture, and jointing from flow to flow but has a rather uniform appearance within any single flow layer. In general, the rock is dense and hard, and it may even be brittle and flintlike in places. The most flinty basalt contains up to 50 percent glass but enough microscopic crystals to give it a stony, rather than a glassy, luster. At the other textural extreme, some rock is largely crystalline and approaches diabase in texture. Some basalt is porphyritic and contains scattered labradorite plagioclase phenocrysts. Most of the phenocrysts are less than a quarter of an inch in length, but in a very few places they are as much as 1 inch long. A few gas vesicles occur throughout much of the rock; most flows are markedly vesicular near the top, and the tops of some flows locally consist of scoria as a result of the concentration of the gas bubbles.

Little secondary alteration has affected the basalt as a whole. Locally, vesicles and shear zones show some zeolitization and silicification. The tops of some flows were moderately oxidized and stained red before being covered by the succeeding flow. Other

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flows have a black, glossy, slightly ropy surface that is remarkably fresh and unoxidized.

Horizontal and vertical systems of joints were formed during solidification and shrinkage of the basalt. Joints belonging to either directional system may predominate within a single flow or within different parts of the same flow. The horizontal system lends a platy character in places but may be so subordinate that it only separates the vertical units by inconspicuous horizontal cracks 5 to 10 feet apart. The main vertical system contains the only plane surfaces within the basalt; it creates a columnar structure that comprises blocks 4 inches to 5 feet in width. The columnar structure is formed in all degrees of perfection and intensity in certain flows and in separate parts of the same large flow. Where the wide columns are sparsely cut by horizontal joints, as they are in the center of many flows and throughout some flows, the most massive blocks of the basalt occur. Where the narrow columns are intricately associated with concentrated platy jointing, the whole rock may be divided by the cooling cracks into fist-sized or football-sized blocks; such a rock is commonly called brickbat basalt. The shrinkage joints are open cracks at the surface but are closed hairline partings at depth within the rock.

Autobrecciated rock, sometimes called flow breccia, that results from the solidification and extensive breaking at the top of some lava during its flowage on the land surface, is rare in this basalt. However, local, thin zones of a rubbly scoria somewhat similar to flow breccia occur at the top of a few flows and create particularly permeable parts of the basalt. Caverns in the lava are rare.

Pillow basalt, ball-like oblates of chilled lava with interstitial fillings composed of chilled and partly hydrated and oxidized glass shards (palagonite) and their decomposition products, occurs at the base of some flows and is generally ascribed to flowage of lava into water. Pillow lavas form a very small part of the mass but are not so rare as natural outcroppings would indicate. Most exposures of the easily eroded pillow lavas are seen in artificial cuts.

Deposits of sedimentary materials and former soils between successive lava flows form a small part of the basalt mass. A few such interflow soils and thin sedimentary deposits are sufficiently extensive to serve as local stratigraphic markers.

SEDIMENTARY DEPOSITS

RINGOLD FORMATION

Overlying the basalt bedrock of the Pasco Basin are sedimentary strata consisting largely of silt, sand, gravel, and volcanic ash. One prominently stratified part of that sedimentary cover is known as the Ringold Formation (Merriam and Buwalda, 1917).

The type locality of the Ringold Formation is in The White Bluffs, against which the Columbia River impinges in the northeastern part of the reservation and along the east side of the reservation. The strata at this locality are the only ones to which the name Ringold Formation was originally applied. The subsurface continuation of these strata, in places completely down to the underlying basalt, was also considered to be Ringold Formation (Newcomb, 1958, p. 328).

With the exception of a conglomerate train, the Ringold Formation consists mainly of silt and fine sand strata that are characteristic od deposition in a current-carrying lake and its environs. The deposition apparently started when the Columbia River drainage was impounded in middle Pleistocene time by the first uplift of the Horse Heaven Ridge (and downwarp of the Pasco syncline) (Newcomb, 1958).

Eastward and northward from The White Bluffs, the Ringold Formation lies at or near the plateau surface for many miles to where the basalt bedrock emerges at the surface. In the lowland swath between the east end of the Yakima Ridges and The White Bluffs, the ancestral Columbia River removed the Ringold strata down to a level below that of the present surface of the terraces. This eroded surface of the Ringold Formation has been covered by various thicknesses, up to about 200 feet, of glaciofluviatile and fluviatile deposits which underlie the land surface in most of the reservation area.

The stratigraphic subunits and the continuity of the Ringold Formation, as well as its relations to the bedrock and to the overlying deposits, are shown by the drillers' logs in table 2 and by the cross sections on plate 1.

GLACIOFLUVIATILE AND FLUVIATILE DEPOSITS

The coarse clastic deposits that lie above the eroded top of the Ringold Formation and beneath the reservation terraces are somewhat similar to the coarsest materials of the Ringold Formation but in detail differ greatly. They are referred to in this report as glaciofluviatile and fluviatile deposits because they were water laid by the ancestral Columbia River, in part while it was swollen by glacial melt water. It is known that during the time of their deposition the ice of a continental glacier occupied parts of the Columbia River basin. Except for some material in the Touchet Beds, the glaciofluviatile and fluviatile deposits are largely current-laid materials.

The glaciofluviatile and fluviatile deposits consist of granule gravel, sand, and pebble gravel with some intermixed and interlayered silt as well as interbedded and included cobbles and boulders. These deposits mantle the eroded top of the Ringold Formation and some slopes of the basalt bedrock. They overlie the Ringold beneath the reservation, form the upper part of the northwestern end of The White Bluffs, and also underlie the terraces southward and eastward from the south end of The White Bluffs to and beyond Pasco. The continuity of these deposits is shown on the cross sections on plate 1. The greatest part of the deposits lie below an altitude of 800 feet, but the special facies, called the Touchet Beds,[1] with its contemporaneous erratics, reaches to a common altitude of about 1,150 feet.

Late in the glacial epoch, the facies of the glaciofluviatile and fluviatile deposits known as the Touchet Beds was laid down in a temporary lake (proglacial Lake Lewis) created by the ponding of the Columbia River by a mountain glacier, ice jams, lava flows, or landslides (Russell, 1893; Allison, 1933) in the Columbia Gorge below The Dalles, Oreg. The Touchet Beds in its type occurrence consists of horizontally layered silt and sand. It includes scattered and clustered erratics that range from granules up to large blocks 6 to 8 feet in diameter. In the reservation area, the lake in which the Touchet Beds was laid down probably submerged a topography somewhat similar to that of the present time. The Touchet accumulated as a lake-bottom deposit no more than 200 feet thick. The unit is best preserved in places that were the backwater or cove parts of the lake. On the reservation the greatest amount of material occurs on the lowest slopes of the Yakima Ridges and in the lower part of the Cold Creek valley (pl. 1).

The youngest of the glaciofluviatile and fluviatile deposits may be those deposits that now underlie the lowest terraces, such as the 400-foot terraces at old White Bluffs and Hanford and the 360-foot terrace at Richland. The demarcation between the last of the glaciofluviatile and fluviatile deposits and the first of the Holocene alluvium is obscure and is arbitrarily assigned in this report. The exact time at which the river ceased to carry outwash of the last continental glacier is difficult to determine. The fact that glacial outwash, icefloes, and icebergs were transported until comparatively recent times in the Columbia River's history — and in the evolution of the present topography — is shown by the pits left by the melting of icebergs in the knob-and-kettle topography on the low (460-ft.) terrace south of the Columbia River in secs. 21, 22, 27, 28, and 33, T. 14 N., R. 26 E., as well as by the low altitude of the Touchet Beds in the lower Cold Creek and Dry Creek valleys and along the Yakima River.

[1]For the sake of brevity, the unmodified term Touchet Beds is employed throughout the text. It is applied to the same deposits called Touchet Beds by Flint (1938, p. 494).

ALLUVIUM

The water-laid materials that are within the vertical range of the natural river stages of the present time are referred to herein as alluvium. Most of the wind deposits, which are a reworked surficial aspect of previous deposits, are not shown as alluvium on plate 1 but are marked as parts of their parent material. The Touchet Beds has been more extensively reworked by the wind than the other deposits and is indicated on plate 1, in places, as wind worked.

The Holocene deposits consist of current-laid gravel, mostly pebble and cobble sizes, containing sand and silt mainly as a matrix, and of slack-water deposits of fine sand and silt. The flood-plain deposits underlying the lower Cold Creek, Dry Creek, Yakima River, and Columbia River flood plains are largely silt and fine sand containing some layers of gravel and rock rubble and various amounts of organic matter. The alluvium is thin; in the river valleys it lies mainly in the vertical interval between the maximum flood stage and the bottom of the stream's bedload. The alluvium in Cold Creek and Dry Creek valleys in places is thin enough that the underlying glaciofluviatile and fluviatile deposits can be identified near the surface.

COLLUVIUM

Some deposits of mixed rock rubble, silt, sand, and land-slumped material have been slightly reworked and deposited on, and at the foot of, the mountain slopes adjacent to the terraced plains of the reservation. The designation of some of that material as colluvium rather than alluvium on plate 1 is rather arbitrary. Moreover, in part the colluvium may contain some material that is probably contemporaneous with the latest glaciofluviatile and fluviatile deposits, but since the surficial part is youthful in those places, it is referred to and mapped as colluvium. On several of the lower slopes of the mountains the colluvium appears to be at least 25 feet thick in places, though this must be estimated from exposures that are limited to the shallow banks of the ravines. Land-slumped areas that retain the identity of the parent ledge material are mapped on plate 1 as landslide deposits.

STRATIGRAPHIC CHARACTERISTICS OF THE GEOLOGIC UNITS

BASALT OF THE COLUMBIA RIVER GROUP

LAYERED STRUCTURE

The basalt is a thick succession of layers that originally were in a near-horizontal position. The individual layers are usually referred to as flows denoting single outpourings of lava. The thicker individual flows consist of both single and multiple flow units not separated by significant time breaks or lithologic changes. The visible breaks between flow layers result from differences in the joint pattern of the overlying or underlying lava, from lithologic differences, such as the vesicular or rubbly top of the underlying flow, and from foreign matter, such as soil or volcanic ash partings or layers.

The flows range in thickness generally from 10 to 150 feet. The length of many of the thinner flows can be distinguished for only a mile or so at the most, but some of the thicker flows can be followed for several miles in places where the continuous exposures afford that opportunity, and for many tens of miles by the correlation of exposures.

VERTICAL SUBDIVISION OF THE BASALT

Upon superficial examination, the basalt may appear to be a continuous succession of layered lava, but some variations are known in the top 1,000 feet of the basalt and are of particular importance to the ground-water aspects of the bedrock.

From the Yakima River valley, near the west edge of the vast basalt area, eastward and northeastward to and beyond the reservation, a number of relatively thin sedimentary deposits are bedded between lava flows. The sedimentary beds are mostly conformable to the layered structure of the basalt and lie at depths ranging generally from 100 to 700 feet below the top of the basalt. These widespread intrabasalt sedimentary strata in the Yakima area consist largely of andesitic, clastic, and tuffaceous materials, and farther east they are composed of tuff, pumicite tuff, gravel (both quartzitic and basaltic), diatomite, and other sedimentary materials. The continuation of these sedimentary layers eastward to the reservation has been described by Mason (1953) and Schmincke (1967).

In the middle part of the Yakima Valley, 50 miles west of the reservation, one sedimentary layer near the top of the basalt includes tuff and water-laid clastic sediments of andesitic composition. The sedimentary layer separates the top 200 feet of the basalt, formerly called the Wenas Basalt, from the great mass of the basalt below (Smith, 1903). The sedimentary deposits within the top part of the basalt in the Yakima Valley were not traced by the writers to the reservation area, but the continuity of the deposits and the lithologic types and distribution described by Mason (1953) seemed apparent during reconnaissance studies in this region. Near Sentinel Gap in the Saddle Mountains north of the reservation, the topmost basalt, the Saddle Mountains Member of the Yakima Basalt, is underlain by a 400-foot-thick tuffaceous layer which was considered to be a part of the Ellensburg Formation by Twiss (1933) and was called the Beverly Member of the Ellensburg Formation by Mackin (1961, p. 26) and Bingham and Grolier (1966).

Sedimentary layers are persistent within the top part of the basalt beneath the reservation and the mountain ridges to the west. The uppermost sedimentary bed originally was covered by 10 to 450 feet of basalt. The top of the uppermost sedimentary zone in some places has not been exposed by erosion. Despite a small amount of general erosion from the top of the basalt and some deep local erosion, the remaining thickness of the basalt above the uppermost sedimentary bed is similar throughout the region.

The various interbedded sedimentary zones in the top part of the basalt were referred to as the lower part of the Ellensburg Formation by Mason (1953), and the top two zones were so designated by Schmincke (1967). Schmincke (1964) identified five sedimentary zones which he called members of the lower part of the Ellensburg Formation, the lowest member being equivalent to Mackin's (1961) Vantage Sandstone Member of the Yakima Basalt. The basalt flows separating and overlying the sedimentary members were considered to be part of the Yakima Basalt by Schmincke (1964); part of this basalt is equivalent to that called the Saddle Mountains Basalt Member of the Ellensburg Formation by Mackin (1961, p. 26) and the Saddle Mountains Member of the Yakima Basalt by Bingham and Grolier (1966).

On Red Mountain, west of Richland, two layers of tuff are exposed within the basalt sequence. The upper is 14 feet thick, and the lower is 20 feet thick. The upper is overlain by only 20 to 30 feet of basalt, and about 450 feet of basalt separates the two tuff beds. The material of the upper bed is semiconsolidated and consists of gray tuff with a medium-sand grain size. Farther north and on the upper slopes of Rattlesnake Mountain, upslope from the old gas-field wells, two tuff layers are likewise exposed. The upper one is a white "sandy" tuff 30 feet thick. This tuff is overlain by 150 feet of basalt and immediately underlain by about 500 feet of basalt. Another 30-foot layer of gray "sandy" tuff underlies the 500-foot thickness of basalt. A mile to the northeast of those outcrops a similar stratigraphic succession was recorded in the logs of the old gas wells, but the lower tuff layer, just below which the main gas accumulation occurred, was recorded as "sandstone and shale" 78 feet thick. (See log of well 11/26–29B1 in table 2.) Six miles farther east, one tuff-and-sand layer 92 feet thick beneath 25 feet of basalt was penetrated by the drill during construction of well 11/27–20M1.

Farther northwest, a layer of tuff crops out extensively along the north side of Dry Creek valley, where its top is less than 100 feet below the top of the basalt. West of the reservation, in the NE¼ sec. 17, T. 12 N., R. 24 E., an exposed sedimentary layer consists of 10 feet of gray tuff with particles of sand and silt size overlying 10 feet of white and light-gray fine-grained "volcanic ash" tuff, which in turn lies upon 15 feet of cream to buff sandy and massive tuff. Along the north side of Dry Creek valley, pebble gravel and sandy tuffaceous conglomerate are present in a layer in which the larger particles are predominantly well-rounded quartzite cobbles. The outcrop shown in NE¼ sec. 25, T. 12 N., R. 24 E., on plate 1 affords a particularly well-exposed section of a pebble conglomerate about 40 feet thick.

A tuffaceous zone crops out beneath about 100 feet of basalt on the flanks of the anticlinal folds between Dry Creek valley and the upper Cold Creek valley. In the Cold Creek valley this zone has been noted in the logs of the six artesian wells drilled prior to 1960. Three sedimentary layers, the upper two of which are divided by 144 feet of basalt, are found in well 13/25–30G1, but apparently only one sedimentary layer was found in wells 13/24–25E1 and –26M1 that lie outside the area covered by plate 1. In the first of these two wells 322 feet of basalt overlies 130 feet of sedimentary material, and in the second, 298 feet of basalt overlies 220 feet of sedimentary material. Artesian wells drilled in Cold Creek valley obtain water from the basalt below the interlayered sedimentary deposits. These wells flowed at the land surface when they were drilled.

At least one sedimentary layer in the basalt crops out extensively around the flanks of the local structural highs on the east end of Umtanum Ridge, north of Cold Creek. Elsewhere, in many of the knobs of the high Umtanum Ridge just west of the area mapped (pl. 1), a tuffaceous pebble gravel layer crops out less than 100 feet below the top of the basalt.

On Gable Mountain two tuffaceous layers occur. The geologic section contains (downward from top):

	Thickness (feet)
Basalt; two flows — one 10-ft flow, top eroded, over one 154-ft flow	164
Tuff, fine-grained, gritty and sandy, gray and tan; local beds of pebble gravel and sand	55
Basalt; three flows — 122, 35, and 117 ft thick, successively downward (pillow structure at places in lower part of lowest flow)	274
Tuff, gray, gritty, opalized and baked at top	8
Sand, buff and white, loose, water-laid; with local pebble layers in lower part	16
Basalt, ropy, with breccia	300±
Total exposed section	817

The similarity of the sedimentary strata between flows in the upper part of the basalt is shown by exposures and by well logs north of the reservation. At the northwest extremity of the Wahluke Slope, in sec. 23, T. 15 N., R. 23 E., the following section is exposed southeast of Beverly (downward from top):

	Thickness (feet)
Basalt	60
Tuff, fine-grained, white and platy at base, brown and massive toward top	30
Conglomerate, gravel and sand, loose, gray	25
Tuff, massive, whitish, with 10 ft of tuffaceous sandstone in center	59
Sandstone, poorly consolidated, well-sorted, medium-grained, quartzose	5
Conglomerate, pebble and cobble gravel with medium quartzose sand matrix	56
Tuff; lower half fine grained and finely laminated; upper half sandy, loose, more massive	32
Conglomerate, largely pebble gravel with tuffaceous sand matrix, loose, gray	61
Tuff, sandy, light gray and white in beds separated by thin layers of fine-grained fissile tuff	17
Conglomerate, consolidated, largely pebble gravel with loose quartzose sand matrix and with 5-ft interbed of tuffaceous sand	20
Total tuff, conglomerate, and sandstone	305
Basalt	3
Total exposed section	368

Tuffaceous sedimentary layers in the basalt have been logged during the drilling of deep wells outside the reservation and in the area where the basalt is deeply covered by postbasalt sedimentary deposits. On the Wahluke Slope at the northwest edge of the reservation, well 14/25–1D1 penetrated 102 feet of "clay" and "sand" beneath 443 feet of basalt (Walters and Grolier, 1960, p. 394). The driller's log of deep well 12/28–24N1 (table 2) at old Ringold, east of the Columbia River, includes several sedimentary beds in a zone from 35 to 515 feet below the top of the basalt.

In the main reservation area, the tuffaceous sedimentary layers within the basalt have been logged as 101 feet thick beneath 109 feet of basalt in well 13/27–30H1 (just south of Gable Mountain) and have been found to occur beneath 113 feet of basalt in well 13/25–1N2. Apparently, the same tuffaceous layer was penetrated without basalt cover in well 13/25–23A2, and data available from well 11/28–21L3 suggests tuff of this type may occur without appreciable cover of basalt.

The continuity of these sedimentary layers in outcrops and in the subsurface, as indicated in drilling explorations, suggests that the layers will ultimately be used as stratigraphic markers in the bedrock beneath the reservation area.

A general lack of widespread permeable material is evident from observations of outcrops and from drill cuttings, as well as from data obtained in bailer tests of wells in which drills penetrated these sedimentary layers within the top part of the basalt. The pebble gravel and coarse sand parts have limited lateral continuity, and most of each sedimentary layer is tuffaceous non-water-bearing material. Overall, these sedimentary layers within the top part of the basalt have yielded less water to wells than the more permeable stratigraphic zones of the basalt.

Studies of diatomite beds and of the foundations of the Priest Rapids and Wanapum Dams, 15 to 30 miles upstream from Coyote Rapids (Mackin, 1961), and data obtained from drilling of wells on the Columbia River Basin Irrigation Project, north and east of the Hanford Reservation (Bingham and Grolier, 1966; Grolier and Bingham, 1969), provide some detailed knowledge on the stratigraphy of the uppermost part of the Yakima Basalt. The reports just cited indicate that feldspar phenocrysts and other lithologic criteria used by Bureau of Reclamation geologists in the Columbia Basin Irrigation Project area (Jones, 1945, 1950) provide a means for identifying some of the basalt flows in outcroppings of the Yakima Basalt over many tens of square miles.

RINGOLD FORMATION

CHARACTER AND EXTENT OF THE STRATA IN THE TYPE LOCALITY

The Ringold Formation in its type locality, The White Bluffs, consists of essentially horizontal beds of coherent silt, sand, clay, gravel, and a little volcanic ash. The most prevalent type of material is a weak siltstone with some interbedded fine sand layers. Zones of semicompact fine sand make up large sections of the bluffs. The thickness of the individual beds of sand and silt ranges commonly from less than an inch to 10 or more feet. The layers containing largely pure volcanic ash occur in distinct beds that in places are as much as 10 feet thick.

Few of the individual laminae of the material extend laterally more than a few hundred feet, though some beds are continuous for several miles. However, zones in which certain types of material prevail can be followed horizontally for miles along the bluffs. The extensive character is apparent in the more coherent materials, such as the main gravel layer and some of the compact silt zones. The main gravel layer occurs in the general altitude range of 285 to 450 feet along the southern part of The White Bluffs. Commonly, it is called "conglomerate" to distinguish it from glaciofluviatile gravel, though it is mostly a rather weak conglomerate or a semicoherent gravel.

The top of the Ringold Formation in the southern part of The White Bluffs is heavily calcified and silicified to a depth of at least 15 feet. This surficial indurated material (commonly called "caliche") underlies the 900- to 1,000-foot plateau that extends eastward from The White Bluffs. The caliche forms a resistant capping to the section exposed in The White Bluffs.

The Ringold Formation contains the fossilized bones of many types of vertebrate animals and some scattered petrified and carbonized wood and plant matter.

The geologic sections that were examined vertically across the strata exposed in The White Bluffs are given below; each was measured with a hand level from an altitude datum established by barometer and river-level control. Key points on the section were controlled by telescopic level and vertical angle transit surveys.

Geologic section westward down the bluffs near the west quarter-corner of sec. 1, T. 10 N., R. 28 E.

[Section downward from leveled mark at the top of escarpment at altitude 882 feet]

	Altitude (feet)
Covered; soil, and reworked rubble as in 694- to 629-ft zone	882–714
Covered; tan silty soil	714–694
Covered; reworked rubble eroded from caliche caprock	694–629
Siltstone, sandy and clayey, tan, massive at base and progressively more finely laminated toward top; thin sandy layers contain a few pebbles and cobbles	629–623
Sand, medium and fine, progressively more silty upward and indurated to sandstone at top; some reworked fragments of siltstone of the Ringold included	623–615

	Altitude (feet)
Clay, sandy and silty, massive, buff-green at base and darkening to brown-green at top	615–601
Sandstone, indurated, fine- and medium-grained; composed mainly of sand-size ash; has minute crossbedding laminae; a strong bed extending horizontally for several miles	601–596
Volcanic ash, clayey, white, dense, massive; conchoidal fracture and fine laminations near base; top part is made up of loose silt-size shards	596–589
Clay, silty, brown, massive at base but more laminar toward top; in places contains a 2-ft bed of fine sand that is weakly coherent in the center	589–580
Claystone, dark-brown, crumbly, massive	580–575
Silt, clayey grading to silty clay in upper part, tan, massive; top foot is calcareous clay	575–557
Sandstone; similar to 550- to 542-ft zone but whitish tan	557–550
Sandstone, fine-grained, gray, weakly indurated, silty and clayey, massive but with highly uniform size of sand grains; top 5 in. is hard cemented layer	550–542
Clay and silt, brown, compact, semiplastic when wet; sandy beds irregularly distributed	542–504
Siltstone, massive, gray, partly indurated	504–494
Siltstone, clayey, massive, yellowish at base and gray above; upper 6 ft has many round concretions up to 10 in. in diameter; has calcified zone of 1- to 2-ft thickness at top	494–480
Sand, fine, and silty sand, fine, laminar bedding; material is gray and contains much mica on bedding planes	480–475
Covered; soft material	475–470
Conglomerate; cobble and pebble gravel with some boulders up to 8 in. in diameter and with a matrix of quartzose and arkosic medium well-sorted sand that comprises about one-half of the material; exotic pebbles and cobbles are mostly quartzite and dense porphyry (granitic types are rare); exotic rock types and Columbia River Basalt about equal; locally, beds up to 6 in. thick are entirely sand, are firmly cemented, and stand out as resistant ledges; in 434- to 415-ft zone many pieces of water-rounded and reworked siltstone of the Ringold are present; pebbles are mostly fresh and clean, but those of Columbia River Basalt have 1/16-in. whitish-brown weathering rind, and some granitic pebbles are crumbly	470–415
Covered	415–349

Geologic section westward down the bluffs near east quarter-corner of sec. 35, T. 11 N., R. 28 E.

	Altitude (feet)
Covered; soil	920–896
Silt and siltstone, irregularly permeated with caliche cementation, brown to red; forms cliff at top of bluff	896–884
Siltstone, clayey, partly calcified, cream and yellow	884–876
Sand, silty, laminated with silty partings, micaceous, yellow; contains calcareous concretions; forms gentle slope above spired cliffs	876–839
Siltstone, clayey, laminated; contains a few irregular thin beds of gray loose sand; forms badland-type cliffs	839–804
Claystone, silty, compact, laminated with micaceous partings, yellow to white; forms badland-type cliffs	804–749
Volcanic ash, laminated, glass shards of silt and fine-sand size, cream to white; continues as prominent band northward	749–713
Sand, medium to fine, well-sorted, loose, micaceous, light-yellow-brown	713–691
Siltstone, much like that of 674- to 652-ft zone but much firmer, gray to tan; forms prominent cliffs	691–674
Siltstone, sandy and clayey in bands, poorly consolidated; makes uniform gentle slope below cliff-forming zone	674–652
Silt, sandy with sand layers, well-bedded, buff	652–604
Sand, fine and medium, loose, micaceous in places, yellow and gray	604–568
Siltstone, clayey, massive, white-tan; contains a few sandy layers; forms prominent cliffs and underlies bench	568–548
Siltstone, sandy and clayey, indurated, well-bedded and with banded coloration, gray to tan; contains a 6-in. sand lens that thickens to 6 ft at 200 ft farther northwest	548–527
Sand, loose, crossbedded in 4- to 8-in.-thick beds, gray; 2-in. layer of pebbles at base	527–514
Siltstone, spotted with calcareous concretions, greenish-gray; a massive zone at 511- to 507-ft altitude makes a prominent escarpment	514–476
Silt, sandy with silty sand at base grading upward to clayey silt at the top, yellow-buff	476–468
Sand, medium, buff; lower part is micaceous and poorly consolidated, and upper part is silty and compact; characterized by 2- to 5-in.-thick crossbedding foreset mostly to west and southwest; a 6-in. calcareous hard sandstone layer lies 1 ft below top	468–444
Conglomerate; same as material from the 470- to 415-ft zone in the first geologic section; river gravels with spherical pebbles and cobbles, rude bedding, shingled structure, and sand-filled interstices; pebbles and cobbles are about 45 percent basalt and 55 percent upriver exotic rock types; in upper 50 ft the sand beds and lenses are more numerous, and the cobbles are more nearly 65 percent exotics and 35 percent Columbia River Basalt; 6-in. layers of strong cementation present at top and at 427-ft altitude	444–371
Covered; roadway and banks	371–351

Geologic section westward down the bluffs at power line crossing sec. 12, T. 11 N., R. 28 E.

	Altitude (feet)
Covered; soil	716–650
Clay, more silty progressively upward, massive; contains vertical sand dikes from above	650–639
Covered	639–609
Sand, fine, angular, micaceous, horizontally bedded and crossbedded, loosely compacted in upper 5 ft; contains silty layers; basal 3 in. is strongly cemented and contains scattered pebbles	609–606
Clay, silty, tan	606–604
Clay, greenish-brown	604–600
Clay, tan	600–597

	Altitude (feet)
Clay, plastic, greenish-brown	597–591
Clay, plastic, tan, iron-streaked	591–588
Silt, massive, tan and yellow banded; becomes more clayey toward top	588–567
Sand, silty, fine to medium, compact, angular, crossbedded; has concretionary lumps and nodules; uppermost 10 ft is finer, silty, and nonconcretionary	567–532
Clay, plastic, jointed, greenish-brown	532–529
Sand, silty, angular, medium; becomes more silty upward; a 6-in. bed at base is iron-stained flaggy sandstone containing a few pebbles and cobbles up to 4 in. in diameter	529–503
Sand, silty, generally loose but compact in places, crossbedded, micaceous, light-gray; becomes more silty and clayey toward top	503–490
Clay, silty, tan in lower part grading upward into light-brown, plastic, relatively pure clay	490–478
Clay, silty, massive; grades upward into clayey white volcanic ash	478–475
Clay, massive, light-tan but brown in lower 4 ft	475–467
Clay, plastic, dark-brown	467–465
Clay, silty, massive, tan	465–462
Sand, clayey, well-compacted, rudely stratified and progressively more massive toward top, tan; has thin laminae of gray clay and iron-stained planes	462–454
Sand, medium, angular, micaceous, tan, loose in lower part but compact and well-bedded in upper part; upper surface shows erosional channels 2 to 4 ft deep	454–433
Conglomerate; well-rounded pebbles and cobbles with a few boulders in a matrix of medium indurated clean angular quartzose sand; rude foreset bedding stratifications are present, and uppermost 20 ft contains several 6-in. beds of sand that are cemented to hard resistant rock; pebbles and cobbles consist of 70 percent exotic rock types (45 percent quartzite, 25 percent porphyries and granitics) and 30 percent basalt; basalt particles have a whitish-brown weathering rind up to ⅛-in. thick	433–346

Geologic section northwest and southwest down the bluff to a point near the southeast corner of the NE¼NW¼ sec. 14, T. 12 N., R. 28 E.

	Altitude (feet)
Covered; whitish-gray silty-sand soil	886–854
Sandstone, medium- and fine-grained, silty; calcified in irregular plates, streaks, and nodules; composed of 75 percent siliceous and 25 percent basaltic and other dark grains	854–839
Diatomite, silty, whitish-pink; a distinct marker bed of considerable lateral extent	839–837
Sand, medium, silty, loose but with top 6 in. strongly cemented to hard sandstone, brown	837–834
Claystone, silty, dun; contains many concretionary nodules; strongly calcified in lowest 2 ft	834–827
Silt, clayey, and silty claystone, massive, buff; lower 18 in. is a mauve clay in places; cliff-forming unit	827–819
Sand, fine, silty, micaceous, laminated, whitish-gray	819–804
Silt and fine sand, interlayered, whitish-buff; top sand laminae cemented to firm sandstone	804–789
Siltstone, sandy and clayey, massive, yellow-buff; a prominent cliff-forming unit of considerable lateral extent	789–717
Claystone, finely laminated, progressively more silty and less laminated toward top, white	717–699
Sand, fine, loose, micaceous; slightly silty and in places contains hard layers	699–694
Siltstone; like that below but more laminar, whiter; becomes sandier and has sand laminae toward top	694–660
Siltstone, banded yellow and white but with rather massive structure, buff and gray in general appearance; a prominent cliff-forming zone that can be seen to continue many miles along the bluffs	660–635
Clay, silty, greenish-brown, progressively more silty toward top	635–624
Sand, medium and fine, clean, well-sorted, loose, tan and gray; carries hard cemented layers and nodules in lower part	624–602
Siltstone, clayey, greenish-brown; has blocky jointing	602–575
Siltstone, sandy containing thin beds of fine sand, coarsely bedded, tan	575–571
Siltstone, massive, white, and zones of greenish-brown clayey silt	571–539
Claystone and siltstone; fissile at base grading into more massive white siltstone above	539–534
Siltstone, sandy in lower 5 ft, clayey above, tan with some fine gray sand layers in uppermost 30 ft	534–483
Sand, fine, silty, micaceous, compact, massive, yellow-tan	483–456
Covered	456–390±

Geologic section southward down bluffs to junction of a farm lane with "River Road" in NE¼SE¼ sec. 33, T. 13 N., R. 28 E.

	Altitude (feet)
Covered; soil with erratic cobbles and pebbles near base	908–891
Caliche; a calcareous and siliceous lumpy horizontal capping	891–884
Claystone, silty, and clayey siltstone; well-laminated in ¼-in. to 2-in. bands; lower half clayey siltstone and upper half silty claystone; whitish-buff	884–802
Siltstone, sandy, clayey, irregular in firmness and size of grains; a central reddish concretionary zone is a prominent cliff former	802–786
Claystone, silty, and clayey siltstone; massive, bluish-gray	786–761
Sand, fine and medium, loose, micaceous in the partings, intricately crossbedded; top is an erosional surface with 5 ft of relief in 50-ft distance but of a general even altitude	761–741
Siltstone, sandy with many sand partings (cemented) and many concretions; upper and weaker part of a strong siltstone cliff-forming zone whose material is part of a gradation between claystone below and sand above	741–702
Siltstone, bedded in laminae ½ in. to 2 in. thick; has some clayey silt and very fine sand laminae; lowest 4 ft and top part are gradational to material below and above	702–673
Claystone, laminated very finely at base and progressively coarser above; smooth novaculitelike material; whitish buff	673–662

	Altitude (feet)
Sand, fine, firm, gray and brown	662–649
Silt and sand interlaminated	649–640
Sand, silty, medium to fine, rather loose except for 2- to 6-in. cemented layer at base; finely crossbedded gray sand with silty laminae	640–616
Siltstone, laminated in bands ¼ to ⅛ in. thick, whitish buff; similar to underlying claystone	616–602
Claystone, banded in yellow and gray-buff laminae ¼ to ½ in. thick; a strong cliff former and distinct marker zone of considerable lateral extent	602–589
Siltstone, clayey, massive, buff toward base and bluish above; has much nodular concretionary matter	589–582
Sand, medium; has silt interlayered in 3- to 12-in. beds at base but is progressively more silty toward top; sand is finely crossbedded in water-laid (lake-current) type of deposition	582–570
Sand, medium, loose, clean, crossbedded, micaceous	570–543
Claystone, silty, dark, damp; has much nodular concretionary matter	543–526
Clay, silty, and clayey silt; blocky and massive, whitish-buff in lower 30 ft and dark-brown-green toward top; fossil bones of peccary *Platagonus* at 525-ft level	526–471
Clay, silty, dark-green and brown but whiter toward top; contains much secondary gypsum, iron oxide, amber, and carbonized wood	471–461
Sand, medium to fine, whitish-gray, secondary gypsum crystals common at base	461–458
Silt, partly indurated, whitish-gray	458–454
Silt, sandy toward base but more clayey and more compact upward; top 10 ft is a green-drab claystone that is hard and "flinty"	454–428
Sand, medium and fine, fairly loose, brown; base not exposed	428–426
Covered	426–410

Geologic section westward down the bluffs to river's edge in NE¼SW¼ sec. 21, T. 14 N., R. 27 E.

	Altitude (feet)
Siltstone, sandy, layered in ⅛- to 1-in. bands with interlayered laminae of fine sand; top is an even erosional surface overlain by Touchet Beds of the glaciofluviatile deposits upward to the 629-ft altitude, above which active sand dunes form the terrain	596–584
Siltstone, clayey, crumbly, massive; contains some calcareous concretions ½ in. in diameter	584–567
Clay, silty, massive; more firm in upper 3 ft, which form resistant ledge	567–558
Silt, clayey, crumbly, bluish-violet	558–553
Siltstone, massive, crumbly, bluish-gray in lowest 8 ft and darker above	553–509
Siltstone, clayey, massive; upper 6 ft marked by iron-stained bands; buff-color	509–462
Claystone, massive, slightly silty upward, dark-brown when damp and grayish-white when dry; top is slightly undulating iron-stained surface, near which fossil wood and bones are located	462–433
Clay, silty at base; beds of brown-green and gray clay; base not exposed	433–389
Clay, massive, brownish-green	389–375

CHARACTER AND EXTENT OF THE STRATA BEYOND THE TYPE LOCALITY

The Ringold Formation, or material of similar lithology, extends downward to the basalt bedrock, or to a thin transitional deposit that may be a product of pre-Ringold weathering or a soil zone at the top of the basalt. While it might be contended (1) that no paleontologic evidence has been obtained to establish the material below river level as a definite extension of the Ringold Formation and (2) that the material might in part be equivalent in age to other deposits, such as the upper part of the andesitic Ellensburg Formation of the Yakima Valley, the siliceous lithology and the stratigraphic continuity of those "below-river-level beds" establish them definitely as a downward extension of the Ringold Formation of the type locality (Newcomb, 1958, p. 330).

The logs of wells 13/27–13N1, 12/28–24N1, and 10/28–10G1 in table 2 show the extension of the Ringold Formation below river level in wells along the east side of the reservation near the type locality. The logs of other wells in table 2 record the lateral continuation of the Ringold Formation at depth beneath other parts of the reservation.

Siltstone, distinctive of the Ringold Formation, crops out in sec. 12, T. 10 N., R. 28 E., east of the river in the road bank south of the Pasco Farms pumping plant. Similar material was dredged up in the abandoned excavation for a public water supply pumping plant at the foot of Lee Boulevard in the east-central part of Richland. Apparently, it is present at very shallow depth at places in the river bank between Richland and North Richland.

DISTINCTIVE LITHOLOGIC ZONES

The lowest part of the Ringold Formation commonly has been logged by well drillers as "blue clays," and that name has come into use locally for the blue and green silts and clayey silts that form the lowest 100 or so feet of the Ringold Formation and extend upward from the basalt bedrock to an altitude of about 290 feet in the Richland area. Close examination of drill samples reveals the material to be more silt than clay and to contain considerable sand, presumably as thin interbeds. Gravel and sand beds are interbedded within the "blue clays" and in some places even predominate over the "clays." Apparently the most distinctive feature is the blue or green color that suggests the material has not undergone oxidation as have the other Ringold "clays" and silts that mostly lie above the regional water table. The "blue clays" zone is well known in the Richland area and southeastward to Kennewick and Pasco where it occupies most of the saturated part of the Ringold and forms a major obstacle to the development of ground water from the Ringold strata.

Above the "blue clays" in the southern part of the reservation, the conglomerate zone extends from an altitude of about 290 feet upward to an altitude of about 450 feet. It is the most distinctive and most permeable subunit of the Ringold Formation and is of paramount significance to the ground-water and waste-disposal situation of the reservation area.

The conglomerate zone extends across the reservation from the Rattlesnake and Yakima Ridges on the west to a transitional margin that runs southeast about through Wahluke and old Ringold, hence southeast toward Pasco. Longitudinally, it extends northwest and southeast beyond the reservation. The base is little, if any, higher beneath the north side of the reservation, and it may be as much as 100 feet lower at the northwest side. The top may be considerably higher in the northern part of the reservation, as it was believed identified at 500 or 560 feet altitude beneath the high terrace lands west of Gable Mountain. Toward its eastern margin the conglomerate becomes progressively more sandy until, near its edge in The White Bluffs, it is made up almost entirely of sand in the bluff exposures in sec. 36, T. 12 N., R. 28 E.

A river-laid train of this type across a broad basin of newly deposited fine-grained materials must have been flanked by active areas of wind erosion. Such wind reworking and removal may have contributed greatly to the eolian loess of the Palouse Formation to the east (Newcomb, 1961b).

The conglomerate is a rather uniform aggregation of well-rounded pebbles and cobbles with the interstitial space almost completely filled by medium to fine subrounded and angular siliceous sand. The pebbles and cobbles consist of about 65 percent quartzite and other metamorphic, granitic, and volcanic porphyry rocks of upriver or exotic types and 35 percent basalt of the type in the Columbia River Group. The sand is largely upriver quartzose material. Sand lenses and beds are common, and lenses of sandy silt are rare in the conglomerate.

The conglomerate zone, lying in the general 290- to 450-foot altitude range but locally extending down to 190 feet and up to 560 feet at the southwestern side of the Pasco Basin, was subjected to late Pleistocene dissection that preceded and accompanied the basin-fill deposition. Thus, beneath much of the reservation area, the gravelly glaciofluviatile and fluviatile deposits lie directly upon an erosional surface cut on the conglomerate. In many wells this circumstance makes difficult the distinction of the exact contact between the two gravelly geologic units. The moderately permeable conglomerate beneath the reservation provides many important functions. The permeability of the conglomerate is sufficiently large to allow moderate quantities of ground water to be transmitted to wells and is still small enough to allow large quantities of waste water to be artificially stored without rapid percolation to the ground-water outlets.

The position, shape, thickness, and lithology of the conglomerate zone indicate that it represents a river-laid train of gravel deposited across the slowly sinking floor of a basin. In this basin, quiet-water sediments had been deposited previously and subsequently were to be deposited again. Thus, the conglomerate testifies to a time in which the impounding rim was still low enough to allow the river to flow as a gravel-carrying stream across the subsiding basin of deposition.

Beneath the west side of the reservation and adjacent to the mountains, the lower part of the Ringold Formation, and particularly the zone occupied by the conglomerate member, contains much angular and subangular basaltic debris in part imbedded in silt. Wells 12/25–3D2 and 12/25–23K1 penetrated materials of that particular character. These materials represent a fanglomerate facies derived by alluvial wash from the adjacent mountain valleys and slopes. It is a local variation of the conglomerate zone but is one which extended over considerable vertical range along this mountain front during the accumulation of the Ringold deposits.

Some of the stratigraphic features of the conglomerate are shown on the cross sections (pl. 1) and in the well logs (table 2).

In large part, the sand, silt, and clay exposed at the type locality are in strata which contain granular gradation toward the type of materials next overlying and underlying. Thus, many of the laminated beds and layers of silt, fine sand, clay, and volcanic ash seem to have rhythmical changes in a vertical direction as though their deposition occurred amid the shifting currents in a large lake. Singularly thick zones of one grain size are the exception rather than a common feature of the formation; however, there are some distinct sequences of strata within which any one general grain size predominates. Thus, thick sand beds are more common to the southern half of The White Bluffs, massive silt predominates farther north, and thick clay is most common at the extreme northern end of the bluffs. There is general evidence that gravel and sand characterized Ringold deposition in the current-carrying part of the lake and that silt and clay characterized deposition in the quieter, shallower, and marginal parts. The thick clay and silt present in the northern part of The White Bluffs do not occur in the part of the formation that erosion left beneath the terrace lands of the reservation.

EXTENSIONS OF THE RINGOLD FORMATION NEAR THE RESERVATION

Ringoldlike strata, which apparently belong to the Ringold Formation, were observed beyond the mapped area (pl. 1) in the SW¼ sec. 25, T. 9 N., R. 28 E., in the ravine southwest of the Richland "Wye," and near the north quarter-section corner of sec. 22, T. 12 N., R. 24 E., in the north side of Dry Creek valley floor. Also, these deposits occur at many places northeast of The White Bluffs as far as Eltopia, Connell, and Othello and at the top of the east bluff of the Columbia River 5 miles south of Beverly (in secs. 26 and 35, T. 15 N., R. 23 E.).

RELATIONS OF THE RINGOLD FORMATION TO THE DEFORMATION OF THE BASALT BEDROCK

The Ringold Formation exposed in The White Bluffs is not deformed tectonically. Many of its marker beds are discernible for miles with negligible variations from the same altitude. Inclinations of strata by fractions of a degree downstream and centripetal to the basin of deposition, as cited by Brown and McGoniga (1960) for the deposits exposed in The White Bluffs, are normal sedimentary and compaction features of this type of lacustrine deposits.

Northeast of the reservation, the Ringold exposed at McChesney Springs, Connell, and Paradise Flats south of Othello show that part of it, presumably the lower part, was elevated along with that part of the region. The observations of Jones (1945) at the Potholes Dam site north of Othello showed that the Ringold, presumably the lowest part, at that place had been tectonically deformed in the Lind Coulee flexure.

In the few places where Ringold strata are preserved near the reservation at the edges of the deformed basalt ridges, the strata show dips that represent tectonic folding. In the ravine southwest of the Richland "Wye," the strata dip to the north. In the Dry Creek locality (sec. 22, T. 12 N., R. 24 E.), they dip to the south. Apparently, near the edges of the basin the lower parts of the Ringold Formation were involved in at least part of the tectonic deformation that produced the present Yakima Ridges and Horse Heaven Upland (Newcomb, 1958, p. 339).

Thus, the lithology and the structure observable in the Ringold Formation corroborate two stages of the deformation of the bedrock basin. The fine-grained deposits below the conglomerate zone or its lateral equivalents, were elevated or deformed in places around the edges of the basin. The part of the conglomerate exposed in The White Bluffs has undergone only the relative downward position change associated with the Pasco syncline. The postconglomerate strata in The White Bluffs and elsewhere do not show evidences of the deformation.

Observations from the structural relations of the Ringold Formation in and near the reservation and those cited at the Potholes Dam agree with Warren's (1941) conclusion that the Ringold Formation was deposited contemporaneously with the uplift and deformation that produced the mountainous ridges of the region. In view of the middle or late Pleistocene age of the Ringold Formation derived by Strand and Hough (1952), the evidence cited above now indicates that the tectonic deformation of the region, with which the deposition of the Ringold coincided and closely followed, is considerably younger (by one million or half a million years) than had been previously supposed.

The middle or late Pleistocene age determination published by Strand and Hough (1952) is reported to have caused thorough reexaminations of several large collections of Ringold fossils, but no evidence for a change or refinement in that age has been published. The formation has been referred to as Pleistocene(?) (Mackin, 1961, p. 39) and has been suggested as "early Pleistocene or even Pliocene" (Brown and Brown, 1961, p. 16 and 17), but no facts have been presented to support such age assignments.

The relatively large group of vertebrates collected by various paleontologists from the Ringold Formation have been Pleistocene forms. One of these forms, the mastodon *Mammut americanum*, was characteristic of the latter part of the Pleistocene; at its type locality at Big Bone Lick, Ky., this form was found in deposits identified as dating from the Wisconsin Glaciation or the Sangamon Interglaciation (Strand and Hough, 1952, p. 154). However, as Jean Hough stated at the time of determination, "* * * the species may well have existed earlier in other parts of North America."

END OF RINGOLD DEPOSITION

The deposition of the fine-grained materials that make up the upper part of the Ringold Formation ceased rather abruptly. That conclusion is derived from the fact that the erosive current of the river, when reestablished through the basin of deposition, did not flow widely over the bed of the Ringold lake. The lack of any river transgression over the lakebed is witnessed by the absence of coarse current-transported deposits of a later Ringold age beneath the broad plateau areas that now represent a close approximation of the top to which Ringold material accumulated. Possibly a rather abrupt erosional lowering occurred in the bedrock lip that controlled the level of the Ringold lake and the upper limit to which Ringold materials could be deposited. The river entrenched itself backward rapidly through the soft materials and became fixed in a broad trough in which it has since remained except for the aberrant flood outwashes, impoundments, and diversions of the later glacial waters. The river's erosion of the Ringold Formation prior to the deposition of glacial outwash was confined to the rather narrow swath which the river is now enlarging in the Pasco Basin.

Also, the top and outer edges of the Ringold deposits must have been extensively altered by wind erosion of the soft light materials. The widespread Palouse Formation to the leeward side of the Ringold deposits is a loess that was, in large part, accumulated between the start of the Ringold deposition and the later arrival of glacial melt waters (Newcomb, 1961a).

That the post-Ringold climate was dry, at least in part, is indicated by the strong calcium and silica ("caliche") impregnation that developed on the interstream plateaus during the interval between the drainage of the Ringold lake and the carving of the transplateau channels of the glacial melt waters. The caliche forms a capping to the Ringold deposits in the type area and some other areas into which the Ringold Formation extends.

The youngest beds of the Ringold Formation are now recognized as those that underlie the surface of the plateau at the top of The White Bluffs. Considering the age of deposition of the Ringold as middle or late Pleistocene, a period of about 300,000 years remained for the subsequent events that shaped the present reservation topography and formed much of the near-surface geology that controls many aspects of the present engineering operations on the reservation.

GLACIOFLUVIATILE AND FLUVIATILE DEPOSITS

HISTORY

The deposition of the Ringold Formation was followed by an erosional period in which the ancestral Columbia River (and Yakima River) stripped the soft Ringold materials and some of the basalt bedrock from the swath in which the reservation is located. With interruptions, and at various rates, that erosion has continued to the present time, but the first onset must have largely accomplished the removal of the Ringold materials to a depth of several hundred feet over all but the eastern side of the swath. The current-laid gravels and sands that were deposited by the river during this erosional stage in large part may have been removed later, but the deposits stemming from that first onset of erosion crop out in few places and probably overlie the eroded Ringold surface beneath some of the higher terraces of the reservation.

The principal, and probably only, southward invasion of the Pleistocene glaciers in eastern Washington is correlated with the Wisconsin, the last of the Pleistocene continental glaciations (Flint, 1937, p. 222). The last advance of this continental glacier may have started but 60,000 years ago. The main advance of the ice lobe down the Okanogan River valley and across the Columbia River Gorge, where the ice lobe diverted the river and melt waters to the scabland channels of the Columbia Plateaus, probably occurred less than 32,000 years ago. A radiocarbon date of 32,700±900 years B. P. (before present) has been determined for woody material dug from outwash gravels, called prescabland in age, along the Columbia River near Beverly, 15 miles northwest of the reservation (Fryxell, 1962).

A sample of wood, U.S. Geological Survey W2310, collected from the next to the oldest of four gravel units exposed in excavations in the SE¼ sec. 19, T. 13 N., R. 27 E., at the southern end of the fault crossing Gable Mountain, was dated as older than 40,000 years (J. W. Bingham, oral commun., 1969). It is not known if this gravel unit is of glaciofluviatile age, though the top unit at that place can be so classified.

At its southern limits the Wisconsin glacial ice reached a generally east-west line 60 miles north of the Hanford Reservation. Thus, the geologic effects in the reservation area were limited to melt water and its debris, icebergs, and climatic changes.

The first significant interruption of the progressive and continuous late Pleistocene erosion of the swath in the Ringold Formation was a filling episode. It is assumed that these glaciofluviatile deposits may have been caused by the overloading of the Columbia River with the debris contributed at the melting front of the glacial ice.

The aggraded glaciofluviatile deposits filled the river valley with gravel and sand to an even surface which sloped about 10 feet per mile downstream; the top of that fill was at an altitude of about 900 feet at the northwest edge of the Wahluke Slope and at an altitude of about 500 feet in the Pasco-Kennewick area. The high terraces on the western part of the Wahluke Slope, the 800-foot terrace in the northwestern part of the reservation, the 500- to 600-foot terraces south of Enterprise (West Richland) and The Horn, and the 500-foot terrace northwest of Pasco and southwest of Kennewick (Highland Terrace) are altered remnants of this level of alluvial fill. The aggradation may have coincided with the maximum advance of the glacial ice — an encroachment which diverted much of the Columbia River drainage southward across the plateaus in the stream-valley scars known as the Scabland Channels. The glaciofluviatile and fluviatile deposits which accumulated in this aggradational fill, as well as minor overlying materials that were deposited locally during the subsequent erosion, are referred to as the "deposits of the high terraces."

Of the numerous scabland channels by which the glacier-diverted river flowed across the Columbia Plateaus to the Pasco Basin, only one, the Scooteney Channel, crossed directly into the area of the reservation. The preserved bed of the earlier branch of the Scooteney Channel lies at an altitude of about 600 feet where it is now truncated by The White Bluffs in secs. 11, 13, and 14, T. 12 N., R. 28 E. The bed of the later channel, a mile farther south, is at an altitude of about 500 feet. The gravel bedload of the Scabland Channels is distinctive — being almost entirely basalt — a type of deposit known commonly as the scabland gravel deposits. The altitude of the channel beds on which the Scooteney Channel deposits were laid down, 100 to 200 feet below the top of the deposits of the high terraces, indicates that these scabland gravels were deposited at this place after the period of maximum aggradation of the glaciofluviatile deposits.

Part of the initial glaciofluviatile fill was removed during an erosional epoch which followed the maximum alluviation, and the resultant terrace "benches" were left along the Columbia River. The degradation may have coincided with an early reintegration of the Columbia River drainage as the ice melted back from where it blocked the river's gorge at the north edge of the Columbia Plateaus. The deposits of the early glaciofluviatile fill were partly eroded away by successively lower sweeps of the river. During these erosional sweeps, the river backlaid the gravel and sand which underlies the terraces of the reservation. The 740-foot terrace south of Gable Butte, the 650- to 600-foot dune-covered terrace that extends eastward from lower Cold Creek valley, the 530-foot terrace northwest of Gable Mountain, the 520-foot terrace and the 460-foot channel south of Gable Mountain, and the prominent 520-foot terrace that extends south and west from T. 12 N., R. 27 E., all received their general form during this degradational epoch. During this degradation, several trains of very large angular basalt blocks and boulders were deposited in the glaciofluviatile and fluviatile materials. A stratum of this type forms the erosion-resistant reef over which the Columbia River cascades in Coyote Rapids. Other boulder trains occur within the fluviatile deposits beneath the 530-foot terrace in sec. 13, T. 12 N., R. 26 E., and secs. 7, 8, 17, and 18, T. 12 N., R. 27 E., south and southeast of Gable Mountain. Because the blocks are angular, or only subrounded by stream transport, it is assumed that they come from a nearby source, mainly from the badly eroded north escarpment of Umtanum Ridge, just west of the reservation.

The degradation had probably proceeded until the river flowed at an altitude of about 400 feet in the Hanford area when it was temporarily interrupted by an impounding of the Columbia River in glacial Lake Lewis, during very late Pleistocene time.

The Touchet Beds and its associated erratics was laid down as a blanket 10–150 feet thick that extended up the inclined sides of the lakebed to a maximum altitude of about 1,150 feet. The lakebed upon which these deposits accumulated was somewhat similar to the present surface. The lake of deposition (proglacial Lake Lewis) remained only a brief time at its maximum level, as discernible shorelines were not produced generally at that level. However, a remarkably large amount of sand- to boulder-size erratic material was deposited in a widespread manner (presumably by iceberg rafting) at all levels up to an altitude of about 1,150 feet.

In the slack-water parts of the lake, rhythmically bedded silt and fine sand accumulated. In some places near the center of the lake, the beds consisted largely of fine sand, as much as 150 feet thick in places. These deposits have been severely eroded and reworked by the wind. Some of the badly wind-worked glaciofluviatile and fluviatile deposits mapped in the central part of the reservation (between Gable Mountain and the Richland area) may belong to the Touchet Beds.

The glacial lake was drained as the river reduced the impounding dam, and the erosional epoch of the river was resumed in the Pasco Basin. The drainage of proglacial Lake Lewis apparently occurred more than 8,700 years ago, as Daugherty (1956, p. 234) reported a carbon-14 age of 8,700±400 years for bones found in a sand layer overlying Touchet Beds at Lind Coulee, 20 miles northeast of the Hanford Reservation.

The glaciofluviatile and fluviatile deposits that are younger than the Touchet Beds underlie the lowest terraces, close to the river, and were deposited as the river cut down progressively nearer its present position. The river-channel scars which form low terraces at White Bluffs, Richland, and other places were cut after the deposition of the Touchet Beds, probably in the very latest part of the glaciofluviatile episode. The river shifted generally against the soft Ringold materials of The White Bluffs. Blocks sliding from The White Bluffs temporarily moved parts of the river channel back to the west, where late glaciofluviatile and fluviatile deposits underlie the lowest terraces west of the river in the old White Bluffs and Hanford areas. Iceblocks still came down the river late in the post-Lake Lewis part of the glaciofluviatile episode, as shown by the knob-and-kettle topography on the low (460-ft) terrace northeast of Allard (in secs. 21, 22, 27, 28, and 33, T. 14 N., R. 26 E.) — suggesting ice jamming at an altitude of about 440–460 feet, up to a level about 75 feet above the present bed of the river. The erosional effects of the glacial ice and melt water apparently continued until the river had cut down to a level near that of its present bed.

LITHOLOGIC FEATURES

Gravel predominates in most facies of the glaciofluviatile and fluviatle deposits. It is a rudely bedded mixture of granule and pebble gravel with many cobbles and some boulders.

The gravels are loose, openwork materials. Cementation is generally absent, and only locally is a compacted, strong matrix filling present.

The gravel is made of well-rounded particles which in general are about 50 percent basalt of the Columbia River Group and 50 percent upriver rock types (quartzites, porphyrys, argillites, granitics, and other igneous rocks). The proportion of basalt to upriver exotic rock types varies from place to place and from one facies of the deposits to another. The scabland gravels are almost wholly basalt. The particles are relatively fresh rock and are devoid of weathering rinds. The granitic pebbles are sound and strong, in contrast to the decomposition found in many of the granitic pebbles of the Ringold Formation. Various amounts of secondary calcium carbonate coat parts of the gravels above the level of the water table. Some of the gravels contain considerable silt that occurs mostly as particle coating — indicating that the waters which deposited them were roily and silt laden. Some of the gravels indicate an influx of local material — those along the mountain fronts include local slope wash, and those near bedrock knobs or escarpments include trains of angular and subangular basalt boulder blocks.

Sand, predominantly coarse, occurs locally as an interstitial filling to the gravel, but it forms some separate beds and lenses within the glaciofluviatile and fluviatile deposits. Rare lenses and beds of silt occur irregularly within the principal current-laid deposits. Along with the finer sizes of sand, silt was the main deposit in the quiet-water facies of the Touchet Beds.

The sand, both that interstitial to the gravel and that in separate beds, differs in the percentage of the lithologic types in separate facies of the deposits. However, in general the siliceous upriver mineral and rock types predominate, in the common range of 60 percent quartzose and other exotic types to 40 percent basaltic types.

The percentages of rock and mineral types making up the grains in sand samples taken from the faces of the Gable Mountain quarry (NE¼ sec. 33, T. 13 N., R. 27 E.) and the concrete-mix plant aggregate pit (sec. 4, T. 12 N., R. 24 E.) are given below. Approximate percentages of mineral and rock types were determined from binocular microscopic examinations. (These quarries were located in the sandier parts of the glaciofluviatile and fluviatile deposits.)

Quarry	Grain size (Percent of total)	Rock and mineral types (percent)				
			Exotic types			
		Basalt	Rock	Quartz	Feldspar	Mica
Gable Mountain	Gravel (5)	60	40			
	Sand:					
	Very coarse to medium (60)	10	40	49	1	....
	Medium to very fine (35)	5	30	64	1	....
	Silt and clay (0)					
Concrete-mix pit	Gravel (5)	60	35	....	5	....
	Sand:					
	Very-coarse to medium (59)	10	38	48	1	3
	Medium to very fine (29)	2	22	70	2	4
	Silt and clay (7)		10±	80±	10±	....

The gravel particles in these quarries are mostly well rounded, but the sand particles are more angular, the coarse sand being subrounded and the finest being angular. The sand is poorly sorted compared with the sand of most of the Ringold Formation.

Special facies of the glaciofluviatile and fluviatile deposits are of somewhat minor extent and thickness but have lithologic differences from the general average. The scabland gravels are predominantly basaltic; the Touchet Beds is largely silt, fine sand, and erratic material. The earliest glaciofluviatile gravels, which closely overlie the Ringold, contain a greater percentage of siliceous exotic material — presumably reworked from the Ringold Formation. Some of the beds of glaciofluviatile gravel, especially those close above the Ringold Formation, contain large blocks of Ringold silt; those silt blocks now exposed in the gravel pit near the Yakima River southeast of The Horn are so angular as to indicate either very limited transport or deposition while frozen.

The glaciofluviatile and fluviatile deposits, in general, are rudely bedded. The main bedding dips gently in a predominantly southeast direction, but the direction of the dip of the crossbedding is irregular from place to place with only a slightly prevalent southeast direction. In a large excavation north of Gable Mountain, in sec. 1, T. 13 N., R. 26 E., a 40-foot thickness of stratified openwork pebble gravel and sand has near its center a 4½-foot bed showing foreset bedding that dips 20° in a north-northeast direction and near the bottom a 4-foot bed showing foreset bedding that dips 10° to the east. In a gravel pit southwest of Gable Mountain, in the northeast corner of sec. 34, T. 13 N., R. 25 E., about 15 feet of openwork pebble and cobble gravel is exposed and shows heavy particle coating of silt. The well-bedded foresets dip 30° to the south. East across the river from North Richland, upward from an altitude of about 345 feet, a 90-foot thickness of cobble and pebble gravel lacks distinct bedding stratifications. East of Richland and downvalley from the reservation, the top part of the glaciofluviatile and fluviatile deposits is exposed on the north side of the river in a 40-foot bank at the Old Timmerman Ferry and in railroad cuts west of Kennewick. In a 600-foot-long exposure in the railroad cuts, 10 feet of pebble and cobble gravel has crossbedding that consistently dips 40° in a southeast direction.

The silty, quieter water deposits that make up most of the Touchet Beds contain generally horizontal beds and locally include a laminar and varve-like bedding. At the type area near the town of Touchet, 32 miles east of Richland, the Touchet Beds consists of 2- to 36-inch-thick layers of silt alternated with 1/10- to 2-in-thick beds of fine sand. Most of the individual silt layers include a gradation upward from sand at the base to silt at the top (Lupher, 1944). In the lower part of the deposits the layers are progressively thicker downward. In different places the Touchet Beds overlies the bedrock basalt, the Ringold, or sand and coarsely bedded gravel, which is of both glaciofluviatile and local origin.

The lithology and bedding common to the type locality also characterize the silts of the Touchet Beds along Cold Creek valley in the western part of the reservation. The remains of these beds where they were laid down in the more open water areas nearer the center of Lake Lewis consist of more sandy material. This sandy material is believed to be the lake-current equivalent of the more quiet-water silt of the Touchet Beds. The less wind-worked sands near the surface in much of the central part of the reservation are fine to coarse, light brown, rudely sorted, and coarsely bedded in a generally horizontal manner, and they contain many silt lenses. Where the sands lack gravel, they have been extensively reworked by the wind. Such areas are the principal wind-worked parts of the reservation.

DIFFERENCES BETWEEN THE RINGOLD FORMATION AND THE GLACIOFLUVIATILE AND FLUVIATILE DEPOSITS

Because the distinction (especially in drill cuttings) between the Ringold Formation and the glaciofluviatile and fluviatile deposits is vital to the success of many ground-water developments and waste-disposal works, the distinguishing criteria of the two deposits are summarized in the table that follows.

Characteristic	Ringold Formation	Glaciofluviatile and fluviatile deposits
Lithology:		
Rock types	Upper Columbia River materials predominate, almost exclusively below medium-sand sizes.	Nearby basaltic materials predominate in gravel sizes and are relatively high in sand sizes.
Grain sizes	Silt and fine sand predominate; many thick and continuous silt and clay strata present.	Except for Touchet Beds, gravels and coarse to medium sand predominate; little clay present—only discontinuous silt beds and lenses.
Induration	Silt and clay compact; gravel and sand compact and contain strongly cemented beds; only newly exposed silt and sand vulnerable to wind erosion.	Material mostly loose; finer grained material blows badly in desert situations.
Sorting	Well sorted but uniform sand fills interstices of gravel; gravel and sand are clean washed.	Mostly poorly sorted except in parts of the Touchet Beds. Gravel particles mostly silt dusted.
Grain shapes	Gravel well rounded; silt and finer sand is angular.	Gravel well rounded; boulder blocks, silt, and sand are angular.
Alterations:		
Rinds	Alteration rinds 1/32 to 1/8 in. thick on basalt pebbles.	No appreciable alterations.
Cementation	Caliche impregnations; concretions in clays; some sand beds contain well cemented layers.	No known concretions; no appreciable cementation; only slight caliche accumulations.
Secondary	Secondary gypsum; fossil bone is petrified.	No known secondary gypsum; no known petrified bone.

HOLOCENE DEPOSITS

The materials that have accumulated since the Pleistocene Epoch, which ended with the melting of the glacial ice of continental type from the Columbia River basin, consist mainly of alluvial deposits closely above and at the present positions of the streams. The flood plain of the Yakima River lies upon the only extensive alluvial deposit in the reservation area. It and the playalike flats of Cold Creek were constructed and widened during post-glacial times.

The river-laid bars of gravel differ somewhat from place to place. Downstream from The White Bluffs the river bar gravels are largely exotic and basaltic gravels with a medium-sand matrix somewhat similar to the composition of the Ringold conglomerates. At the northern side of the reservation the postglacial gravels contain a larger percentage of the coarse basaltic material such as that on which the river is cutting in the Priest Rapids area to the northwest of the reservation.

The playas of Cold Creek and Dry Creek valleys are underlain by laminated silt and clay (pl. 1) to a thickness that locally exceeds 25 feet, as at Rattlesnake Spring.

White siltlike volcanic ash occurs locally on the lee sides of ridges trending transverse to windswept slopes. The index of refraction indicates that this ash belongs to the widespread fall identified as the Mazama Ash (Powers and Wilcox, 1964), from the ancestral Mount Mazama in which Crater Lake is situated. A distinct fall of such ash occurred about 6,600 years ago.

TECTONIC STRUCTURE OF THE ROCKS

GENERAL REGIONAL SETTING

The broad synclinal sag of the basalt bedrock beneath the Pasco Basin is flanked on the south by the 1,000-foot rise of the basalt to form the elongate Horse Heaven Ridge and on the southwest by the 500- to 2,500-foot rise of the basalt to form the slopes of the Yakima Ridges, of which Rattlesnake Hills are the largest and highest in and near the reservation.

The basalt is mildly folded and faulted into the structures that form the principal eminences and the bedrock downwarps of the region. The lower part of the overlying Ringold Formation is also deformed locally, though that structure is poorly exposed. The glaciofluviatile and fluviatile deposits have not been deformed tectonically.

The deformation in the basalt, aside from its part in forming the large units of the terrain, imposes limitations on the thickness and extent of the overlying sedimentary materials and exercises functional control over the deep circulation of ground water.

The magnitude of the regional deformation that has produced the present uplands and basins is suggested by citing some altitudes of the top of the basalt beneath and adjacent to the reservation. From the common base altitude of 200 feet beneath the Pasco and Richland districts, the top of the basalt rises southward to an upland altitude of 1,500 feet in the broad Horse Heaven Ridge to the south. Northward from Richland the top of the basalt is an irregular surface which extends down below sea level and rises over ridges that reach their greatest height in Gable Mountain. (See geologic sections and altitudes of bedrock given by spot figures on pl. 1.) At the southwest edge of the reservation, the Rattlesnake Hills attain an altitude of 3,500 feet, and the various secondary heights of the Yakima Ridges in upper Cold Creek and Dry Creek basins have altitudes of 2,500 feet within 10 miles of the reservation terraces. Northward from the reservation the basalt rises evenly to emerge from beneath its sedimentary cover and to reach an altitude of 2,000 feet in the linear Saddle Mountain anticlinal ridge 10 miles north of the Columbia River. Eastward the basalt rises evenly, and 12 miles east of the reservation, near Eltopia, it emerges from beneath the Ringold Formation at an altitude of 700 feet.

The master structural units of the region to the west of the reservation include long mountainous anticlinal ridges between which intervening synclines lie beneath valley lowlands. The main anticlinal ridges extend generally eastward from the Cascade Range and are collectively known as the Yakima Ridges (Newcomb, 1970). The principal ridges on or near the Hanford Reservation include (1) the Saddle Mountains, from which the Wahluke Slope descends southward to the Columbia River; (2) Umtanum Ridge, which terminates as the ridge north of upper Cold Creek but has the outliers Gable Butte and Gable Mountain; (3) Yakima Ridge, which terminates in the small mountains to the south of upper Cold Creek valley; (4) Rattlesnake Hills, from whose eastern end a strong cross structure continues diagonally southeast to connect with the northern part of the Horse Heaven Ridge; and (5) Horse Heaven Ridge, which lies south of the Yakima River valley and extends eastward to the Blue Mountains. The reservation area lies at the eastern end of Umtanum and Yakima Ridges and Rattlesnake Hills and is underlain in part by structures that belong to the Saddle Mountains and the Horse Heaven Ridge.

ALTITUDE OF THE BEDROCK BENEATH THE RESERVATION

The top of the basalt lies at a generally uniform level beneath the terrace lands in the southern and northern parts of the reservation. It rises toward the mountain ridges and toward the outliers of those uplifts. It also approaches, and even reaches, the surface in a few isolated highs. The altitudes of the basalt surface at depth beneath the reservation are given for a number of points on plate 1.

The northeastward dip of the basalt beneath the Richland area and the opposing westward dip beneath the plateaus farther northeast meet in the axial part of the Pasco syncline, which lies approximately beneath the Columbia River north from Richland to the old White Bluffs townsite and from there curves to an east-west trend along the north foot of Umtanum Ridge anticline (pl. 1). A secondary syncline that branches west from the Pasco syncline lies between Gable Mountain and Rattlesnake Hills and continues into upper Cold Creek valley. This secondary syncline, the Cold Creek syncline, contains some of the most deeply folded basalt and is of major importance to the geology of the reservation.

From an altitude of about 200 feet beneath Richland, the top of the basalt slopes to the east and north. It lies below sea level in a broad sag under the terrace plains in the south-central part of the reservation, in T. 12 N., R. 27 E. At well 12/27–16M1 the bedrock surface is more than 100 feet below sea level. North from this low sag the basalt rises to emerge steeply in the sharp and narrow structures of Gable Butte and Gable Mountain; its rather even rise to Gable Mountain is interrupted by a shallow trough, which may be partly erosional. This shallow trough continues northwest as the bedrock low between Gable Mountain and Gable Butte.

North from Gable Mountain and Gable Butte, the bedrock surface dips into the east-west part of the Pasco syncline. In well 13/25–1N2 the top of the basalt lies more than 200 feet below sea level. From about the south line of T. 14 N., it rises evenly toward the Saddle Mountains to the north. This even subsurface rise to the north is comparable to the rise of the bedrock eastward toward the Eltopia area east of the reservation.

At several places on the reservation at least one tuffaceous sedimentary zone occurs in the upper part of the basalt. This stratigraphic zone has been reported in logs of wells 11/27–20M1, 11/28–21L3, 13/26–34J14, 13/25–1N2, 12/25–23K1, and 13/25–30G1. The sedimentary zone occurs in much the same position and with the same relationships in these wells as it does in outcrops on the mountain slopes as described above under "Vertical Subdivision of the Basalt." The stratigraphic continuity of this tuffaceous zone further establishes the belief that the top of the basalt, beneath the postbasalt sedimentary deposits that underlie much of the reservation, is largely an original stratigraphic surface and, in general, has not been changed greatly by deep erosion.

The results of subsurface explorations indicate that the bedrock surface is essentially free of pre-Ringold river canyons. The data for the reservation area, combined with the bedrock information of Walters and Grolier (1960) for the area to the north and east, indicate that the freedom from pre-Ringold river canyons extends to much of the Pasco Basin.

DEFORMATION IN THE BASALT

SHAPE OF THE DEFORMED UNITS

The dominant structural shape of the uplifted mass (and of the downfolded mass so far as it can be determined) is the fold with asymmetrical cross section. Rattlesnake Hills are a type example. Of secondary importance is the symmetrical and elongate fold, of which Red Mountain is a type example. (See pl. 1.)

The broad downwarping of the basalt beneath the reservation is characterized by a gentle tilt of wide areas that separate the abrupt lines of greater deformation. Both gently tilted and sharply folded and faulted structures are present in the exposed basalt and, by inference, are judged to be present in the deformed basalt under the sedimentary cover. Along the western edge of the reservation the basalt emerges from its sedimentary cover and continues the same structural tilt upslope to near the anticlinal axes of Rattlesnake Hills and Yakima Ridge. In the lesser tilted blocks, the dips over wide areas are as low as 2°; two of the large areas of uniform dip comprise the dip slopes at the east and southwest sides of Rattlesnake Hills. Locally, dips as great as 85° are present along the lines of more severe deformation. Possibly still steeper dips, or local areas of overturned basalt, are covered by the slumped debris in some of the steepest parts of the severely deformed folds.

The top of the basalt before tectonic deformation is partly preserved in some of the uplifted units and is believed to be largely preserved beneath sedimentary cover in some areas of downfolding. In some sharply deformed structures — such as the north face of Umtanum Ridge, Gable Mountain, Gable Butte with its associated knobs, and the covered escarpment beneath secs. 1, 2, and 12, T. 12 N., R. 26 E. — the original top of the basalt after deformation has been destroyed by slump and erosion. In some severely uplifted parts, such as the north face of Rattlesnake Hills, the original surfaces on the basalt have been destroyed by landslides.

FOLDING AND FAULTING

The exposed structures indicate folding or bending of the basalt was by far the dominant type of deformation. Shearing and faulting appears to be confined largely to the steeply dipping parts of the asymmetrical folds. Within the zones of great

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deformation, the basalt rock yielded by bending as far as possible and sheared only where still further stress occurred. The steeply dipping northeastern limb of Rattlesnake Hills anticline contains shear planes parallel to the layering of the basalt. Some of this interlayer shearing has produced gouged and granulated zones each a foot or two wide in the planar contact zone between successive lava flows. This shearing between flows is evident in exposures of basalt dipping 70° to 80° to the northeast in ravines northeast of the highest part of Rattlesnake Hills.

Minor asymmetrical and symmetrical folds occur in some deformed units, and effects of minor slippages and bendings indicate that the basalt accommodated to the greatest stresses with combinations of bending and breaking. Gable Mountain exhibits this type of complex strain relief along the axial part of a steeply folded anticline. The flexures exposed in Gable Mountain have different directions of asymmetrical folding at each end of the mountain. The rocks of nearby Gable Butte are not exposed so well, but the intricate folds of the general anticlinal structure of the butte indicate complex stresses produced the typical linear zones which occur in greatly strained basalt.

The faulting observed was all of the normal type, in which the plane of shearing dips toward the downthrown side. Some reverse, or thrust, faulting may be present in the deeper parts of the steepest asymmetrical anticlines, such as the Horse Heaven Ridge southwest of Benton City, Umtanum Ridge north of Cold Creek valley, and Rattlesnake Hills.

SYNCLINAL STRUCTURES

Local downfolds and uplifts occur within the general synclinal structure of the Pasco Basin. Though geographically less conspicuous than the upfolded units, the synclines are of great importance in such phenomena as the accumulation and movement of ground water.

In addition to the deep sag beneath the southeast-central part of the reservation and the two east-west trending branches of the Pasco syncline north and south of the Gable Mountain uplift, two rather steep downwarps, which may have some interconnection, follow the foot of the mountain slopes in the western part of the reservation. One trends southeast beneath lower Cold Creek, at the lower end of the subsurface extension of the northeastward dip from Rattlesnake Hills (well 11/26–5B1). Farther north, another local downwarp trends north-south just east of the mountain front and across the emergence of upper Cold Creek valley (well 12/25–10N1). This sharp descent of the basalt across the east end of the mountain valley of upper Cold Creek alines with the abrupt end of Yakima Ridge to the south and may be a monoclinal flexure which includes some fault shear.

PATTERN OF STRUCTURAL DISPLACEMENTS

The traces of the axes of deformation shown on plate 1 form a parallelogrammatic pattern. The two main directions of trend have the general bearings N. 50° to 55° W. and N. 70° E. The trends change a few degrees progressively toward an east-west trend at the northwest edge of the map. Beneath the terrace lands of the reservation the northwesterly trend includes the structures of greater displacement; but the northwesterly structures are arranged sufficiently en echelon that they belong to a general east-west direction.

Major deformations with the conspicuous N. 50° to 55° W. and N. 70° E. trends are paralleled by subordinate folds. Also, there are distant continuations beyond the apparent ending of the major displacements. The Gable Mountain–Gable Butte uplift is this type of distant continuation of the trend of the main Umtanum Ridge anticline. The bedrock knobs in the south-central part of the reservation (sec. 34, T. 11 N., R. 27 E.) are apparently a continuation of trends from the west and the south. The knobs east of the mouth of Dry Creek are continuations of the asymmetrical fold along the north side of Dry Creek valley; they are a part of the Yakima Ridge.

EFFECT OF TECTONIC STRUCTURES ON THE OCCURRENCE OF GROUND WATER

BASALT OF THE COLUMBIA RIVER GROUP

A tilt of the basalt at the surface is advantageous to ground-water recharge either for direct infiltration or for the movement of water from streambed gravels and from deep sand and gravel aquifers, because it places permeable interflow zones in position to accept the water directly. In areas where the basalt layers are generally horizontal, the impervious nature of the dense central parts of many of the flows limits the opportunity for water to move downward and to recharge the ground water. This exclusion of water from horizontal basalt results in a general lack of water for wells and springs in this environment as compared with areas of tilted basalt. In horizontal basalt, ground water may be recharged predominantly by movement of water laterally for great distances.

Water in the unsaturated basalt moves laterally through porous interflow zones and any associated open joints and crossflow openings. Below the water table, movement of water through the interflow zones of the basalt is in response to a pressure gradient and, under similar conditions, can take place as readily in horizontal as in tilted aquifers.

The forces of deformation produced excessive strain on some of the basalt and developed planes of shear. Whether the deformation is in the form of tight folding with interflow slippage or solely in the form of shear rupture and fault displacement, gouging and grinding of the rock generally reduces its permeability at the shear planes. These zones of crushed rock can be barriers to groundwater movement. Such barriers cause the damming of ground water and, in some areas, may confine ground water so that it has pressure levels relatively close to the surface (Newcomb, 1961a).

The potentiometric surface of the ground water in the basalt, as known from relatively few wells beneath the reservation, is generally at about the level of the water table in the overlying Ringold Formation. Along the axial area of the Pasco syncline, the water level in the basalt is near that of the Columbia River. In the area between The Horn, on the Yakima River, and the Columbia River, the water level in the basalt stands near the level of the Yakima River. At well 10/28–10G1, north of Richland, the potentiometric surface is about 35 feet above the water table, which is at about the level of the nearby Columbia River. The basalt in the eastward-plunging synclines of upper Cold Creek and Dry Creek valleys, in and west of the reservation, contains confined ground water, apparently confined behind structural barriers that cross the lower ends of the valleys.

Wells drilled to a general depth of 600 to 1,000 feet in upper Cold Creek valley (well 13/25–30G1 in table 1), at West Richland (9/28–5C1), and at old Ringold (12/28–24N1) obtain confined water with yields of about 1,000 gpm (gallons per minute). The potential water yields of the basalt have not been tested in large areas of the synclinal structure beneath the reservation.

RINGOLD FORMATION

A slight warping type of deformation characterizes the conglomerate zone and the subconglomerate part of the Ringold Formation in the basinal area beneath the reservation. This warping elevated the conglomerate about 100 feet higher beneath the high terraces than along the axis of the Pasco syncline. This uplift, along with the subsequent erosion and the deposition of the glaciofluviatile and fluviatile deposits, gave the reservation its gravelly terrain and created the excellet drainage conditions of the high terraces.

PHYSIOGRAPHY

A résumé of the geologic features at the surface clarifies their origin and method of formation and should help in the proper and efficient use of the topography as well as the subsurface materials. The constructional features, such as mountain slopes, plateau surfaces, terraces, and valley plains, along with the destructive or erosional features, such as river bluffs, canyons, landslides, declivities, and blowouts, are the result of geological events that have formed this industrial site.

MOUNTAIN SLOPES

Despite minor subsequent erosion, many of the mountain slopes in and to the west and south of the reservation represent the basalt surfaces much like they were when they were more nearly horizontal. The southwest slopes of Rattlesnake Mountain, the apronlike slope descending from an altitude of 1,200 feet on that mountain to the Cold Creek valley, the broad ridge southwest of The Horn (on the Yakima River), and many lesser surfaces are largely dip slopes on the top of a resistant basalt flow. In many such places the top layer may be one that formed at the original top of the basalt accumulation. Other mountain surfaces, such as the top of Red Mountain and the crests of the dome-shaped mountains north of Dry Creek valley, are now subaerial erosion surfaces beveled across many basalt flows and interflow layers.

The whole north slope of Rattlesnake Mountain and smaller areas on other mountain slopes, such as those on the north side of Gable Mountain and on Umtanum Ridge west of the area shown on plate 1, consist of rock debris that has slumped and slid to its present position. Many of the lower slopes of the mountains have been mantled by alluvial wash from the higher parts and by materials transported from elsewhere. The north and east slopes of most of the ravines, hills, and mountains have a heavier cover of windblown soil than do the south and west, the wind-struck, slopes.

PLATEAUS

The principal plateau feature of the area is the upland surface at an altitude of about 1,000 feet that extends east and north (beyond the area of pl. 1) from the top of The White Bluffs. This surface is underlain by a thin layer of windblown soil and by erratic glaciofluviatile materials, but it is largely founded on the strong caliche zone at the top of the Ringold strata. To the north and east of The White Bluffs, this plateau extends for many tens of miles with only minor dissection by fluvial channels. Far beyond The White Bluffs, the plateau merges with regional slopes that are underlain by the basalt beneath a common cover of unconsolidated materials, such as the loess broadly referred to as the Palouse Formation. In the northern part of the reservation the plateau's escarpment has been sapped by the side sweeps of the Columbia River and entrenched by glacial melt water drainage; the plateau's surface is interrupted by low escarpments which descend to terraces underlain by glaciofluviatile and fluviatile deposits.

Adjacent to the reservation, the basalt underlies some uplands that are sufficiently level to be classed as plateaus; also, low-angle dip slopes, such as the southwest side of Rattlesnake Hills and the broad ridge southwest of The Horn, can be so classified.

TERRACES

By far the largest part of the reservation is terrace land. Some of these terraces have matched equivalents on each side of the Columbia River. Some of the highest terraces are essentially fill terraces and are underlain by deep sections, up to about 200 feet thick, of glaciofluviatile and fluviatile deposits, but most of the terraces below an altitude of 500 feet are essentially cut-and-filled surfaces formed by single sweeps of the Columbia River during the erosive part of late glacial-outwash time.

At present the vertical range of the river (from the bottom of its bedload to the maximum reach of its flood stages) is about 70 feet. Such a range commonly determines the maximum depth to which a river can deposit sediments during a single lateral sweep.

Most of the terraces are underlain by 50 to 100 feet of glaciofluviatile and fluviatile deposits, as shown in the well logs of table 2 and the geologic cross sections on plate 1. In places, the surficial part of the deposits underlying the terraces consists of wind-worked material, much of which originally belonged to the Touchet Beds facies of the glaciofluviatile and fluviatile deposits. The lowest terraces, such as those at old Hanford and at Richland, contain part of the form of the last channels vacated by the river. One of these youngest channel scars trends south from North Richland and passes through Richland. It contains the main fields of water wells used for many years for the Richland water supply.

ALLUVIAL PLAINS

The flood plain of the Yakima River west of Richland is a wide alluvial bottom land built up in the reach where the river apparently is base leveled on basalt bedrock ledges south of Richland. In this alluviated reach, downstream from the basalt ledges near The Horn, the Yakima River has a gradient of but 3 or 4 feet per mile southeastward to the rock ledges south of Richland. The flood plain deposits of that reach have little equivalent along the Columbia River above the mouth of the Yakima River. The low terrace plains farther up the Yakima River between Kiona and The Horn stand a little higher above the river and are underlain by slightly older material.

The alluvial plains along Cold Creek are underlain largely by playa-type silt and clay deposits built up as the velocity of the stream diminishes and the flood rushes of Cold Creek and Dry Creek deposit their loads of fine-grained sediment. These deposits also contain rock rubble delivered by flood runs from the arroyos of the adjacent mountain slopes.

DECLIVITIES AND LANDSLIDES

The northeastern extremity of the Umtanum Ridge, which forms the high escarpment along the Columbia River just west of the area shown on plate 1, the Gable Butte–Gable Mountain ridge, and various rock slopes and knobs along the Yakima River have been strongly eroded by the Columbia and Yakima Rivers. These slopes are erosional as contrasted to the constructional surfaces and the surfaces of minor subaerial erosion common to the basalt elsewhere on the reservation. The impingement of the Columbia River against the Umtanum Ridge has removed the northern and steeper limb of a large anticline and established a bold escarpment. The steep face exposes edges of the horizontal and southeastward dipping basalt near the anticlinal axis. The Gable Butte–Gable Mountain ridge in places has been stripped of several hundred feet of rock by the Columbia River during post-Ringold time.

The swing of the Columbia River outward against Ringold Formation has established and pushed eastward the escarpment known as The White Bluffs. Large blocks of the bluffs have broken loose and slid with rotational motion toward the river — those now remaining are labeled landslide deposits on plate 1. Some of those blocks are now unstable, and large open crevices along their slide planes testify to recent motion. The block in secs. 11 and 14, T. 13 N., R. 27 E., is in a position to cause some impoundment and diversion of the river, should it move rapidly across the river's present channel. The samples of drill cuttings of the Foster Ranch well, 13/27–13N1, indicate that disturbed material extends to a depth of 48 feet, a level that is probably the slide plane of the land-slumped block. Such a position in the well would indicate that the slide plane probably crops out near the lowest part of the riverbed. The toe of the slide block is now near the altitude to which the river stage could be artificially raised in floodtime by McNary Dam. The stability of the block could be adversely affected by greater immersion. The stability of other parts of The White Bluffs may become progressively threatened by the wetting of the formation farther east, in the newly irrigated parts of the plateau.

The north face of Rattlesnake Hills has slumped in large blocks, which moved toward Dry Creek valley. Other land slumps and slides are shown on plate 1. Some of the older slides of the basalt were contemporaneous with the mountain uplifts, but others occurred in late Pleistocene or Holocene time. The slumping that took place during the tectonic deformation resulted from the fracturing off of the top part of the oversteepened limbs of asymmetrical folds. In those slides, weak interbedded zones of tuff served as planes of failure; this can be observed in well-preserved landslides that occur along the northeast side of Rattlesnake Hills. The conversion of the tuff zones to slide planes has occurred commonly in many large slides in the steeply dipping parts of the basalt elsewhere in the region.

HYDROLOGY—GENERAL GROUND-WATER CONDITIONS

UNCONFINED GROUND WATER

The Columbia and Yakima Rivers are the base-level drainage below which the pore spaces of the earth are saturated. The top of the saturated zone of unconfined ground water is the main (or regional) water table. In general, it slopes toward the rivers. The slope of the water table depends directly on the resistance to the percolation of water through the rock materials and on the quantity of water that is present for transmission.

SHAPE OF THE WATER TABLE

The natural shape of the regional water table was mainly a subdued replica of the larger elements of the land surface. Because the unconfined ground water moves in the general direction of the slope of its top, the shape of the water table gives an indication of the input of water, the ease of percolation, and the velocity of travel of the ground water. The natural form of the water table in 1944 is approximated by reconstituted contour lines on plate 1, and artificially changed forms for 1948 and 1953 are shown on plate 2. The altitude and shape of the regional water table in 1961 are shown for the main reservation area by equal-altitude lines on plate 3.

The natural shape of the water table beneath the northwestern part of the reservation was dominated by a general high along the mountain front and by a slight high which underlay an area of recharge in the upper part of Cold Creek valley.

From the high level (altitude about 440 ft) near upper Cold Creek, the water table descended away from the mountains for about 3 miles at a gradient of about 10 feet per mile. Elsewhere, the natural ground-water gradient beneath most of the terraced plains of the reservation was a more gentle gradient of about 5 feet to the mile outward to where it approached the high levels of the Columbia River. In its natural state, the water table lay in the Ringold Formation eastward to the zone of bank storage and to a few channel scars along the east side of the terrace lands, where in places during high levels of the river the water table occurred just above the base of the glaciofluviatile and fluviatile deposits.

Within a belt along the Columbia River and extending irregularly for an average of about 2 miles from the river, the level of the ground water rises and falls in response to the river levels (figs. 3 and 4). During rising stages of the river, the adjacent water table rises by virtue of the physical transfer of river water to bank storage as ground water (Newcomb and Brown, 1961). Beneath the low terraces north of Gable Mountain, the ground water is annually recharged at floodtime by infiltration at the riverbed along the western side of this peninsulalike area. Part of the bank-stored ground water along the Columbia River just downstream from Allard progresses east and southeast to discharge in the river north and south of old Hanford townsite. The shape of the water table there differs from that in other parts of the bank-storage zone.

South and east of The Horn the water table slopes away from the Yakima River and toward the Columbia River, near which the water table rises and falls with variations in bank storage. Part of the ground water drains to the surface along the river-channel scar that traverses north-south through Richland.

Outside the reservation and across the Columbia River, the water table in the Ringold Formation and the basalt has a general slope of about 35 feet per mile southwest to the river (Walters and Grolier, 1960, pl. 2).

In general, the regional water table is the surface of a free, or unconfined, body of ground water which is under only the pressure of the atmosphere. However, at places this ground water is slightly confined by passage beneath less permeable materials, and the water table may represent, or coincide with, some potentiometric surfaces that are included within the general irregularities of the regional water table.

WATER-BEARING MATERIALS

Within the reservation the regional water table lies mostly in the Ringold Formation. The ground water moves in the Ringold Formation and in the underlying basalt downgradient toward points of discharge. In only a few places are the glaciofluviatile and fluviatile deposits known to extend downward to slightly below the natural position of the water table. (See sections on pl. 1 and tables 1 and 2.) However, the closeness of the base of the highly permeable glaciofluviatile deposits to the water table at the east side of the reservation (fig. 2) indicates that these permeable deposits served as overflow outlets for rapid drainage of ground water that has reached high levels. During or following high stages of the river the water table rises to the level of these more permeable glaciofluviatile materials at North Richland (well 10/28–14K2), at the old Hanford townsite (well 13/27–36G7), and at a few places along the river farther upstream (such as near well 14/27–32R1).

Most of the Ringold Formation, where it occurs beneath the terraced plains of the reservation, is sufficiently sandy to transmit water vertically to the water table. Consequently, few bodies of perched ground water occur naturally. In a horizontal direction the Ringold beds transmit water more readily than they do in a vertical direction, especially so in the sand and gravel (conglomerate) strata. The conglomerate seems to provide a path of relatively uniform permeability for the general lateral movement of the ground water beneath the reservation.

The basalt has an overall low to moderate permeability largely owing to the high permeability of relatively thin individual porous interflow zones. The hydraulic continuity of the permeable zones in the basalt is sufficiently integrated that over broad areas there is general agreement between the level of the unconfined and confined water in the basalt and the level of the water table in the overlying sedimentary materials. Locally, variations in the overall average permeability and in the structural conditions govern interchange of water between the basalt and adjacent materials. These variations result in the occurrence of minor bodies of confined water at places in the basalt beneath both the reservation and the adjacent areas.

The glaciofluviatile and fluviatile deposits, much of the alluvium, and the colluvium are sufficiently

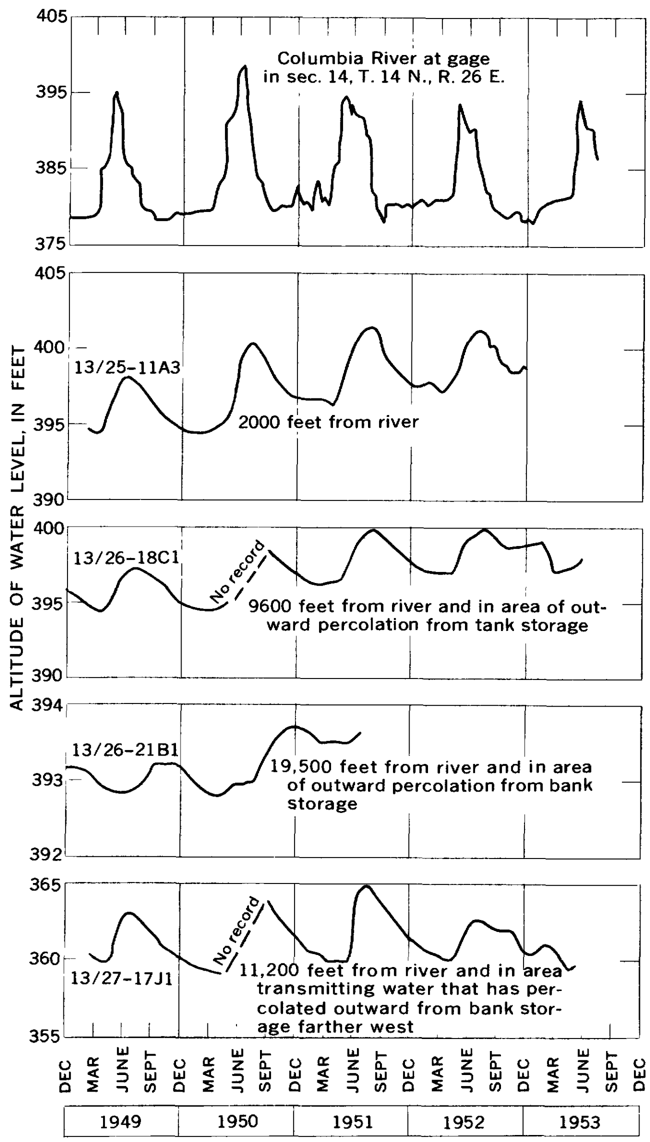

Figure 3. — Water levels in four wells in the northern part of the reservation compared with the water level of the Columbia River.

permeable to permit water to infiltrate readily and to transfer downward to the water table or to the underlying earth materials. The high vertical permeability of these porous materials is of great significance both to the transmission downward of the meager natural recharge and to the infiltration of liquids disposed from industrial plant operations.

CHANGES IN THE LEVEL OF THE WATER TABLE

Records of the level of the water table beneath the reservation show three general conditions — two natural and one artificial. The two natural conditions are: (1) A lack of any appreciable recharge in conformity with the annual precipitation cycle

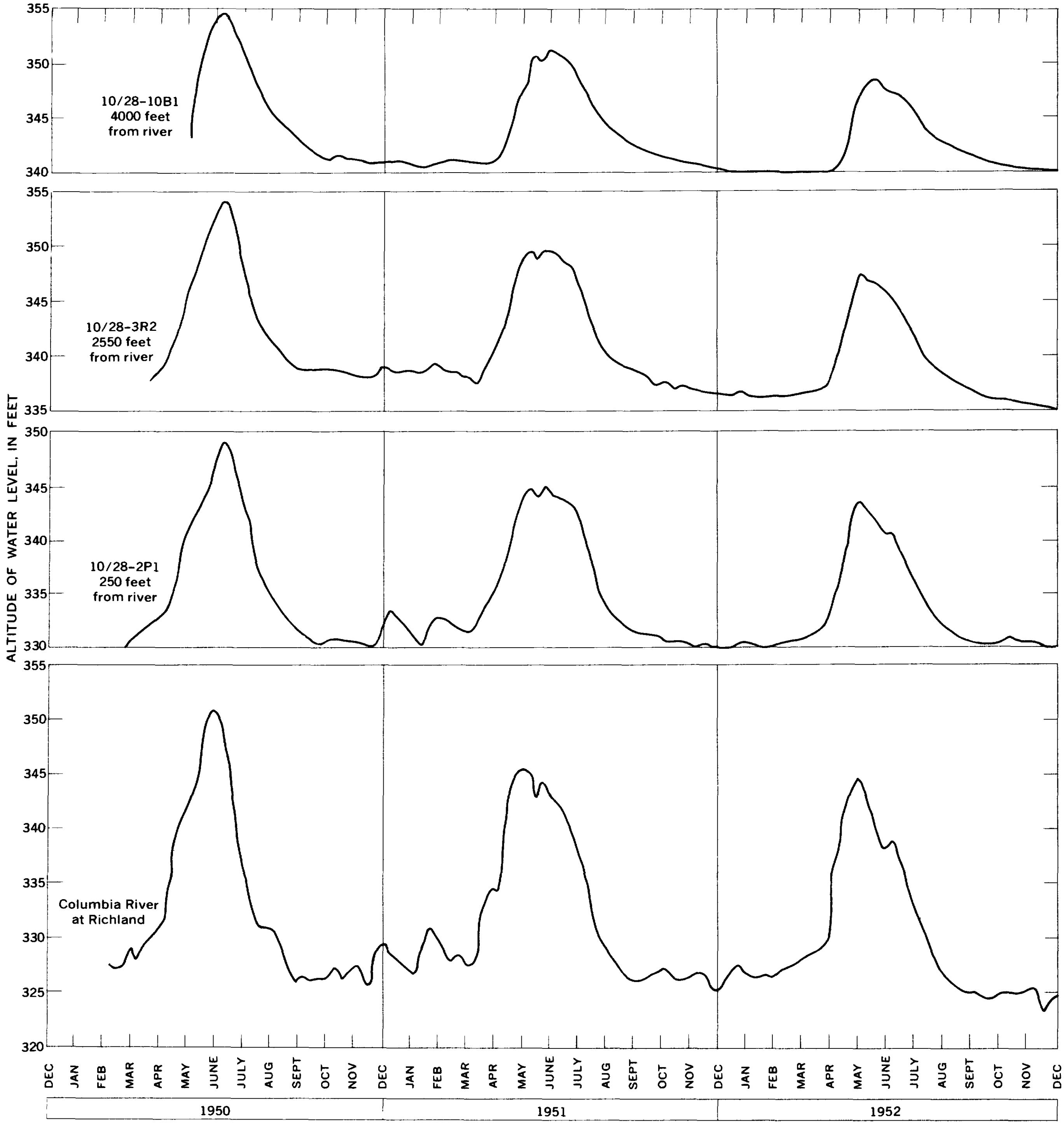

FIGURE 4. — Water levels in three wells in the southeastern part of the reservation compared with the water level of the Columbia River.

(figs. 6 and 7) over wide areas away from the river and (2) an annual rise and fall of the water table along the Columbia River in response to the river's flood stages. (See figs. 3 and 4.) The third general condition is the artificial rise and fall, largely a progressive rise, of the water table beneath and adjacent to areas where plant liquids are being discharged to the ground. Superimposed upon the short-period fluctuations may be a small but progressive rise that conforms with the greater amount of precipitation recorded in general over the Pacific Northwest since about 1941. The small, long-term weather effect is difficult to distinguish in most of the water-level records on the reservation. It may be distinguishable in records of the wells at the southwestern end of the reservation but seems to be masked by the progressive rise resulting from distant artificial recharge.

RECHARGE AND DISCHARGE

Beneath broad areas of the desert terrain the levels of the ground water show that little, if any, water transfers downward through the desert soils to the water table. During the period of observation for many of the wells in the southern part of the reservation (see fig. 5), no annual recharge additions have shown on the water-level records. If any transfer of water downward to the water table occurred in that area, it must have been in amounts that would produce less than a few hundredths of a foot seasonal rise in the water table each year. Evidently, over the broad desert plains of the reservation, the zone of aeration effectively separates the precipitation on the surface from the water table. Only in rare years of greatest precipitation could these soil zones be wetted sufficiently to cause any appreciable recharge to move to the water table.

The contour lines on the water table (see pls. 1, 2, and 3) indicate that the principal natural recharge to the unconfined ground water occurs in the upper and middle parts of the Cold Creek valley, at places where the discharge of upper Cold Creek and Dry Creek valleys spreads out on the valley plains, along the Yakima River downstream from The Horn, and along the Columbia River during its annual high stages.

The surface runoff from the uplands in and west of the reservation is small; in most years it is a measurable flow only during brief periods and in only two places — upper Cold Creek valley and Dry Creek valley. This surface runoff either sinks beneath the valley floor or evaporates. About the time the atomic plant was started (1944), a loose fill was placed in Cold Creek at its mouth, and until 1972 that fill had not been reached by runoff, not even by the unusually heavy but brief flood from Dry Creek during March 1952.

The runoff from the higher reaches of upper Cold Creek valley sinks into the unconsolidated deposits beneath the upper valley plains, mostly in secs. 34, 35, and 36, T. 13 N., R. 24 E. In some years no runoff reaches eastward into R. 25 E. and the reservation proper. The average annual flow of Cold Creek to the reservation is estimated as about 200 acre-feet of water. At least twice that much water is estimated to infiltrate in R. 24 E. Of the estimated 600 acre-feet of infiltrated surface water, at least half must have evaporated before it could move down to the ground water.

Approximately 500 acre-feet of ground water was used annually for irrigation in upper Cold Creek valley until about 1954, when this use was discontinued. It is estimated that at least 25 percent of the water applied during the irrigation season went to deep percolation. For many years prior to October 1952, about 500 acre-feet per year had leaked from well 13/24–25E1 and descended to the ground water, and 15 acre-feet had likewise escaped from well 13/24–26G1. The leakage from two wells farther west was unknown but may have been considerable.

During periods of unusually rapid snowmelt or heavy rainfall, the runoff of the upper part of Dry Creek valley extends beyond Rattlesnake Spring in sec. 29, T. 12 N., R. 25 E. On the basis of occasional miscellaneous observations of the authors, the runoff is estimated to average about 200 acre-feet per year, though during an extreme flood stage the discharge may be as much as 200 cubic feet per second for short times (March 1952 flash flood near Rattlesnake Spring, estimated unmeasured flow). The flow of Rattlesnake Spring ranges from as little as 50 gpm to as much as 450 gpm. Its average flow in recent years is estimated as about 100 gpm, or about 100 acre-feet per year. The direct source of the spring is probably the unconfined ground water in the alluvial deposits of Dry Creek valley rather than the artesian water rising from the basalt, though part or all of the basalt source cannot be ruled out. The spring discharge emerges from alluvial fill and infiltrates a short distance downstream from the spring. It is estimated that evapotranspiration depletes, by about 50 percent, the water infiltrated from both Dry Creek and Rattlesnake Spring.

Estimated annual recharge to ground water in the western part of the reservation

	Prior to 1952 (acre-feet)	1952–54 (acre-feet)	After 1954 (acre-feet)
Irrigation infiltration	125	125	0
Leakage from wells	515	15	15
Streams:			
Cold Creek	300	300	300
Rattlesnake Spring and Dry Creek	150	150	150
Total	1,090	590	465

The estimated total of about 1,100 acre-feet of water prior to December 1952 and about 500 acre-feet of water after 1954 was the annual recharge to the unconfined ground water that moved east

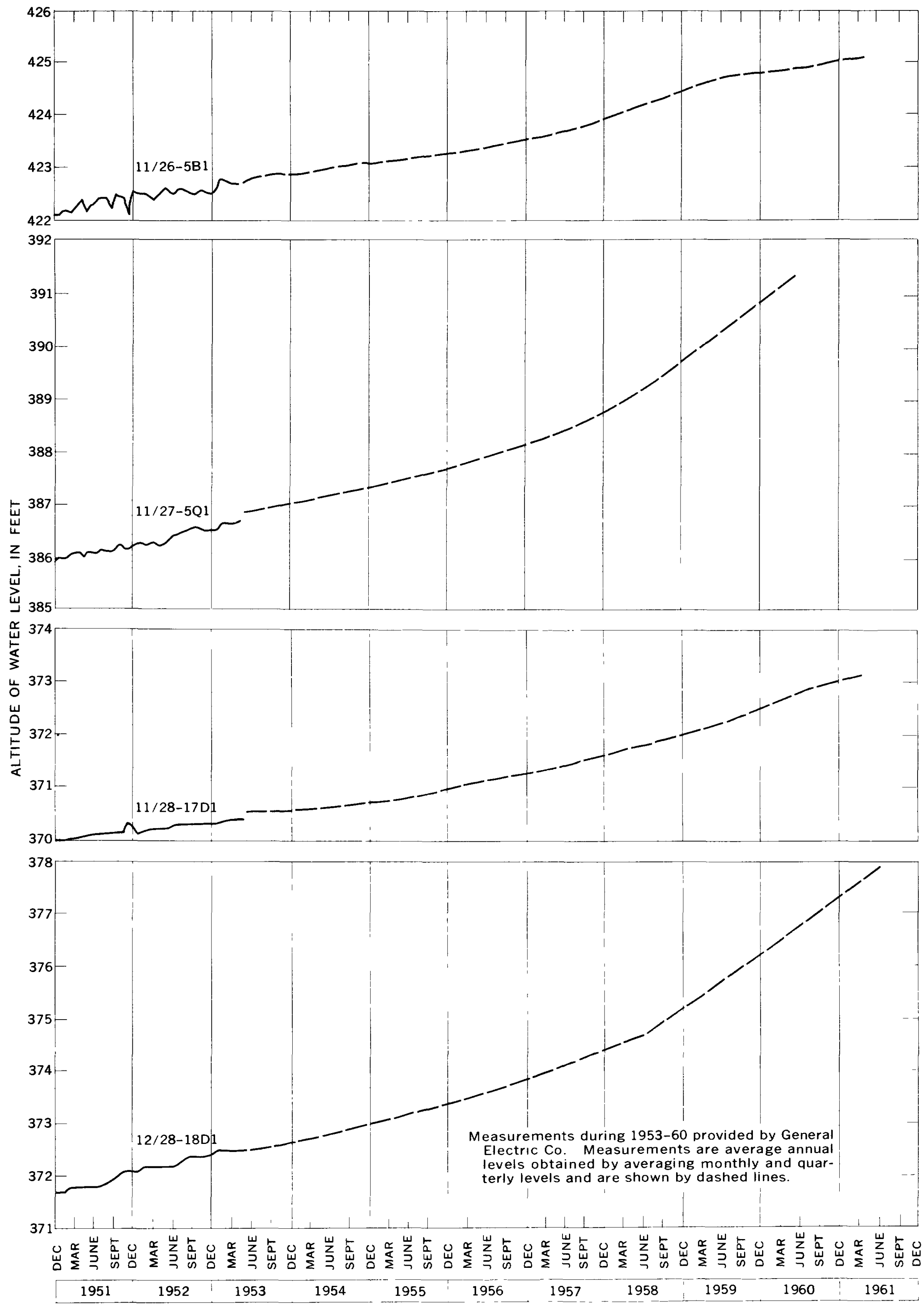

FIGURE 5. — Water levels in wells where there is little or no natural recharge and where a steady rise occurs because of pressure transfer from distant artificial recharge.

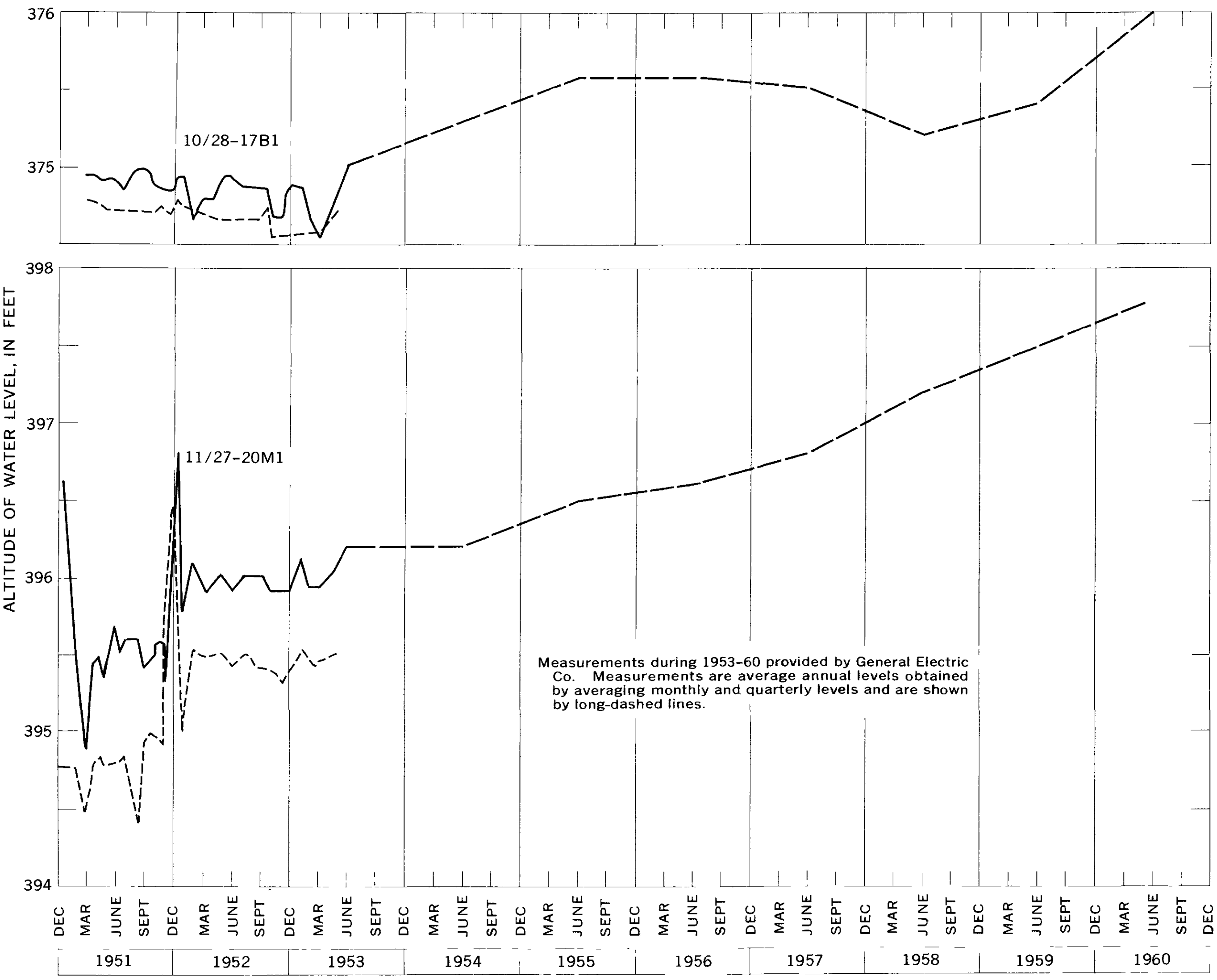

FIGURE 6. — Water levels in two wells that tap unconfined water in the basalt (solid lines) and in the overlying Ringold Formation (short-dashed lines) in the southern part of the reservation.

and north beneath the higher parts of the reservation plains.

There is an unknown amount of recharge to the unconfined ground water in Cold Creek valley by the natural leakage of artesian water at the terminal barrier in the lower end of the mountain part of the valley. Such leakage could contribute as much as a few hundred acre-feet of water to the maintenance of the high level of the unconfined water in that area.

Graphs of water-level records for wells that are located far from areas influenced by artificial recharge show some small fluctuations which coincide with fluctuations in precipitation. (See fig. 6, wells 11/27–20M1 and 10/28–17B1.) These wells are constructed so that the levels of ground water in both the basalt and the overlying unconsolidated materials can be measured. The annual recharge response is shown especially by the water in the basalt. On the mountain slopes at the western side of the reservation, some recharge from precipitation infiltrates where the occasional storm runoff is concentrated in arroyos and rills. In this manner small quantities of water are recharged and apparently are reflected in the annual fluctuations of a few inches that occur in wells 11/27–20M1 and 10/28–17B1 (fig. 6).

All the water-level records on basalt wells, except the record on well 10/28–17B1, shows a slow and steady rise since 1951. This rise may be due to a progressive effect of the artificial-recharge mounds in the unconfined ground water 10 miles to the north, or it may be part of a region-wide rise in response to the greater annual average precipitation that has prevailed since about 1941.

Along the Columbia River within the 2-mile-wide belt in which the ground water rises with the 20- to 30-foot annual rise during flood stage in the river, a great deal of water is recharged to bank storage and then discharged back to the river during its declining stages (Newcomb and Brown, 1961). For example, if the belt is taken as extending 10,000 feet from the river, the average maximum fluctuation as 10 feet, and the effective porosity as 14 percent, then a maximum of about 1,700 acre-feet of storage space is used per mile of riverbank. Such a situation exists along the south and west sides of the Columbia River from China Bar, at the northwestern corner of the reservation, to the Richland area. The north and east banks may have less space available for bank storage because the conglomerate zone is absent from the Ringold Formation for a greater distance along that side.

The main discharge of the bank-stored water occurs during the falling stages of the river; presumably this effluent from the ground is largely through the bed of the river, where entry takes place during periods of infiltration. Bank discharge is visible as little seeps just above river level during the river's falling stages. Large springs have been observed only in sec. 23, T. 13 N., R. 27 E., near Hanford, where the water drains from the highly permeable zone of gravel that occurs along the northeast side of Gable Mountain. One spring, known as Kashier Spring, in the SE¼SE¼ of sec. 23, formerly flowed as much as 800 gpm from 200 yards of the riverbank in summer. During periods of rising river level, such as occur in April, May, or June, the whole bank line of the reservation was observed by the authors to be devoid of ground-water outflow.

Along the Columbia River in the Allard-to-Wahluke area, the level of water in bank storage rises sufficiently high that some of the water does not return directly to the river nearby. The high level of bank-stored water imparts a ground-water gradient eastward toward the area between the Hanford and White Bluffs townsites. In most years the levels of the bank-stored ground water south of Coyote Rapids become sufficiently high to cause a natural ground-water gradient through the gravel-filled gap between Gable Mountain and Gable Butte and to increase the gradient southeastward in the glaciofluviatile and fluviatile deposits south of Gable Mountain. Prior to the time when artificial recharge greatly altered the levels of the ground water in places near Gable Mountain, the southeastward gradient from the bank storage farther north caused the ground water to rise above the 396-foot altitude of the land surface at the spring in the stream-channel scar in the SE¼NW¼ sec. 22, T. 13 N., R. 26 E. Though records of its level were not maintained, the high level of the spring pond was observed each summer by the authors, 1 or 2 months after the annual flood rise of the Columbia River.

The evaluation of Newcomb and Brown (1961) gave 84,000 acre-feet of water as the probable volume of the annual bank storage along the right bank of the Columbia River beneath the Hanford Reservation. They concluded that about 99 percent is infiltrated from the river and 1 percent is ground water whose discharge to the river is delayed.

Within the terrace lands of the reservation, the discharge of ground water to the air by evaporation or by the transpiration of plants is negligible. Only in the channel scar southwest of Gable Mountain, in the old channel swale at Richland, and locally on some of the low terraces and riverbanks is the water table close enough to the surface that plants can transfer ground water to the atmosphere.

LOCAL BODIES OF CONFINED GROUND WATER

ARTESIAN WATER ASSOCIATED WITH THE UNCONFINED GROUND WATER

In the basalt, the relatively high permeability of some of the interflow zones (mostly the rubbly tops of flows) and the watertight character of the centers of some of the flows cause water to move laterally under pressure (Newcomb, 1959, p. 6). Where percolation in an aquifer is impeded farther downslope, the water in the permeable zones may be under considerable pressure. Such aquifer and water-pressure conditions produce confined ground water that rises in a well that pierces the upper, confining layer. Water that is locally confined is tapped by wells 10/28–10G1, 11/28–21L3, and 14/27–18J1 near the axial area of the Pasco syncline. In these wells, clays at the base of the Ringold Formation seem to be the principal confining stratum. It is logical to expect that some of these aquifers may be leaking water to the unconfined ground water above. There is little likelihood that the confined aquifers exert any significant influence on the recharge or discharge of the unconfined ground water beneath the main part of the reservation, for the following reasons: (1) The total extent of the areas having distinctive levels of confined water is a small part of that underlain by unconfined water, (2) the strata of hard clays near the base of the Ringold Formation are poorly permeable in a vertical direction, and (3) the head differential between the unconfined water and the confined water is small.

Locally, ground water confined in some parts of

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the gravels of the Ringold Formation has a few feet of hydrostatic head above the level of nearby unconfined ground water, but this occurs in an insignificant part of the formation.

ARTESIAN AQUIFERS ISOLATED FROM THE REGIONAL UNCONFINED GROUND WATER

In the mountain valleys in and west of the reservation local bodies of confined ground water occur in the synclinal areas of the basalt. They are present in both Dry Creek valley and upper Cold Creek valley; the wells in this latter valley are the best known of several such artesian occurrences within the region.

The east-sloping basin of the upper part of Cold Creek is part of an eastward-plunging syncline in which the confined ground water occurs in the basalt beneath beds of tuff and associated sedimentary deposits. The confining strata may be either the sedimentary deposits or the massive centers of basalt flows within the lava succession. The nature of the barrier that closes the lower end of the artesian basin is incompletely known. The east end of the area of artesian flow alines with a rather tight downfold in the basalt, the monoclinal flexure previously mentioned, and there may be some fault displacements or tight folds forming the barrier across the covered lower end of this part of the Cold Creek syncline. The altitude of the original pressure level of the ground water in the Cold Creek artesian basin may have been as high as 1,138 feet (altitude of the water level reported in 1925 by the driller of the Ford well, 13/24–25E1). In 1960 the potentiometric surface stood at about 1,000 feet at the McGee well (13/25–30G1); from there it rose upvalley at about 7 feet per mile (Hart, 1958). Both the artesian aquifer of the upper Cold Creek syncline and, by inference, that of the Dry Creek syncline are believed to be terminated by structural barriers that aline with the mountain front north and south of Dry Creek.

LOCAL PERCHING OF GROUND WATER ARTIFICIALLY RECHARGED

The water-level observations and drilling records show that natural perched ground water has not been encountered on the reservation, but artificially recharged water in a perched condition has been found. It occurs at depths of 80 to 90 feet beneath the high terrace lands in part of sec. 1, T. 12 N., R. 25 E. One thin zone of perched water, resting upon a silt bed, has been penetrated by the drill in several wells just west of a disposal swamp. Wells 12/25–1G1 and –1F1 and a well drilled later 2,000 feet farther west passed through the base of that perched water (Brown and Rupert, 1950) and into the perching silt layers at an altitude of 580–585 feet.

The various silt beds that occur in the glaciofluviatile and fluviatile deposits in places perch artificially recharged ground water and cause it to move laterally to the edge of the silt bed before continuing its vertical descent toward the water table. However, except for silt beds beneath one disposal swamp, none of them — of either glacial or Ringold age — has been found to perch significant amounts of ground water.

The normal path of artificially recharged water as it sinks toward the water table is apparently a direct, almost vertical, movement until it reaches a layer of lesser vertical permeability. Upon reaching such a layer, the recharging water spreads out and builds up a local saturated zone until it covers an area sufficiently large that it will transmit a given quantity of water vertically downward through the perching layer or until the water moves over an edge of the perching bed.

CHANGES IN GROUND-WATER REGIMEN

ARTIFICIALLY RECHARGED MOUNDS

Most important of the changes in the ground-water body beneath the reservation is the raising of the water table at each of the two chemical-separation plants. These elevated parts of the water table, generally called mounds, have been constructed by artificial recharge from water disposal, mostly at the sites of artificial swamps. One large mound (western mound) lies mainly in secs. 1, 2, 11, 12, 13, and 14, T. 12 N., R. 25 E.; another large one (eastern mound) lies beneath the mutual corner of Tps. 12 and 13 N., Rs. 26 and 27 E.

The two mounds have grown progressively at various rates. (See pls. 2 and 3.) The western mound in 1961 reached a peak height of 60 feet above the natural water table and had a basal area of about 15 square miles. The eastern mound was only half as high, had less basal area, and was more elongate than the conical western mound.

The small ground-water mounds beneath the reactor sites and other plant facilities along the Columbia River differ from each other, and each of these small mounds varies in height from time to time with the amount of liquid being recharged and the level of the river during those disposal operations. These mounds rise at times less than 5 to 10 feet above the normal water-table positions and extend less than a square mile in area.

GROWTH OF THE LARGE MOUNDS BENEATH THE HIGH TERRACES

Between 1948 and 1953 the western mound increased in height, width, and length and became

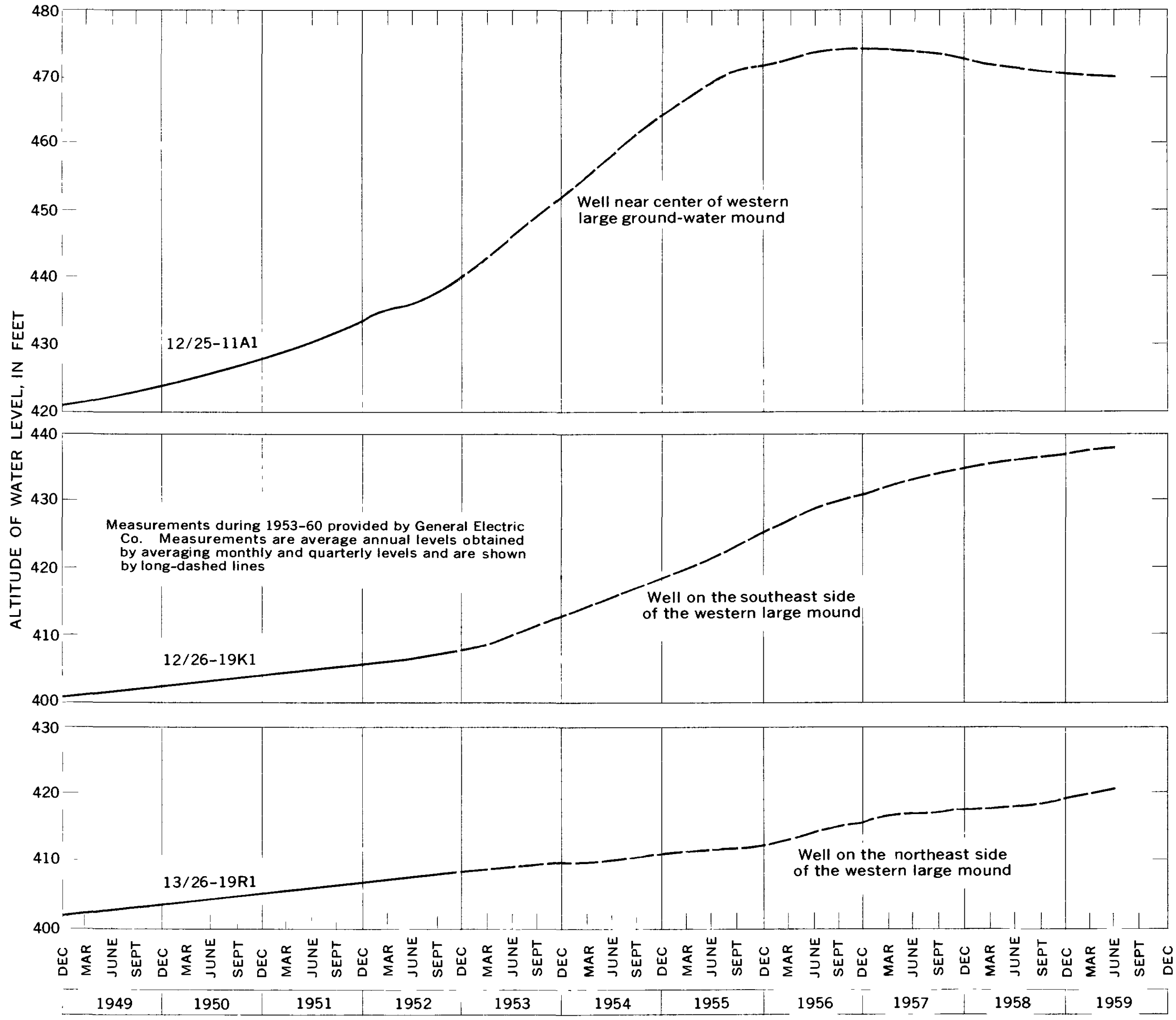

FIGURE 7. — Rise of water levels in wells at and near the western large recharge mound.

more complex in shape (fig. 7). The 1948 apex altitude of 440 feet (Parker and Piper, 1949) on the western mound increased to 450+ feet by 1953, and a new apex farther south had resulted from infiltration at new disposal swamps. At this more recently formed apex, the rise of water level from 1948 to 1953 was about 45 feet. At a distance of about 2 miles from the recharge swamps, the rise between 1948 and 1953 was about 7 feet (in well 12/25–3D2 to the west, in well 13/26–19R1 to the northeast, and in well 12/26–19K1 to the southeast). During that period the upper part of the whole mound spread, but relatively small rises of water levels in wells at the sides indicated that the spreading had not greatly enlarged the mound below an altitude of 400 feet. By 1961, the apex of the western mound had risen to an altitude above 470 feet. The mound had shifted southward and had enlarged throughout its somewhat conical form (pl. 3).

The eastern large mound, beneath the common corner of Tps. 12 and 13 N., Rs. 26 and 27 E., decreased in height because of lesser recharge during the period 1948–53, but its base spread and lengthened in a southeasterly direction (pl. 2 and figs. 8 and 9). Later, after recharge from swamps increased, the top of the mound again rose, and the whole mound enlarged greatly (pl. 3). The southeastward extension of the mound is caused by preferential movement of the ground water due to the greater permeability of the glaciofluviatile and

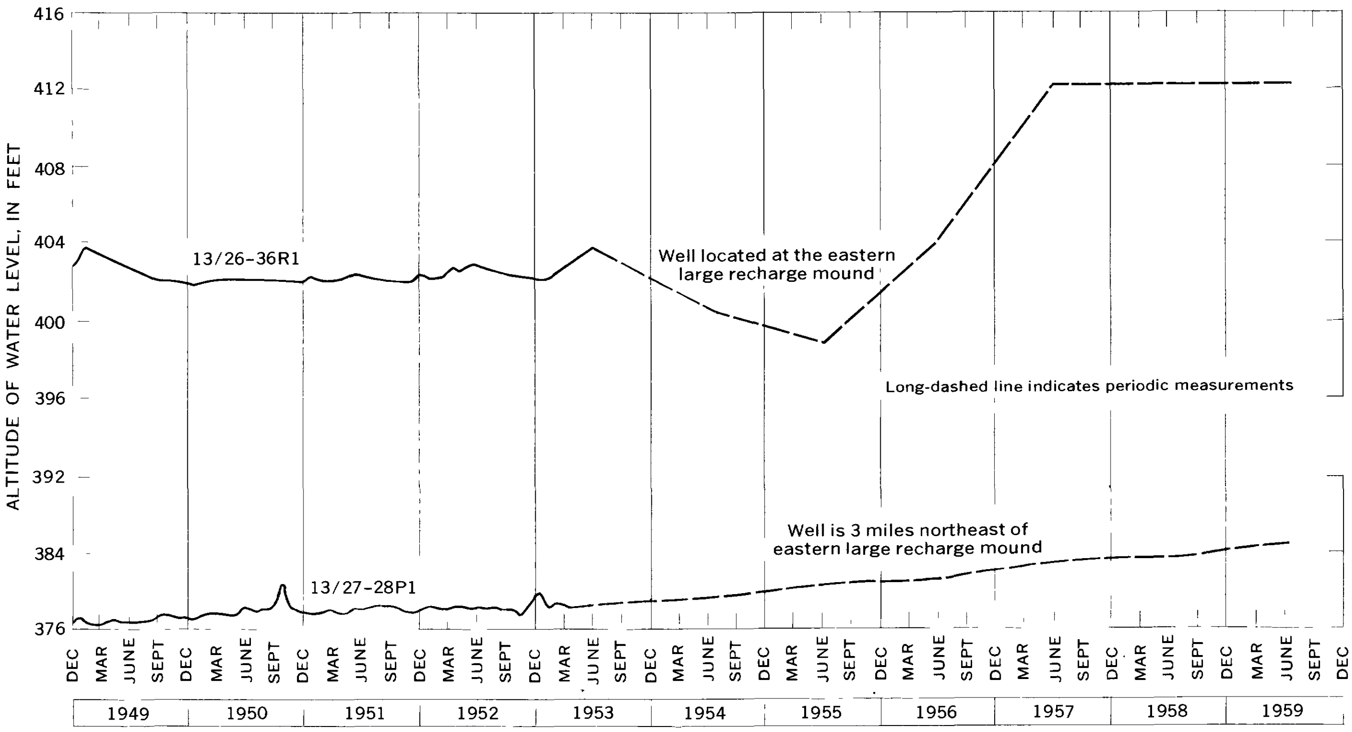

FIGURE 8. — Changes in ground-water levels at and distant from the eastern large recharge mound.

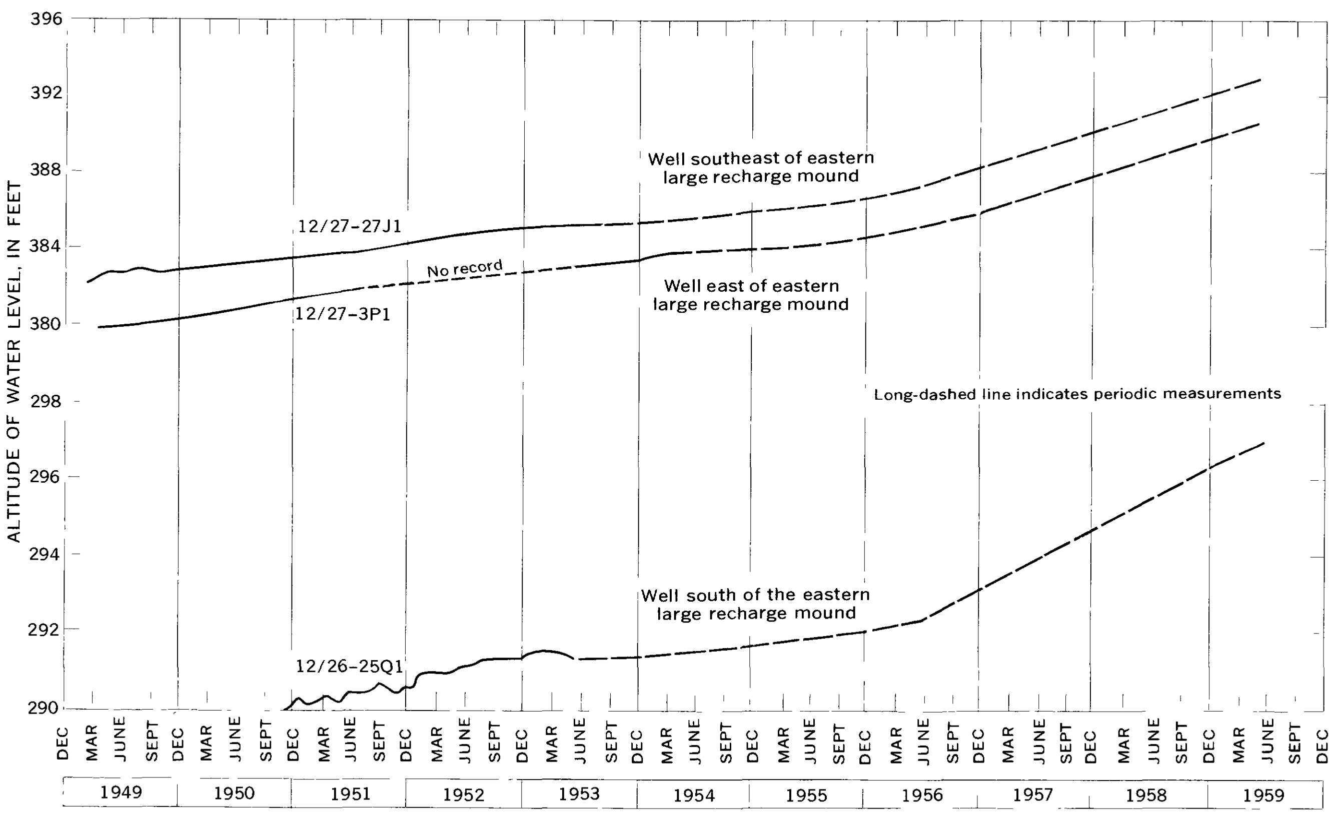

FIGURE 9. — Rise of water levels in wells several miles from the eastern large recharge mound.

fluviatile deposits which extend below the water table in this locality (sec. *A–A′* on pl. 1). The extension of this mound southward together with the general eastward encroachment of the western mound closed a shallow basin-shaped area in the water table by 1953 (pl. 2).

By 1961 the crest of the eastern mound was above an altitude of 415 feet (pl. 3), and ground water was accelerated downgradient south and southeastward in the basal part of the glaciofluviatile and fluviatile deposits, as described beyond.

DIRECTION OF MOVEMENT

The natural (1944) shape of the water table is shown on plate 1 as it was reconstructed empirically from a few known levels. The general direction of the natural movement of ground water is shown by arrows and by the contour lines of the water table deduced for 1944.

The artificially recharged mounds, which show on the water-table maps for 1948, 1953, and 1961, have locally altered the direction of ground-water movement. The newly imposed directions and rates of movement are of prime importance to the waste disposal and other problems in the operating areas.

The exact direction, rate, and manner of movement of the ground water outward from the recharge mounds are still only partly known. Some of the lateral spreading of the mounds may occur by hydrodynamic adjustment in the ground-water body — the movement of water downward below the water table at the point of recharge, outward horizontally, and upward beneath the fringes of the mound — rather than by direct lateral percolation in simple, generally horizontal, radial directions from the centers of the mounds. However, idealized uniform percolation in a horizontal direction is postulated in most of the equations used below to calculate the average hydraulic coefficients of the saturated zone beneath the top of the western large mound as the mound occurred in 1953.

RATE OF GROUND-WATER MOVEMENT

By eliminating the irregularities of the mounds, one can approximate a reasonably smooth cone-shaped figure for the western mound and a smooth ellipsoidal cone for the eastern mound as they occurred in 1953 (pl. 2). Such smoothed and integrated conical figures were used for computing the approximate values of (1) effective porosity (specific yield), (2) transmissivity and permeability of the Ringold conglomerate, and (3) velocity of movement of the water outward in the western mound (Newcomb and Strand, 1953).

POROSITY

The effective porosity (the percentage of the rock's volume occupied by the saturating fluid less the specific retention) of the saturated part of the Ringold Formation can be approximated by dividing the volume of the mound's growth between 1948 (as given by Parker and Piper, 1949) and 1953 (pl. 2) into the total amount of water recharged from the respective plants during the period November 1948 to May 16–20, 1953. These quantities give:

For the western mound

Volume 1953	165×10^8 ft³ (adjusted to conical shape)
Volume 1948	62.2×10^8 ft³
Volume increase Nov. '48–May '53	102.8×10^8 ft³
Average water delivery rate to plant	3,757 gpm
Average discharge rate to ground	3,657 gpm (100 gpm evaporation assumed)
Water recharged to ground each year	257.5×10^6 ft³
Total water recharged Nov. '48–May '53	11.6×10^8 ft³
Pore space used	$\frac{11.6 \times 10^8}{102.8 \times 10^8} = 0.11$, or 11 percent

For the eastern mound

Volume 1953	102.5×10^8 ft³ (adjusted to ellipsoidal conical shape)
Volume 1948	49.2×10^8 ft³
Volume increase Nov. '48–May '53	53.3×10^8 ft³
Average water delivery rate to plant	1,867 gpm
Average discharge rate to ground	1,832 gpm (35 gpm evaporation assumed)
Total water recharged Nov. '48–May '53	5.76×10^8 ft³
Pore space used	$\frac{5.76 \times 10^8}{53.3 \times 10^8} = 0.11$, or 11 percent

GRADIENTS

Natural slopes of the water table prior to 1944, as they can be reconstructed beneath and outside of the artificial mounds, show that the gradients under which the naturally recharged ground water moved through the Ringold Formation eastward from the mountain front to the river ranged from about 3 to 15 feet per mile. One part of the water moved northward from Cold Creek valley in the Ringold Formation at a gradient of about 10 feet per mile as far as the low terraces along the river west of Gable Butte, where the water table in the more permeable glaciofluviatile and fluviatile deposits was nearly horizontal and in balance with the river level.

Across the southern part of the reservation, in T. 11 S., the water table in 1953 was still largely in a natural condition and sloped eastward 4 to 5 feet per mile in the Ringold Formation from the lower valley of Cold Creek to the Columbia River.

Southeast of The Horn, ground-water movement is eastward from the Yakima River to the level of the Columbia River at a gradient of about 10 feet to the mile in the Ringold Formation. This steeper gradient results from the relatively large amount of recharge in this area and the short distance from the places of infiltration to the outlets along the riverbank and in the low swales near Richland.

Gradients on the small ground-water mounds near the industrial plants along the Columbia River are indefinite because of the coarseness of the observation-well net, the variations in the amounts of water recharged, and the changes in the natural levels of the ground water in the zone of bank storage.

In 1953 the conical shapes of the two large mounds beneath the high terraces were modified by the several points of recharge to each mound and the variations in the permeability of the saturated materials; but from the general shapes of the mounds it was possible to measure some approximate values for the gradients of the artificially recharged ground water. The western mound had a slope of about 8 feet per mile on the lower part of its west side and 12 feet per mile on the lower part of its east side. The sides of the two pinnacles had various slopes that approached 40 feet per mile on the south side of the southern pinnacle. However, the pinnacles built in 1951–53 comprised but a small part of the total volume of the mounds in 1953.

By 1953 the eastern mound, with its upper surface in the glaciofluviatile and fluviatile deposits, had spread south and southeast toward a bulge in the water table. The higher part of the eastern mound had gradients of only 1 or 2 feet per mile, and the surface on the bulge extending eastward through the southern part of T. 12 N. had gradients of 5 feet per mile (pl. 2).

Between 1953 and 1961 the height of the eastern mound increased about 15 feet, and the mound lengthened 3 miles to the southeast. Gradients of about 10 feet per mile developed eastward to the old Hanford townsite, with a marked encroachment of the mound on the zone of bank storage along the Columbia River (section *A–A′* on pl. 1). The map of the water table in 1961 (pl. 3) shows the flat gradients of 1 to 2 feet per mile at the south end of the mound connected to an eastward-protruding zone of highest permeability across the southern part of T. 12 N. Also, a major movement of ground water was obviously underway along that zone in the base of the glaciofluviatile deposits.

HYDRAULIC COEFFICIENTS OF THE WATER-BEARING MATERIALS

The inherent characteristics of an earth material determine the rate of movement of ground water under a given slope of the water table. The capacity of a formation to transmit water may be stated as its transmissivity or its permeability. The capacity to store water is indicated by the storage coefficient.[2]

In the estimations of the transmissivity and permeability of the portion of the Ringold Formation containing the western large mound, an unsolved question involves a decision on how much of the thickness of the aquifer should be used for the preliminary computations. This difficulty has been referred to previously under "Direction of Movement." Under the conditions that determined the position of the water table, the movement of water was largely in the saturated part of the conglomerate zone of the Ringold Formation. It is probable that the entire saturated part of the conglomerate is involved to some extent in the outward transfer of the water from the recharge mound, but the conglomerate is anisotropic, and the layered character of the material must preclude an ideal pattern of flow vertically downward across the stratification and laterally outward from beneath the mound. The actual shape of the flow net may be something between the two idealized concepts of: (1) Downward and laterally outward movement in the symmetrical flow net by which water percolates in isotropic materials, and (2) the essentially lateral movement radially off the mound without deep circulation, by which water moves in fully anisotropic materials.

The recharge to the western mound was carried on at a rather uniform rate in four general periods of operation; the average rates of recharge for those periods and the average total height and altitude of the ground-water mound are given below (as derived from data in the files of the General Electric Co. and the Atomic Energy Comm.):

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[2]As used in most field studies of ground water and as defined by O. E. Meinzer (Wenzel, 1942), the permeability is the rate of flow of water, in gallons per day, through a cross-sectional area of 1 square foot under a hydraulic gradient of 100 percent at the prevailing water temperature.

Transmissivity (formerly called coefficient of transmissibility) is equal to the permeability multiplied by the thickness of the aquifer. It was defined by Theis (1935) as the number of gallons of water per day, at the prevailing water temperature, that will pass through a section of the aquifer 1 foot wide extending the full saturated thickness of the aquifer under a hydraulic gradient of unity.

The storage coefficient of an aquifer is the volume of water released from or taken into storage per unit of surface area of an aquifer per unit change in the component of head normal to that surface. In confined ground water the storage coefficient gives a numerical expression of the compressibility of the water and the elastic properties of the water-bearing material.

Time period	Time (days)	Recharge rate (gpm)[1]	Altitude of mound crest (ft)	Average total height of mound (ft)
Dec. 1944	0	0	400	0
Dec. 1944 to Nov. 1948	1,440	2,048	440	40
Dec. 1948 to June 1950	2,010	2,048	442	42
July 1950 to May 1951	2,340	3,123	453	53
June 1951 to May 1953	3,060	4,946	459	59

[1]Metered plant discharge rate less an estimated small amount of evaporation derived from evaporation rates for this climate and the area of the swamp-disposal sites.

If it is assumed that in the vicinity of the western mound the strata of the Ringold Formation are laterally homogeneous, an approximation of the transmissivity may be obtained by considering the flow through one or more of the closed water-table contour lines around the 1953 mound. Thus, according to a modified form of Darcy's law, the gradient formula (Wenzel, 1942) is

$$T=\frac{Q}{I\ L},$$

where

Q is the average recharge, in gallons per day;
T is the transmissivity, in gallons per day per foot;
I is the average hydraulic gradient transverse to the contour line, in feet per mile; and
L is the length around the contour line, in miles.

Considering the position of the 440-foot contour line on the western mound in 1953 (pl. 2), a weighted average gradient of 26.7 feet per mile was determined by averaging the gradients for several segments around the 440-foot contour line. The length of the contour line is 7.8 miles, and the average input to the mound in the period 1944–53 was 3,660 gpm. Then from the gradient formula above,

$$T=\frac{3{,}660\ (1{,}440)}{26.7\ (7.8)}$$
$$=25{,}400 \text{ gpd per ft.}$$

Then the permeability (P) for thickness (m) of 240 feet would be

$$P=\frac{T}{m}=\frac{25{,}400}{240}=106 \text{ gpd per sq ft.}$$

Considering the 435-foot contour line on the western mound, the length of the contour line is 12.5 miles, and the average hydraulic gradient in the vicinity of this contour line is 17.3 feet per mile. Thus

$$T=\frac{3{,}660\ (1{,}440)}{17.3\ (12.5)}$$
$$=24{,}400 \text{ gpd per ft.}$$

Then

$$P=\frac{T}{m}=102 \text{ gpd per sq ft.}$$

The average of these two gives a P of 104 gpd per sq ft for the conglomerate of the Ringold Formation in the vicinity of the western mound in 1953.

The velocity of ground-water movement can then be calculated.

From Darcy's law,

$$v=\frac{48.9\ P\ I}{p},$$

where

v is the velocity, in feet per year;
P is the permeability, in gallons per day per square foot;
I is the hydraulic gradient, in feet per foot; and
p is the porosity, in percent.

The average slope of the water table on the outer edge of the mound in 1953 was approximately 16 feet per mile. Therefore, the average velocity of water movement on the edge of the mound is derived as follows:

$$v=\frac{48.9\ (104)\ (16)}{0.11\ (5{,}280)}=140 \text{ feet per year.}$$

Considering the rate of movement in the vicinity of the 440-foot contour line, the average rate of movement outward is derived as

$$v=\frac{48.9\ (104)\ (26.7)}{0.11\ (5{,}280)}=235 \text{ feet per year.}$$

The average yearly rate of water movement differs from place to place for points at similar altitudes on the western mound, and it is greater for the steeper gradients near the apex of the mound. This can be seen readily by comparing the water-table map showing the mound in 1953 with that for 1948 (Piper and Parker, 1949, pl. 1). (See pl. 2.) These differences in the rate of water movement probably are due in large part to differences in permeability within the Ringold conglomerate and to differences in hydraulic gradient imposed by the placement of the recharged water. The derived average rates of movement for the specified points selected at random on the water-table contour lines on the western mound between 1948 and 1953 are listed at the top of the next page.

No computations of hydraulic coefficients were attempted for the materials saturated within the eastern mound between 1944 and 1953. This was due in part to the fact that the eastern mound was built up into the glaciofluviatile and fluviatile deposits, which have a much higher permeability than the conglomerate of the Ringold Formation, and in part to the complication brought about by irregular use of the disposal swamps feeding the mound. The irregular recharging at these places resulted in a decline of the mound's altitude between 1948

Rate of advance of specified points on the western recharge mound for the period November 1948 to May 1953

Altitude of water-table contour line, in feet	Direction from center of mound	Average rate of contour line movement, in feet per year
400	N	0
405	N	167
410	N	722
430	N	978
395	NE	578
400	NE	835
395	E	875
400	E	1,355
405	E	1,090
390	SE	200
400	SE	890
430	W	1,445

and 1953, a variable growth of the mound between 1953 and 1957, and an overall increase in size from 1958 to 1966.

An early determination of the permeability of water-bearing materials beneath the reservation was reported by Parker and Piper (1949, p. 6) near the former Hanford townsite, where a value of 35,000 gpd per ft was derived from pumping tests of wells tapping water in "terrace deposits" (glaciofluviatile and fluviatile deposits).

A pumping test of well 13/26–5D2, obtaining water from 88 feet of saturated conglomerate of the Ringold Formation, gave a transmissivity of 50,000 gpd per ft and a storage coefficient of 2×10^{-4} (J. R. Strand and D. H. Hart, written commun., 1952).

Two pumping tests were run on wells tapping a combined section of the glaciofluviatile and fluviatile deposits and the conglomerate of the Ringold Formation at North Richland. In both tests water-level observations could be made only in the pumped well. The test on Richland public-supply well 3000–F (10/28–14K2) gave a transmissivity of 1,080,000 gpd per ft; however, the main water yield was from the glaciofluviatile deposits at the river level, which was at an altitude of 344 feet during the test. The test on 3000–G (10/28–23P4) gave a transmissivity of 146,000 gpd per ft (D. H. Hart, written commun., 1951).

A pumping test of well 13/26–13R2 in the old stream channel north of Gable Mountain gave a transmissivity of 1,430,000 gpd per ft and a storage coefficient of 0.03 for the 31 feet of saturated glaciofluviatile and fluviatile deposits. A hydraulic barrier a short distance from the well affected the results obtained from this test; the water level in one observation well, which taps the same saturated zone 400 feet south of the pumped well, did not move during the 7 days of pumping (D. H. Hart and F. J. Frank, written commun., 1954).

Other determinations of hydraulic coefficients of aquifer materials on the reservation were obtained in a 1956 test by General Electric Co. personnel (Raymond and Bierschenk, 1957, p. 729) on well 13/26–26B2. This well, which was drilled by the U.S. Geological Survey, taps water in 45 feet of highly permeable glaciofluviatile and fluviatile deposits beneath the old stream channel south of Gable Mountain. This test gave a transmissivity of 3 million gpd per ft, a storage coefficient of 0.20, and a permeability of 66,700 gpd per sq ft.

Results of pumping tests made prior to 1956 for the glaciofluviatile and fluviatile deposits and the conglomerate of the Ringold Formation show the following ranges of hydraulic coefficients:

Test	Deposit	Transmissivity (gpd per ft)	Permeability (gpd per sq ft)	Storage coefficient
Old Hanford	Glaciofluviatile	....	35,000	....
13/26–13R2	......do......	1,430,000	46,000	0.03
13/26–26B2	......do......	3,000,000	67,000	.2
10/28–14K2	Combined (predominantly glaciofluviatile)	1,080,000	....	....
10/28–23P4	Combined (predominantly Ringold conglomerate)	146,000	....	....
13/26–5D2	Ringold conglomerate	50,000	450 (average	2×10^{-4}

Summarized, these few pumping tests show that the transmissivity of the glaciofluviatile and fluviatile deposits ranges from about 1 to 3 million gpd per ft, and permeability from 35,000 to 67,000 gpd per sq ft, as contrasted to about 20,000 to 100,000 and 200 to 600, respectively, for the same coefficients of the Ringold conglomerate. By comparison, the permeability of the glaciofluviatile and fluviatile deposits is seen to be roughly 100 times that of the conglomerate, the most permeable part of the Ringold.

The great permeability of the glaciofluviatile and fluviatile deposits relative to that of the conglomerate of the Ringold Formation produces important differences in the movement and storage of ground water within these two principal water-bearing materials. For example, at equal gradients and comparable porosities for the two water-bearing materials Darcy's equation, as used for velocity computations above, would indicate that the water in the glaciofluviatile and fluviatile deposits moves nearly 100 times as rapidly and that it would move at equal velocities with only 1 percent as much gradient. Further application of this equation shows that great changes will occur in the water table when it is elevated across the boundary between these unlike aquifers.

Where the water table is raised from the Ringold conglomerate to the glaciofluviatile and fluviatile deposits (section *A–A′* on pl. 1; Newcomb and Strand, 1953, p. 97 and pl. 3), the much lower gradient required for percolation of comparable quantities of water through the glaciofluviatile materials frees over 90 percent of the water for accelerated migration downgradient. Movement of the augmented ground water in the more permeable glaciofluviatile and fluviatile deposits downgradient off a ground-water mound at the new velocities toward surface outlets is retarded only by the necessity to fill any unsaturated materials below its new gradients. The practical operation of this theoretical analysis is mentioned previously under sections "Changes in Ground-Water Regimen" and beyond under "Ground Disposal of Radioactive Wastes."

The horizontal permeability of the bedrock basalt differs greatly from one stratigraphic element to the next but, on the average, is much less than that of glaciofluviatile and fluviatile deposits. However, the average horizontal permeability of most any 500- or 1,000-foot section of the basalt is greater than the permeability of 450 gpd per sq ft commonly found for the Ringold conglomerate. Six pumping tests on wells drawing water from the basalt (Newcomb, 1959 (3 tests); Price, 1960; an unpublished test at Larson Air Force Base, 40 miles north of the Hanford Reservation, D. H. Hart, oral commun., 1960; and at The Dalles, Foxworthy and Bryant, 1967) gave transmissivity values ranging from 500 to 1,000,000 gpd per ft. Permeability, approximated by dividing the derived values of transmissivity by the saturated thickness of the basalt, ranged from 2 to 50,000 gpd per sq ft. However, an attempt to state an average permeability for the basalt can be misleading because the rock consists of many layers of relatively impermeable lava separating some relatively thin strata of moderate to great permeability. Estimates based on many drilling records and well-capacity tests indicate that the basalt has an overall water-carrying porosity of between 1 and 2 percent (Newcomb, 1969). This is the part of the basalt that effectively contributes water to wells of moderate and high yield. Storage coefficients of the basalt aquifers, derived from several pumping tests, are approximately equal to the compressibility of water, suggesting that the ground water occurs confined in nonelastic aquifers.

GROUND DISPOSAL OF RADIOACTIVE WASTES

The disposal of wastes at the Hanford Reservation involves many types of radioactive materials as well as many levels of radiation energy. Certain similar methods of disposal are common throughout the plant, even though the byproduct wastes differ in various sections of the production and manufacturing areas. The Atomic Energy Commission and the plant contractors maintain quantitative and qualitative data on the radioactive material passed to the ground, the streams, and the atmosphere. The fixation or movement of the radioactive material disposed to, or stored in, the ground is observed by monitoring.

Common definitions of the three levels of radioactivity in waste place the upper limit of activity of low-level waste at 1.0×10^{-5} μc per ml (microcuries per milliliter) and that of intermediate-level waste at 100 μc per ml; high-level waste has more than 100 μc per ml and commonly has up to 1,500 μc per ml, which is somewhat more than 5 curies per gallon. (A curie is defined as 3.7×10^{10} disintegrations per second. This is a refinement of the older definition, which was the number of disintegrations per second emanating from 1 gram of radium which is in equilibrium with its daughter element, radon.)

In many of the descriptions of the radioactive waste disposal methods, the large quantities of reactor cooling water disposed to the Columbia River and the large quantities of wash water and cooling water disposed to swamps from the chemical-separation plants are termed nonradioactive water on the basis of monitoring data. However, the disposal of these lowest level wastes is described here because the waste water at times may acquire a higher level of radioactivity and because, at most times, its disposal creates part of the hydrologic conditions where other wastes of much greater radioactivity are placed.

HISTORY OF DISPOSAL

Up to mid-1959 the total volume of liquid waste discharged to the ground since 1945 and the equivalent number of curies of gross beta activity (excluding metal wastes stored in subsurface tanks and the spills therefrom), as listed by Belter (1963, p. 19 and 20), were:

	Volume (billion gallons)	*Activity (curies)*
Cribs (72)	4.0	1,900,000
Trenches (18)	.028	647,000
Swamps	37.5	2,500

These totals included 95 percent of the 2.6 million curies of radioactivity in the low- and intermediate-level liquid wastes disposed to the ground within the United States prior to January 1959 (U.S. Congress, 1959, p. 21).

EARLY PROCEDURES

During construction and early operation of the Hanford Works, from 1944 to 1947, the disposal or storage of radioactive wastes underground (or to the river) included the following means in the areas cited:

Reactor areas:

(1) Retention of large volumes of slightly activated reactor coolant for about 2 hours before release to the river.

(2) Trench infiltration of coolant containing dissolved and suspended metal and fission products as well as irradiated salts sent to trenches after the rupture of a uranium container in the reactor.

(3) Burial of contaminated and irradiated solid material in established burial pits and vaults.

Chemical-separation-plant areas:

(1) Tank storage of metal wastes and fission products originally mostly in solution (first-cycle wastes).

(2) Injection to the ground through wells, tile fields, and cribs of dissolved and suspended fission products and small amounts of metal wastes (second-cycle wastes).

(3) Lagoon infiltration of wash water and coolants having low-level radioactivity of all types.

(4) Burial of contaminated and irradiated materials.

Laboratory areas:

(1) Burial of contaminated materials, sweepings, and refuse.

(2) Lagoon infiltration of metallic, wash, and laundry wastes.

(3) Trench infiltration of wash, laundry, and laboratory wastes.

Service areas:

(1) Burial by covering with soil.

(2) Liquid infiltration in cribs and swamps.

LATER DEVELOPMENTS

Changes in the disposal system have included the addition of monitoring wells and the improvement of radiation-detection instruments and techniques to indicate the extent of underground contamination. Also, new practices resulted in the abandonment of deep injection wells in favor of cribs for second-cycle and other liquid waste of high or intermediate radioactivity, and the addition of evaporation and treatment to reduce the volume of metallic wastes needing tank storage. Other changes have included the reduction (to about 1½ hours in some instances) of the holding time of reactor coolant before discharge to the river, and the recovery and reuse of metallic wastes stored in tanks. A number of spills, leaks, migrations of ground water carrying radioactive isotopes, and unplanned wastages of radioactive liquids to the ground have provided the opportunity to test the monitoring and emergency disposal arrangements.

A most significant development in subsurface disposal involves the movement of ground water carrying tritium and ruthenium-106 southeastward and eastward from the area of the eastern large recharge mound through the highly permeable glaciofluviatile and fluviatile materials for 14 miles to the zone of bank storage along the Columbia River (Brown and Haney, 1964). This movement in general followed the direction of highest permeability, as indicated by the relatively flat hydraulic gradients and the bulging of contour lines on the ground-water contour maps of 1953 (Newcomb and Strand, 1953) and of 1951, 1955, and 1957 (Bierschenk and McConiga, 1957). Movement of the tritium and ruthenium at the rate of about 2 miles per year (Brown and Haney, 1964) through the glaciofluviatile and fluviatile deposits over a 6- to 8-year period illustrates the acceleration that occurs in the ground-water flow once the water table has risen above the base of the highly permeable deposits, as described above from a theoretical standpoint under the section on "Rate of Ground-Water Movement."

An attempt was made to locate recharge mounds resulting from swamp and crib infiltration so as to contain the radioactivity in the ground water at places from which it would move most slowly. Still practically untouched is the whole field of water-table manipulation which can be of vital use in waste disposal and control. A first beginning at these practices, for better containment of the radioactive wastes underground in materials of low permeability, was proposed by Parker and Piper (1949, p. 95–96).

The location of the open artificial recharge areas (swamps), which build the bulk of the large water-table mounds, and the location of radioactive isotopes from the crib infiltrations, which supply most of the contamination to the ground water, are susceptible to greater control. For example, an installation of ten 500-gpm wells, drawing nonradioactive ground water from the western side of the two large recharge mounds, could have removed water equivalent to the recharge placed in the two large mounds during the period 1944–61. A similar judicious removal of excess nonradioactive water might be used to control the location and movement of radioactive ground water.

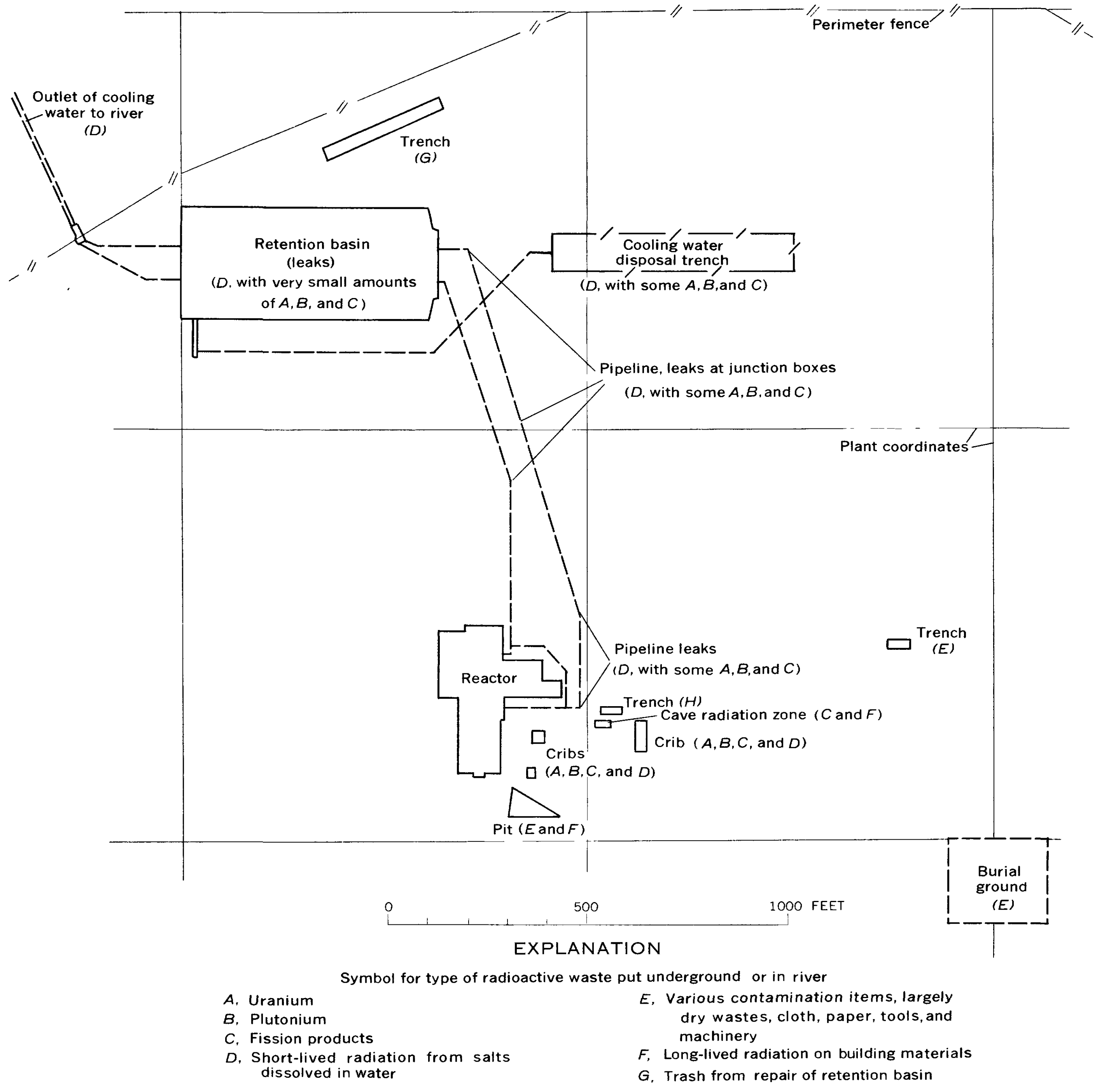


FIGURE 10. — Typical Hanford nuclear reactor plant, showing points of disposal of several types of radioactive waste.

TYPES OF WASTES DISPOSED

REACTOR AREAS

Materials containing a variety of radionuclides are included in the wastes from reactor areas. Uranium, plutonium, fission products, short-lived radioactive salts dissolved in water, long-lived activity imposed on parts of structural materials, and miscellaneous contaminated items are disposed in these areas (fig. 10).

Thousands of gallons per minute of filtered river water are pumped through each operating reactor for cooling purposes. The dissolved mineral matter, in part, becomes slightly irradiated, and the water is held about 2 hours in coolant-retention basins to allow some decay of radioactivity before the coolant returns to the river. Besides the natural dissolved materials that are irradiated, this coolant can carry radionuclides from water-treatment chemicals and rust-inhibiting coatings.

Under unusual conditions, which result in an increase in the radioactivity of the reactor coolant, the water as it comes from the reactor may be switched to special trenches. There it infiltrates, moves down to the water table, and percolates through glaciofluviatile and fluviatile deposits and the Ringold Formation in its return to the river.

Burial grounds for solid materials such as contaminated building materials, equipment, and accessories are maintained in the reactor areas.

CHEMICAL-SEPARATION PLANTS

Uranium, plutonium, fission products, short-lived radioactive salts dissolved in water, and miscellaneous contaminated items (largely dry wastes) form most of the wastes from separation plants (fig. 11). Stack gases and emissions have been of minor significance and are commonly an atmospheric-disposal matter, but at times they coat the soil sufficiently to become a ground disposal. All types of radionuclides are present in this group of wastes.

The radioactive metallic wastes from which plutonium has been removed contain mostly uranium and fission products. These high-level wastes are largely in concentrated solutions when placed in steel-lined concrete tanks about 25 feet underground; this placement is called storage, not ultimate disposal.

Waste solutions and condensate from the subsequent steps in the plutonium-production process contain largely fission products, of which cesium-137 is reported to be the principal emitter. These high- and intermediate-level wastes are disposed to the subsurface through cribs built to assure the infiltration of large quantities of pipe-transported dissolved (and suspended) radioactive materials.

Low-level waste, mostly wash and cooling water, is piped to swamps, where most infiltrates the ground and small amounts evaporate or are transpired.

MEANS OF WASTE DISPOSAL AND MANAGEMENT

RETENTION BASINS

The cooling water from each reactor is normally returned to the Columbia River after retention for a short period in concrete or steel basins to allow natural decay of radioactivity. When an accidental rupture of a uranium container introduces a slug of contaminant and raises the level of radioactivity in the coolant discharging from a reactor, the coolant is temporarily switched to disposal trenches where it infiltrates and percolates underground, presumably with retention of the contaminants on the earth materials.

PITS AND TRENCHES

Most pits and trenches are temporary features dug 5 to 20 feet deep for immediate use for the catchment of waterborne wastes or the burial of dry materials that cannot be transported any great distance to other disposal sites. In addition, trenches are used to dispose of waterborne radioactive wastes in reactor coolant, spills in chemical processing, waste from cleanup operations around the pile buildings, and leaks of retention basins and pipelines, as well as to dispose of waste solids and liquids incident to the repair of the retention basins.

CRIBS AND TILE FIELDS

Cribs are covered, porous walled and bottomed, dry wells lined with wood, metal, or concrete. They are constructed to provide a protected means of discharging waterborne radioactive materials at a safe depth in the ground. If a large volume of water is anticipated or if sludge is likely to clog the crib, tile fields may be tied in with the cribs to aid in the disposal of the surplus liquid. The main use for cribs is the disposal of waterborne contaminants carrying long-lived radioactive elements (the "second-cycle" or fission-product-rich waste) from the chemical-processing plants.

In most crib disposal, some precipitation of the radioactive adsorbable cations is provided for within the crib. The amount of base-exchangeable radioactive ions placed in each crib is planned so as to be only a small part of the previously estimated adsorption and base-exchange capacity of the mineral material to be traversed by the solutions en route to the water table.

BURIAL GROUNDS AND VAULTS

In each of the operating-plant areas there are burial grounds that receive solid wastes, in large part packaged, from the laboratories and plants. These wastes are placed in trenches in the burial grounds and covered. Some individual buildings or groups of buildings have nearby burial vaults for packaged dry waste. Other burial grounds receive contaminated building materials, equipment, and cleaning material wastes of a lower level of radioactivity.

TANK FARMS

Metal-processing wastes whose radioactivity is considered too highly concentrated or long lived to be released safely underground in quantity, and metal wastes that may be reprocessed at some future time, are stored underground in tanks. The tanks are made with a substantial concrete floor slab, 10-inch concrete walls, and a domed roof. The sides and top are poured around a steel liner that is three-fourths of an inch in thickness and extends across the floor slab. A tar coat is applied to the steel tank surface. The entire tank farm is covered with earth to at least a depth of 10 feet, with only the vents reaching to the land surface. The inflow pipes lead from one tank to another in series of three. Overflow ports in the tank sides are above the level of the inlet and outlet lines. Overflow and condensate are piped to cribs and infiltration lines.

INJECTION WELLS

Disposal to shallow injection wells was a former practice which was limited to small quantities of liquid wastes, although not necessarily to low-level wastes. If sludge was present in the solutions, settling tanks were connected with the pipelines, and the supernatant liquids were then sent into the injection wells. Most of the wells still in use in 1947 were planned so that discharge of wastes would be at some height above the water table; some of the first disposal wells at some reactor and chemical-separation areas led radioactive wastes directly to the ground-water body or close to the water table.

SWAMP AREAS

Normally, nonradioactive water and water containing low-level wastes from sewers, powerplants, laundries, or holding basins are sent to swamps for disposal by infiltration and evaporation. Small amounts of higher level wastes have entered swamps on some occasions. Swamps that are no longer used are backfilled with an earth cover, and the surface is fixed against contemporary erosion. Swamps contribute the major part of the water that reaches the ground-water body, and infiltration from them has produced much of the saturated volume in the large mounds on the water table, as previously described.

UNPLANNED DISPOSAL

Pipelines, diversion boxes, and storage-tank systems have at times leaked radioactive wastes directly underground or onto the land surface where little or no attention has been given to the wastes other than monitoring their radioactivity and covering them with earth. Small spills, or the accidental spread of contaminants on the land surface, are generally immobilized with an earth, asphalt, or concrete cover, if practicable, and are fenced and marked with signs as necessary.

LOCATION OF DISPOSED WASTES

The following outline summarizes briefly the placement of the radioactive wastes:

1. Subsurface
   - a. Above the water table
     - (1) Tank storage (metallic wastes)
     - (2) Capillary bond of water, with dissolved wastes, onto "dry" mineral grains
     - (3) Adsorption on mineral grains by ion exchange or other physicochemical processes
     - (4) Burial (dry solids)
   - b. Ground water (solution of fission products)
2. Surface
   - a. Swamps and sumps (waste water, spills, dust flares, and precipitates)
   - b. Columbia River (slightly irradiated solutions — mostly reactor coolant)
3. Atmosphere (gases and vapors)

The tank-stored metallic wastes and the crib-disposed "second-cycle" wastes contain the most important disposals — the bulk of the radioactivity. These storages and disposals are placed far above the water table in the glaciofluviatile and fluviatile deposits beneath the high (600- to 800-ft) terraces in the northwestern part of the reservation. Downward movement from the cribs, as described above, carries some dissolved radioactive materials into the underlying Ringold Formation and, in a few places, into the top part of the bedrock basalt.

The liquid that infiltrates within the cribs of the chemical-separation plants is the major disposal of potential long-lived radioactivity; part of this reaches the ground water. These wastes form a small part of the large ground-water mounds which have been built up mainly by the water descending from the swamps, where nonradioactive water and low-level wastes are disposed.

Locally, less permeable layers cause some perching of the descending water. The liquid wastes from two cribs have been monitored where they accumulated above silt or clay layers. A 1-foot-thick "clay" bed in the glaciofluviatile and fluviatile deposits "perched" the infiltrant from one temporary crib at a depth of 30 feet below the surface in 1948. A clayey silt layer at a depth of 89–114 feet caused the infiltrant from a second crib to be perched and to spread laterally and spill over the edge of the perching layer. Elsewhere the infiltrants from many other cribs have largely descended freely to the water table.

In the process of infiltration and transfer to the water table, dissolved and suspended radioactive cations are partly taken up by the earth materials (Atomic Energy Comm., 1951), presumably by base exchange and adsorption. Some of the cations with

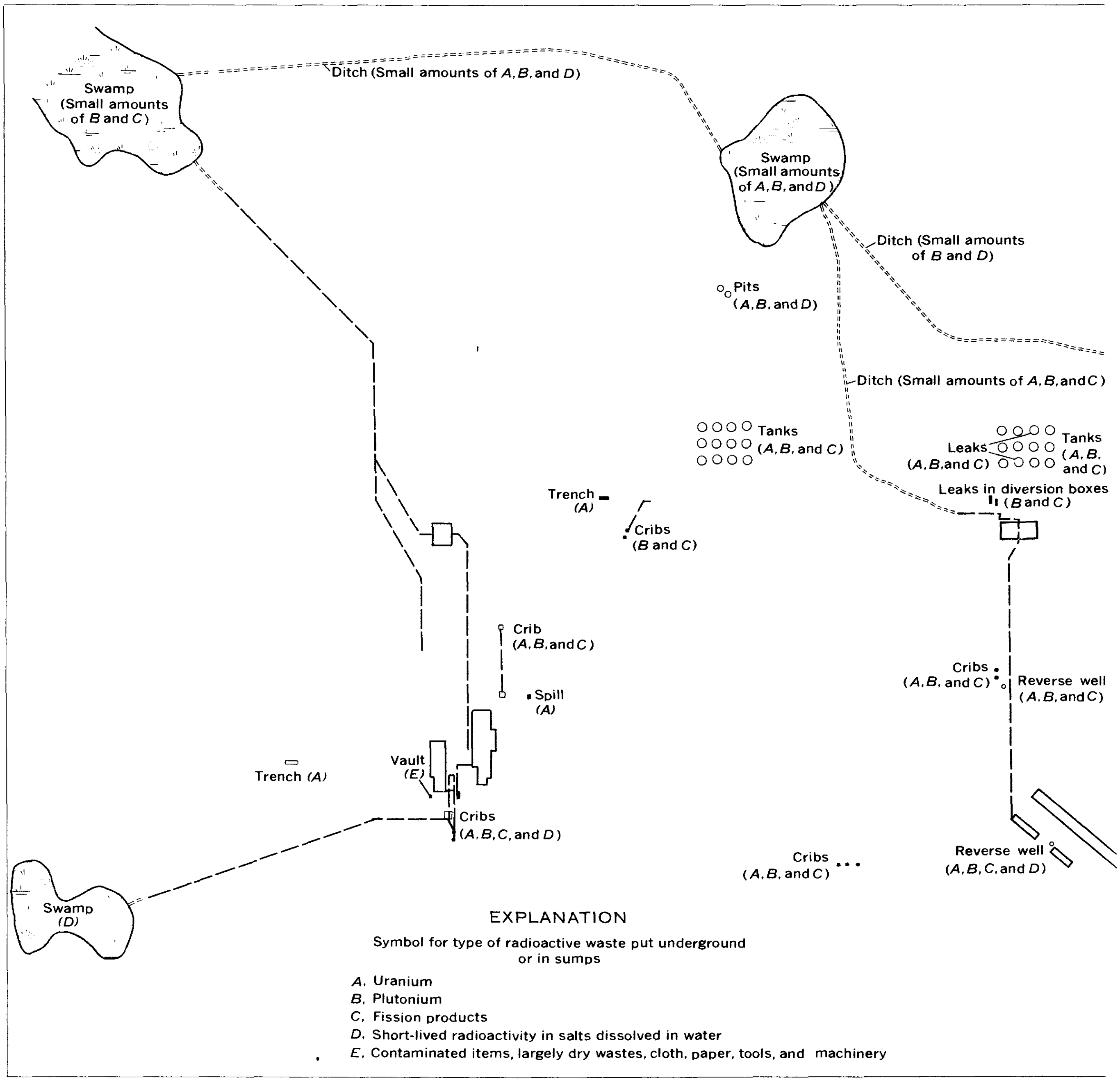
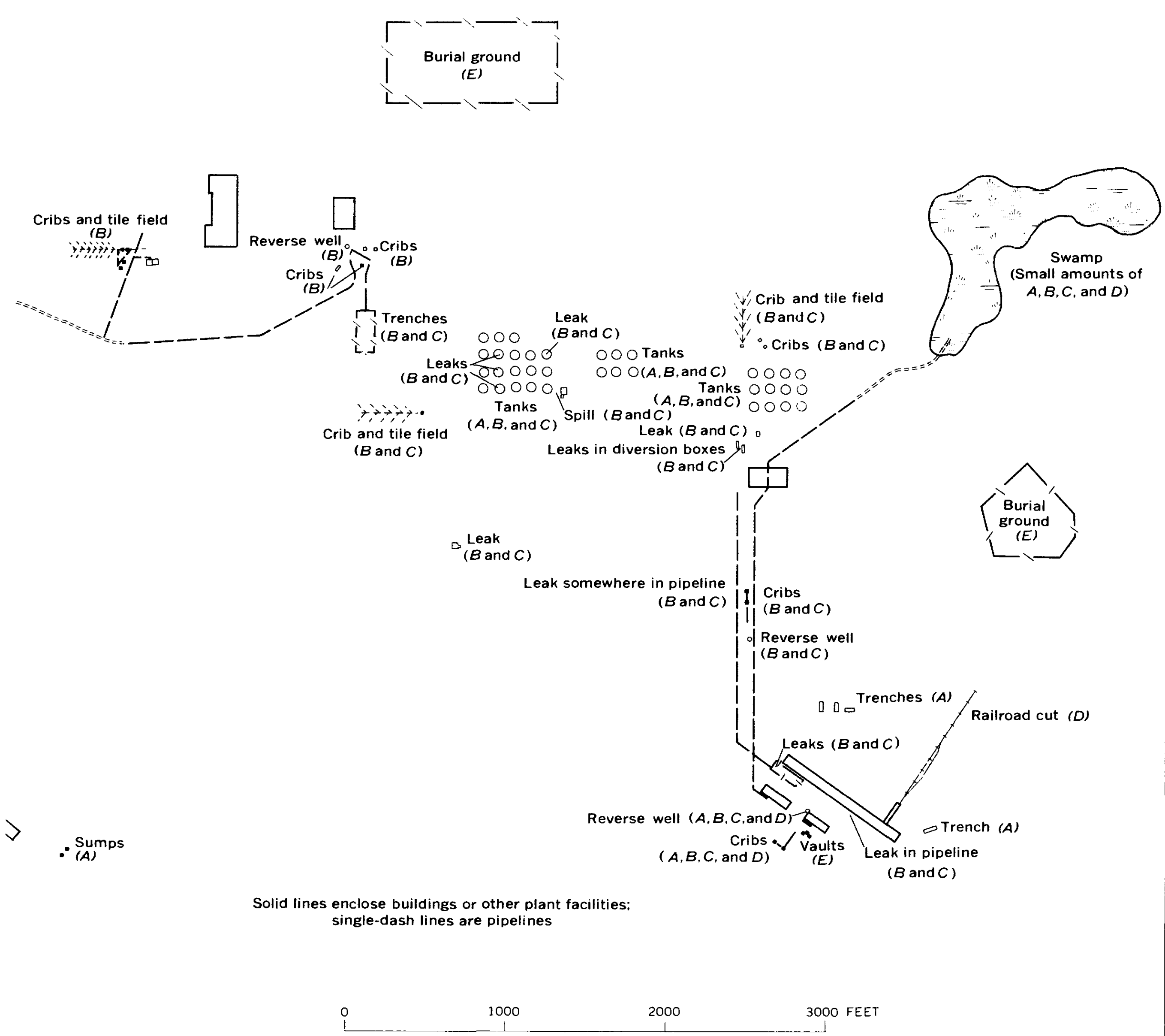


FIGURE 11. — Typical Hanford chemical-separation plant, showing

the longest half life apparently are taken up in such a short distance from the bottom of a crib that their location is monitored with great difficulty. Excess cations present in the calcium-rich deposits of these geological materials are reported to be instrumental in this take up of radioactive cations by base exchange. The rapidity with which the different radioactive cations are lodged and fixed in the earth materials is reported to be in the general order of plutonium-239, strontium-90, zirconium-95, yttrium-91, cesium-137, and ruthenium-106. Some comparative travel rates for ruthenium and cesium have been described by Belter (1963, p. 20). Much of the ruthenium-106 and most of the tritium (H^3) are not fixed on the geologic materials and are free to migrate with the water.



points of storage or disposal of several types of radioactive waste.

Where base-exchangeable radioactive ions have reached the water table and have been detected in the ground water, that crib usually has been taken out of service. The most distant of the emplaced ions is generally the nonradioactive nitrate, except where ruthenium and tritium are being placed underground in large quantities.

Of the subsurface disposals, the least hazard to the hydrologic environment results from the burial of radioactive building materials and equipment and other solids above the water table, where the radioactive material is protected from wind erosion and is far from surface streams. The solid state and the decay of their general low level of radioactivity make these disposals only a minor radiation hazard within a few years, except near the river, where these disposals may be subject to flooding and erosion during abnormal changes in the river channel.

The potential hazard from large quantities of tank-stored metallic wastes and the adsorbed wastes of long half life cannot be entirely overlooked. The true structural life of the tanks and the permanence of the ground fixation of the base-exchanged and adsorbed crib-disposed wastes are not entirely known. If large quantities of the crib-disposed wastes, which were fixed by base exchange, became unlocked by unnatural chemical conditions, they could move with the ground water until readsorbed by natural cation exchange. The knowledge of ground-water movement and geochemistry is vital to the monitoring and control of these waste disposals.

The movement of ground water carrying ruthenium and tritium from the eastern large mound can be controlled by management of waste disposal and, to some extent, by the manipulation of ground-water levels and hydraulic gradients.

SPECIAL GEOLOGIC SITUATIONS THAT AFFECT OPERATIONS OF AN INDUSTRIAL PLANT

TERRAIN, FOUNDATIONS, AND BUILDING MATERIAL

The general levelness of the terraces, the ease of excavation, and the ready drainage give the reservation advantages as an industrial site. The terrain advantages are formidable when combined with the adjacent large supplies of water of excellent quality, the area's lack of usefulness for some other purposes, and the accessibility to transportation. The glaciofluviatile and fluviatile deposits and the gravelly parts of the conglomerate of the Ringold Formation provide stable foundation materials. The bearing strength of the silts and clays of the Ringold Formation is much less, but these materials reach the surface or approach close beneath possible building sites in very few places in the northern part of the reservation.

The gravel and sand of the glaciofluviatile and fluviatile deposits are unweathered and (except for the basaltic scabland gravel facies) consist mostly of rock and mineral particles that are nonreactive with common portland cements. Largely siliceous sand in the medium to fine sizes can be procured from the live dunes to build up the percentage of these particle sizes in concrete mixes. Common fill and miscellaneous-size basalt stone are abundant. Silty clay can be obtained at a few locations, mostly from the Ringold Formation.

STORAGE SPACE FOR FLUIDS AND GASES

The volume of space available for artificial storage of water in the unconsolidated deposits (mainly the Ringold Formation) beneath the high terrace lands south of Gable Mountain and Gable Butte can be computed as near 3 million acre-feet. This volume is obtained by postulating levels at which the raised water table would not (1) intercept the land surface, (2) saturate the lowest part of the glaciofluviatile and fluviatile deposits, nor (3) cause an undue increase in the discharge of ground water to the Columbia River or to Cold Creek. At present only a small amount of the underground storage space is used for the recharged 130,000 acre-feet of water in the ground-water mounds near the chemical-separation plants and for the small amounts of recharge near the reactors and the Richland well fields. Unsaturated ground space forms a valuable asset for nuclear industry on the reservation.

Space suitable for underground storage of commercial gas or lighter-than-water fluids may exist in the basalt bedrock. The fine-grained sedimentary beds that occur between some of the basalt flows may in places form a confining layer. The occurrence of such a capping of impervious material below the water table is necessary to the efficient storage of gas in the basalt; this requirement was indicated by the quick depletion of the methane gas that occurred with a pressure of only 2 pounds per square inch in the wells of the old gas field on the east slope of Rattlesnake Mountain. (See well 11/26–29B1.) In this occurrence, the methane gas had accumulated above the water table and beneath the sedimentary layer that cropped out in the mountain slope to the west (pl. 1). An impervious capping in places may be provided by dense flow centers in the basalt, but fine-grained sedimentary beds can form a more uniform and less permeable containment. Where the basalt is gently arched and interstratified tuff beds form impervious layers below the water table, such as may be the situation in the anticline at and near sec. 18, T. 9 N., R. 28 E., southeast of Red Mountain, the main requirements for off-line underground storage of commercial gas may be present in the porous tops of the basalt flows below the tuff beds.

DISPOSAL OF RADIOACTIVE WASTES

Because time is the only ultimate rectifier for the health hazards of long-lived radioactivity, the common requirements for waste disposal are protective shielding, isolation, and conditions of relative immobility. Convenient and economical methods of disposal for its wastes are inherent necessities for a nuclear plant. Protective shielding for small amounts of radioactive waste, even that having a long half life and a high level of radioactivity, can be provided by earth cover that will remain indefinitely. The cover over permanent disposals of high-level wastes must be sufficient to prevent its disturbance. Isolation may be provided by closure of the area to unnecessary entry and is more easily managed where ordinary uses of the area are negligible. Stability of the waste disposal — the opportunity for it to stay in place — is largely controlled by the geologic and hydrologic conditions.

DISPOSAL BENEATH THE HIGH TERRACES

The high terraces of the central and northwest-central parts of the reservation provide a setting that meets the above requirements for subsurface disposal of some radioactive wastes.

Solid wastes placed underground, with the surface protected from wind erosion, are relatively safely fixed against natural disturbances in the high-terrace areas. Except for finer grained materials of the Touchet Beds in Cold Creek valley, the mantle of glaciofluviatile and fluviatile deposits that underlies the high terraces readily accepts wastes in solution and assures the liquid's transfer downward to the Ringold Formation, in which the water table lies 100 to 300 feet below the surface and in which ground water moves slowly except where influenced locally by artificially steepened hydraulic gradients.

The results of analyses by the plant-operating companies and the Atomic Energy Commission show that during downward movement to the ground water the radioactive wastes pass through some materials having a high capacity for base exchange. In this downward movement of the waste solutions, much of the longest lived radioactive-cation content is adsorbed or fixed by base exchange on the transmissive materials (Belter and Bernard, 1963, p. 179). Some of the radioactive cations, particularly cesium, are so slowly adsorbed, however, that some of this waste reaches the water table (Belter, 1963, p. 20).

Personnel of the operating contractors have contended orally in many conferences that no foreseeable natural phenomena or artificial effect can reverse the base exchange, or sorption, and free the adsorbed radioactive cations and permit them to migrate. Apparently, all agree that such columns of mineral-fixed radioactive cations need to be monitored and permanently protected from human access.

The ruthenium (Ru^{106}) and tritium (H^3) are the principal radioactive ions whose distribution has been relatively unaffected by sorption. The 1-year half life of the ruthenium renders this isotope less persistent than the tritium, which has about a 12-year half life and is able to enter directly into the water molecules.

The spot introduction to the ground water of radioactive waste in solutions having a density similar to that of the ground water is followed by dispersion that accompanies movement of ground water in granular materials. This dispersion normally dilutes initial concentrations many times during long movements through deposits like the Ringold Formation.

The direction and rate that the radioactive wastes travel in the ground water of the Ringold Formation is influenced artificially by control of the slopes of the water table. The average accelerated rate of movement of the artificially recharged ground water through the conglomerate is a few hundreds of feet per year in the directions of the slopes of the recharge mounds. The contours of the mounds show that in some parts of the Ringold Formation, such as the southeast side of the top part of the western large mound (Brown and Haney, 1964, fig. 5), the ground water is traveling outward faster than elsewhere, as indicated by the rate-of-movement computations given for 1953.

Thus, from the ground-water travel rates previously described, we may conclude that some of the residual radioactivity from disposals beneath the high terraces of the northwest-central part of the reservation, if kept entirely in the Ringold Formation, would reach the Columbia River only after at least many scores of years, and probably after a hundred years. Also, during these periods of time the radioactivity of any effluent waste would have been greatly lessened by decay, adsorption or base exchange, and dilution. If radioactive waste is disposed to ground water that is rising into or traveling in the glaciofluviatile and fluviatile deposits, the waste can be flushed to the Columbia River in about one-hundredth of the average time of travel for a similar distance in the Ringold conglomerate.

DISPOSAL BENEATH THE LOW TERRACES

The low terraces along the Columbia River stand only 30 to 100 feet above the natural water table and lie over the riverside zone of bank storage in which ground water rises and recedes with the annual flood level of the river. Water carrying radioactive waste to ground water beneath these low terraces might reach the river within a few tens of years. Though the radioactivity would be lessened by dilution, decay, and adsorption in amounts that depend on the type of waste and the manner and place of its disposal, the low terraces afford less favorable waste disposal sites than the high terraces. Radioactive wastes disposed to the ground in solid form are conceivably vulnerable to erosion by the river as mentioned below under "Geologic Hazards of the Reservation."

THE POSSIBILITY OF DISPOSAL IN THE BASALT

Suitability of the basalt of the Columbia River Group as a disposal place has been intermittently considered by the Atomic Energy Commission and the prime contractors. The costs of waste-emplacement and monitoring installations and the lack of knowledge on rates and directions of ground-water movement in the basalt have discouraged tests of the potential utility of the upper several thousand feet of the basalt for this purpose. The circulation of ground water probably is confined to relatively few and thin aquifers. The ground water in the top thousand feet or so of the basalt is a part of the basic water supply of the region and is developed by an ever increasing number of wells; consequently, radioactive wastes improperly placed in the upper part of the basalt could be subject to movement toward ground water now in use by the public. The possibility of using space in the basalt or in the bedrock formations below the basalt is a matter for further study.

WATER SUPPLY

Besides the water available in the adjacent rivers, large quantities can be obtained from wells in some parts of the reservation. Wells with yields of 1,000 gpm can be obtained by deep drilling in the basalt and also by proper well construction in the conglomerate of the Ringold Formation beneath part of the reservation. Wells of much larger yield can be constructed in the glaciofluviatile and fluviatile deposits in the few places where these gravelly materials extend below the water table.

At present the only appreciable withdrawal of ground water is by the city of Richland, which obtains water from about 20 wells. These wells are clustered around ponds in which water from the Yakima and Columbia Rivers is used for artificial recharge to increase the thickness of saturation in the sand and gravel. The producing zone is mostly in the Ringold conglomerate until the recharged water raises the water table into the overlying glaciofluviatile deposits (Price and others, 1965). In winter, when water is not recharged and the water table is low, some of the wells have only one-third or one-fourth of the yield that they have during the recharge period of the summer. This difference in yield is especially evident for the wells in which the recharge water saturates part of the overlying glaciofluviatile and fluviatile deposits. Recharge water from the Columbia River has been substituted for part of the supply formerly taken from the Yakima River in order to decrease the hardness resulting from the very hard water of the Yakima River during the late summer and fall (Price and others, 1965).

GEOLOGIC HAZARDS OF THE RESERVATION

Earthquakes of sufficient intensity to create damage are unlikely in any one year, but their occurrence is probable within any one century. Records of the past 90 years include only six earthquakes that produced slight damage. These six are earthquakes felt most strongly at Walla Walla, December 16, 1872, and January 4, 1873; Umatilla, March 6, 1893; Corfu, November 1, 1918; and Umapine, July 15, 1936, and November 17, 1936. Corfu is at the northern foot of the Saddle Mountains, 8 miles northeast of Wahluke; Umatilla is 24 miles south of Richland; and Walla Walla and Umapine are along the north side of the Horse Heaven anticline, 45 miles southeast of Richland. The inferred epicenter for the Corfu earthquake was at the foot of the Wahluke Slope 10 miles northeast of Gable Mountain. Other earthquakes felt in the region of the reservation had epicenters at more distant places. The geologic youthfulness of many lines of bedrock deformation suggest that an earthquake potential is present.

Landslides, or block slumpage, represent an ever present hazard along parts of the Columbia River, especially at The White Bluffs. This hazard is somewhat related to the others, because earthquakes are a common trigger mechanism for landslides and because flooding can be either a cause or a result of landslides. Major damage can result from flooding by landslide-blocked streams. The competence of the Ringold strata exposed in The White Bluffs in places may be decreasing because of progressive wetting from irrigation on the plateau to the east. The blocked-channel type of flood hazard from landslides is greatest for the low terraces, especially in some places near the Hanford and White Bluffs townsites. Near these places, some radioactive wastes have been disposed to the ground, and flooding could result in their release to the river.

Among various proposals for hydroelectric power and navigation developments is a 45-foot-high dam, called the Ben Franklin, in sec. 1, T. 11 N., R. 28 E., 12 miles north of Richland (U.S. Army Corps of Engineers, 1958, p. 228–233). The proposed 400-foot level of the reservoir would cause a rise of ground water in accommodation to reservoir level. Some of the damage and the hazards that are expected to be induced by raising the water table beneath the terrace lands on the east side of the Columbia River have been evaluated in studies by the Atomic Energy

Commission (U.S. Army Corps of Engineers, 1958, p. 228), but the increase in landslide hazards created by raising the level of saturation within large slide blocks along The White Bluffs (pl. 1) may surpass the evident flooding, increased operating costs, and other detriments that have been evaluated for such a dam.

Flash-flood types of water damage have occurred in the valleys of Cold Creek and Dry Creek, but such sudden runs of water are infrequent. This kind of flooding is destructive only at a few places within the valleys of those streams.

The flood record of the Columbia River indicates the highest river level was reached during the annual early summer peak in 1894; the second highest occurred early in June 1948. Most of the atomic-plant structures and installations along the river are sited to withstand levels comparable to the level of the 1894 flood, but they could be damaged by the release of additional water when a flood crest comparable to that of 1894 or 1948 was passing the plant.

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TABLES 1–3

TABLE 1.—*Data on wells of the Hanford Reservation*

Topography: S, slope to major valley; T, terrace. Altitude: Numbers in whole feet interpolated from map; those to tenths of feet surveyed by U.S. Geol. Survey, Gen. Elec. Co., or other agency.
Type of well: Dg, dug; Dr, drilled.
Water levels: The measuring point (MP) is generally the top of the casing or the top of an extended pipe of lesser diameter; the figures in whole feet are reported; those in tenths and hundredths were measured.
Use for which well was constructed or is now employed: D, domestic; G, gas; Ind, industrial; Irr, irrigation; M, monitoring; N, none; O, observation of water level; PS, public supply; Th, test hole (for water or foundation).
Remarks: The following abbreviations are used: alt, altitude; Ca, chemical analysis in table 3; dd, drawdown; ft, feet; gpm, gallons per minute; hr, hours; L, log in table 2; rptd, reported; rwl fig. 9, record of water level in indicated figure; temp, temperature.
Owner of land in nearly all instances is U.S. Government. Other owners and former owners are shown in the remarks column.

Well No.					Casing			Water-bearing zone or zones				Water level			
USGS No.	Hanford Operations Office No.	Topography and altitude (feet)	Type of well	Depth (feet)	Diameter (inches)	Depth (feet below land surface)	Perforated interval (feet below land surface)	Depth to top (feet)	Thickness (feet)	Character of material	Altitude of MP (feet)	Feet below MP	Date	Use	Remarks
T. 9 N., R. 27 E.															
20E1		T, 625	Dr	138	6	71	....	70	68	Basalt	....	80	10–1–50	PS	Penetrated Touchet Beds to 70 ft. Owned by Kiona Auto Court.
T. 9 N., R. 28 E.															
3B2	L903A (F36B)	T, 382	Dr	55	6	54.5	....	52(?)	2	Sand	382.5	31.38	10–1–48	Th	
5C1		T, 390	Dr	572	16–12	180	77–79	173	399	Basalt	....	8	1–8–57	PS	L; supplies city of West Richland (formerly named Enterprise).
10G2	RD18W	T, 403.0	Dr	178	24–20	178	145–170	48 94 145	....	Sand, gravel Gravel Boulders	404.10	44.41	1–11–45	PS	Dd 130 ft after 7 hr pumping at 300 to 500 gpm.
10J1	RD2W	T, 354.0	Dr	62	12	62	22–52	40	11	Gravel	355.91	5.80	9–29–44	PS	Dd 16 ft after 8 hr pumping at 470 gpm.
15J1	RD5W	T, 360.0	Dr	72	18	72	46–68	45	25	Sand, gravel	359.98	17.00	9–29–44	PS	L; cement plug set at alt 291 ft; dd 27 ft after 15½ hr pumping at 2,550 gpm. Type well of Richland pond recharge group.
T. 10 N., R. 26 E.															
11D1		S, 1,320	Dr	420	8–6	....	....	338	82	Basalt	1,320	338.5	12–7–53	N	Ca; former Hodges Ranch well.
T. 10 N., R. 27 E.															
2N1	NN1040–1	T, 420	Dr	89	8–6	44 67.5	....	60 77	8 12	Sand Basalt	....	19	8–1–49	D	
T. 10 N., R. 28 E.															
2P1	303–3	T, 374.6	Dr	77	8	77	20–75	40	37	Sand, gravel	375.61	38.19	4–12–51	M	Rwl fig. 3.
3R2	303–5	T, 394.2	Dr	102	8	101.5	50–83	62	8	Gravel, sand	395.15	57.50	4–12–51	M	Do.
10B1	303–8	T, 395.2	Dr	119	8	114	43–70 98–106	65 99	2 7	do. Gravel	396.35	56.92	4–12–51	M	Do.
10G1	303–13	T, 387.8	Dr	212	8	194.6	....	192	15	Sand, basalt	389.31	10.09	4–12–51	M	L.
11D1	303–4	T, 383.3	Dr	101	8	100.3	40–75	55	....	Gravel, sand	384.34	47.95	4–12–51	M	
11E3	300–4	T, 406.1	Dr	175	8	162	140–160	....	....	do.	....	....	....	Th	
14K1	3000–4	T, 374.4	Dr	191	8	176	60–93 120–146 172–176	60 120 172	38 26 4	Sand Gravel	375.60	28.19	5–20–52	Th	Pumped at 300 gpm.
14K2	3000–F	T, 374	Dg	71.4	17	....	....	....	....	Gravel	373.97	25.58	5–20–52	PS	Dd 1.7 ft after 4 hr pumping at 730 gpm.
17B1	USGS 12	T, 458.3	Dr	228	8 4	225.3 187.4	93–103	93 220	10 4	Sand, gravel, silty gravel. Basalt	460.28	85.57 85.43	9–26–51	O	Ca; L; rwl fig. 6.
23P4	3000–G	T, 399.1	Dg	74	17	74	38–74	....	....	Gravel	398.94	45.65	5–15–52	PS	Dd 5.1 ft after 7 hr pumping at 405 gpm. Well at A–J recharge pond of city of Richland.
34C1	F45	T, 372.4	Dg	19.5	48	....	....	....	....	....	372.79	16.17	2–1–49	O	
35D2	1100–8	T, 369.0	Dr	120	10	95	24–27 44–95	18 44	6 22	Gravel, sand do.	....	....	....	....	Dd 4 ft after 5 hr pumping at 985 gpm. Type well at Duke recharge pond of city of Richland.
35H1	1100–1	T, 346.6	Dr	101	8	101	15–45 80–100	10 80	31 21	Sand Gravel	....	10	3–1–48	Th	L; test pumped at 660 gpm; type well at N–K recharge pond of city of Richland.
T. 11 N., R. 25 E.															
5E1		S, 1,160	Dr	1,003	....	....	....	....	....	....	....	....	....	....	Spokane-Benton Natural Gas Co.; Rattlesnake gas field test well 1 No. 1 (on former Snively Ranch).
27N1		S, 2,720	Dr	935	....	....	....	....	....	....	....	....	....	....	Gas test well, known as Horseshoe No. 1.

T. 11 N., R. 26 E.															
2F1	10/45	S, 560	Dr	380	8	348	170–220	165	60	Coarse gravel		182	8–16–57	O	Entered basalt at about 375 ft.
3G1	USGS 3	T, 513.7	Dr	200	8	200	108–123	116	24	Gravel, sand	516.58	117.68	12–5–50	O	Ca; L.
5B1	USGS 4	T, 549.9	Dr	167.5	8	165	137–147	121	46.5	do	552.21	130.15	12–5–50	O	Ca; L.; rwl fig. 5.
20R1		S, 1,275	Dr	1,234			800–?					451	11–6–50		Discovery well (No. 1) of former gas field.
27E1		S, 1,150	Dr	670											Known as Big Bend Land Co. well No. 1; reportedly produced gas from 670 ft.
29B1		S, 1,420	Dr	3,660											L; formerly W.W.O.G. and PL Co. well No. 6, deepened from 803 ft by Northwest Natural Gas Corp.
34R1		S, 1,220	Dg,Dr	1,000	36–16	742		800	200	Basalt		800	1959	PS	Ca; supplied defense cantonment.
T. 11 N., R. 27 E.															
2Q1	USGS 5	T, 520.3	Dr	200	8	200	151–166	143	25	Sand, gravel	522.81	142.69	12–5–50	O	Ca; L.
5Q1	USGS 2	T, 554.6	Dr	204.2	8	204.2	169–184	169	16	Gravel, sand	567.16	168.79	12–5–50	O	Ca; rwl fig. 5.
20M1	USGS 7	T, 525.6	Dr	321	8 6 ... 4	143.7 141.8— 293 150.2	128–138	128 293	9 28	do Basalt	527.12 527.12	131.53 132.32	1–17–51	O	Ca; L; rwl fig. 6.
26D1	USGS 6	T, 506.1	Dr	148	8	148	117–132	116	19	Gravel, sand	504.01	123.73	12–5–50	O	Ca; L.
T. 11 N., R. 28 E.															
17D1	USGS 8	T, 475.1	Dr	147.5	8	147.5	106–121	107	34	Gravel, sand	477.14	107.11	12–5–50	O	Ca; L; rwl fig. 5.
21L3	321–3	T, 433±	Dr	461	8	322		75 414	75 47	do Basalt		46.83	6–10–53	M	
29N1	USGS 11	T, 433.2	Dr	110	8	110.0	69–84	69	39	Gravel, sand	435.68	68.89	12–5–50	O	Ca; L.
T. 12 N., R. 25 E.															
1A14	361T14	T, 705	Dr	534	8	509	275–325	305	27	Sand, gravel		285	11–30–50	M	L.
1F1	224T10	T, 671.4	Dr	230	6 4 ...	210 144— 230	202–230	135	95	do	674.07	214.75 217.40	12–5–51 5–15–53	M	
1G1	224T9	T, 670	Dr	106	8	111.5	77–83	64	25	Sand, silt		83	9–28–51	M	Backfilled to 109 ft and cemented at 106–109 ft; water at 64–89 ft is perched.
3D2	USGS 13	T, 646.2	Dr	306.8	8	306.8	237–247	244	12	Sand, gravel	648.16	219.34	1–16–51	O	Ca; L.
10N1	34/88.5	T, 633.0	Dr	688	8	647.5	222–252	220	13	Sand, cobbles, gravel.	634.8	207.4	12–20–48	Th	L.
11A1	39/79	T, 671.6	Dr	295	8	294.7	264–294	260	34	Gravel	673.3	267.26	9–8–48	Th	Rwl fig. 7.
12K6	241S6	T, 664.7	Dr	262	6	261	195–260	249	13	Sand, silt, gravel		234 223.54	4–5–52 4–21–53	M	Drilled in 25-ft excavation.
12M1	35.5/78	T, 660.3	Dr	279	8	277.5	230–245 262–268 272–279	240 262 275	5 4 4	Sand, gravel	661.8	246.5	8–15–48	Th	
13E1	32/77	T, 652.2	Dr	290.7	8	290.1	204–290	259	12	do	653.74	242	5–5–51	Th	
23K1	25/80	T, 614.8	Dr	336	8	170		210 250	10 86	Sandy tuff Volcanic rocks	615.9	191.2	11–22–48	Th	L; level of water rose from 220 to 190 ft when well deepened from 250 to 336 ft.
26M1		T, 610	Dr	2,000	12–8	1,314		126 1,314	178	Gravel, sand Basalt		106	9–1–44		L; old Benson ranch well; test well for gas.
27M1	20/87	T, 740	Dr	388	8	360	70–170	120	10	Gravel		128	11–4–57	O	Apparently entered basalt at 360 ft.
33D1	17/93	S, 800	Dr	55	8	40								Th	Entered basalt at 35 ft.
T. 12 N., R. 26 E.															
2E1	361B4	T, 689.7	Dr	321	8	320	295–321	290	31	Sand, gravel	691.18	290	4–1–48	Th	
2J1	361B10	T, 665.1	Dr	310	6	310.8	287–310	280	30	do	665.93	280	5–17–48	Th	
2M1	361B8	T, 704.6	Dr	348	8	348	317–343	325	23	Sand, gravel, boulders.	709.36	321	4–19–48	Th	L.
3A3	361B9	T, 681.3	Dr	320	6	320	278–300	295	15	Sand, gravel	685.54	294	8–1–51	Th	
4N1	40.3/61.5	T, 745	Dr	384	8	384	359–374	360	14	do	356		1–14–49	Th	
7B1	38/70	T, 720	Dr	413	8	386	255–380	270	90	do		270	6–18–57	O	
7Q1	34.5/69.5	T, 691.7	Dr	325.4	8	324.3	295–310 315–320	291 296	1 29	do do	693.00	291.12	9–8–48	Th	L.
9L1	36.5/60.5	T, 746.6	Dr	390	8	390	348–389	358	32	do	747.8	357	8–11–48	Th	
10K1	241–BC–5	T, 742.7	Dr	367	8	367	330–365	320	45	do		346	8–29–56	O	
11B8	A–10–4	T, 710	Dr	351	8	351	295–398	290	58	do		295	6–6–56	O	
12H1	38/43	T, 685	Dr	517	8	510	275–310	300	10	do		300	11–3–55	O	Entered basalt at 510 ft.
14D1	34/51.5	T, 733.2	Dr	386.0	8	383.3	341–381	360	25	do	734.4	346.4	11–22–48	Th	L.
17Q1	30/65	T, 665	Dr	450	8	450	258–330	258	72	Gravel, sand		268	7–11–57	O	
18E1	32/72	T, 675	Dr	580	8	571	210–410	226	186	do		225	7–31–57	O	
19K1	25/70	T, 628.8	Dr	460	8	440.8	240–270	240		Sand, gravel, boulders.	629.35	228.45	9–2–48	Th	L; rwl fig. 7.
22L1	25/56	T, 673.4	Dr	315	8	315	284–314	288	27	Sand, gravel	674.4	285.49	8–7–48	Th	
25Q1	USGS 1	T, 549.2	Dr	202.8	8	200.3	169–182	169	34	Gravel	551.78	161.79	12–5–50	O	Ca; rwl fig. 9.
T. 12 N., R. 27 E.															
3P1	40/24	T, 465.0	Dr	120	8	119	85–115	90	30	Sand, gravel	466.5	86.71	7–17–48	Th	L; rwl fig. 9.
5Q1	40/35	T, 530.8	Dr	283	8	276	155–185	155	30	Gravel, sand	535.0	141	2–9–49	Th	Entered basalt at 283 ft.
6L1	42/39	T, 530	Dr	314	8	304	174–273	180	120	Gravel		185	8–22–56	O	Entered basalt at 304 ft.
16M1	31/30	T, 520	Dr	640	8	595	135–200	139	61	Sand, gravel		139	2–23–56	O	Didn't reach basalt at 640 ft.
18C1	35/40A	T, 534.0	Dr	167	8–6	167	127–167	145	21	Gravel, sand	535.2 535.7	Dry 144.70	7–1–48 6–10–53	Th	L. Deepened from 130 ft in 1953.
19D1	28/41	T, 535	Dr	470	8	467	150–270	160	110	Gravel		162	5–16–56	O	

TABLE 1. — *Data on Wells of the Hanford Reservation*—Continued

Well No.					Casing			Water-bearing zone or zones				Water level			
USGS No.	Hanford Operations Office No.	Topography and altitude (feet)	Type of well	Depth (feet)	Diameter (inches)	Depth (feet below land surface)	Perforated interval (feet below land surface)	Depth to top (feet)	Thickness (feet)	Character of material	Altitude of MP (feet)	Feet below MP	Date	Use	Remarks
								T. 12 N., R. 27 E. — Continued							
20P1	25/35	T, 528.7	Dr	165.5	8	164.5	144–164	141	23.5	Sand, gravel	531.22	134.5	8–12–48	Th	
27J1	20/20	T, 503.5	Dr	158	8	156.5	130–155	130	28	do	505.07	120.57	7–28–48	Th	L; rwl fig. 9.
33Q1	14/27	T, 515	Dr	350	8	346		130	20	do		131	4–12–56	O	Basalt not reached.
								T. 12 N., R. 28 E.							
6A1		T, 407	Dg	68	60					Sand, gravel	407.5	65.34	3–16–43	D	Well No. 53 of Jenkins (1922).
18D1	USGS 10	T, 497.5	Dr	176	8	164.0	120–135	117	16	Sand, silt, gravel	500.03	128.34	12–5–50	O	Ca; L; rwl fig. 5.
24N1		T, 430	Dr	755	12							19 19	1921 1940	D	L; old Stubblefield well near Ringold School.
31H1	USGS 9	T, 433.2	Dr	105	8	105	57–72	65 93	12 12	Sand, gravel Sand, silt, gravel	434.7	61.98	12–5–50	O	Ca; L.
								T. 13 N., R. 25 E.							
1N2	107B–2	T, 420.3	Dr	790	8	650		764 785	5 5	Basalt Sandstone		41	9–21–53	M	Ca; L.
3Q1	G 447	T, 436	Dr	52	8 6	52					433.0	39.37	5–15–53	O	Old farm well.
5P1		T, 461	Dg	69	42						461	56.94	5–15–53	O	Well No. 53 of Jenkins (1922).
7M1		T, 450	Dg	93	8			62	31	Gravel		62	12–17–52	D	Ca; well at military camp.
7Q1	RRYC/D2W	T, 461.8	Dr	128.5	12	128	95–125					72.9	1–26–44	Ind	Pumped at 540 gpm with dd of 0.60 ft.
11A3	108B3	T, 460	Dr	91	8	90	70–90	70	21	Sand, gravel	461.16	66.26	3–10–49	Th	Rwl fig. 4.
11J3	105–C–1	T, 476.5	Dr	119	8	117	90–117	93	25+	Gravel		68	7–10–52	M	Drilled in crib excavation.
12P1	Robinson Ranch.	T, 490.8	Dg	100	72							Dry	3–15–51	O	May be well No. 170 of Jenkins (1922).
14N1		T, 580	Dr	111	12							Dry	10–1–43	Th	
16J1	62.5/90	T, 510	Dr	253	8	237.9	115–147	116	122	Gravel	511.9	112.44	11–12–48	Th	L.
23A2	60/80B	T, 580.6	Dr	198	8	181		190	8	Basalt	582.6	179.96	9–2–48	Th	L.
25R1	51/75	T, 638	Dr	382	8	377		205	30	Sand, gravel		206	10–4–57	Th	Entered basalt at 376 ft.
26N1	50/84	T, 730	Dr	600	8	585		295	55	do		297	10–21–57	Th	Entered basalt at 585 ft.
27C1	55/88.5	T, 607	Dr	235	8	234.4	192–222	200	25	do	607.80	190.38	11–26–48	Th	
30G1	McGee	S, 831	Dr	1,110	8			700	410	Basalt	827	+192	11–28–51	Irr	Ca; L; flow 1,375 gpm on 3–7–43; temp of water 79°F; easternmost of 6 artesian wells in upper Cold Creek valley.
33D1	USED (L–6)	T, 800	Dr	540	6			392	26	Sand, gravel		365	4–1–43	Th	L; well now 334 ft deep with uppermost 2 casing joints broken.
36D1	49–79	T, 687.5	Dr	290	8	266.8		265	25	do	688.6	267.0	7–10–48	O	L.
								T. 13 N., R. 26 E.							
1A1	S1610	T, 441	Dg	44	72						441.37	34.77	10–7–44	O	Well No. 74 of Jenkins (1922). Caved in.
1G1	74/44	T, 440	Dr	150	8	150	17–67	58	9	Silty sand		58.15	5–15–57	O	
2N1	71/52	T, 520	Dr	210	8	204	120–160	129	31	Gravel, sand		133	7–22–54	O	Did not reach basalt.
3B1	77/54	T, 475	Dr	150	8	150	70–120	80	40	do		80	5–24–57	O	
5D2	100K–10	T, 464.6	Dr	170.5	12	170	126–131 137–139 154–164	126 137 154	5 2 10	Gravel do do	466.1	76.1	8–4–52	PS	Ca; L; tested at 560 gpm with 50 ft dd.
7C1	70–68	T, 526.3	Dr	149	8	149	126–147	127	22	Gravel, sand		126	7–6–54	O	
13R1	Gable Mtn. R1	T, 430.1	Dr	72	8	72	55–65	54	11	Sand, gravel	432.08	39.15	1–8–53	O	Water level did not move when 13R2 pumped.
13R2	Gable Mtn. R2	T, 419.7	Dr	68	12	68	33–63	33	30	Gravel	420.21	32.90	3–29–54	Th	Ca; Test pumped for permeability determinations; located 400 ft north of 13R1.
14C1	65/50	S, 465.3	Dr	585	8	583	55–85 100–125	100	25	Sand, gravel		70	8–12–55	Th	Entered basalt at 578 ft.
17Q1	61/65	T, 530	Dr	225	8	216	115–160	125	25	do		126	6–16–55	Th	Entered basalt at 220 ft.
18C1	Ranch 13	T, 533	Dg Dr	60 216	12	216					540.36	148.28	3–15–43	O	Rwl. fig. 4. Well No. 169 of Jenkins (1922).
19R1	55/70	T, 567.9	Dr	205	8	200.5	182–200	181	19	Gravel	569.1	168.1	7–10–48	Th	L; rwl fig. 7.
20Q1	200ND3W	T, 577.6	Dr	146	20 16							Dry	5–1–44	Th	Casing pulled.
21B1	60/60	T, 508.5	Dr	128	8	126		110 123	4 3	Sand Sand, gravel	511.29	116.66	12–13–52	Th	Rwl; fig. 4.
21Q1	200ND5W	T, 570.5	Dr	288	24 14	10 288	230–285	230	55	do	571.34	179.07	8–16–44	Ind	Dd 1 ft after 26.5 hr pumping at 1,280 gpm; temp of water 62°F.

25A1 54.5/42.5	T,	509.7	Dr	210	8	202.2	140–145 180–185 195–200	128	12	Sand	511.3	118.38	12–13–52	Th	L.
26B1 55/50	T,	441.3	Dr	108	8	101	70–100	60	35	Sand, gravel	442.6	47.67	12–13–52	Th	
26B2 55/50–2	T,	440	Dr	98	12	85		40	45	Gravel		40	9–28–56	Th	Basalt at 98 ft; screen set 38–85 ft; test pumped and dismantled.
28B1 200ND1W	T,	569.8	Dr	233	12 10	132.2 233	190–230	180	53	do	569.84	130.0	10–28–43	Th	Dd 2 ft after pumping at 565 gpm; temp of water 58–60°F.
31R1 45/69.5	T,	718.2	Dr	368	8	368	336–366	338	27	Sand, gravel	719.2	319.9	7–10–48	Th	
33K1 47.5/60.5	T,	650.3	Dr	285	8	278	269–277	270	8	do	649.0	257.64 255.12	7–20–48 12–16–52	Th	L.
34J11 241BY2	T,	647.9	Dr	275	8	264	252–262	264 265	1 10	Sand Basalt	649.92	257	7–20–49	Th	
34J14	T,	620	Dr	415	8	232						227	9–21–53	M	
34R20 241B5	T,	633.8	Dr	258	8	230	204–220	204	16	Sand, gravel	635.3	241.7	1–27–53	Th	Basalt found at 247 ft.
35R1 361B11	T,	616	Dr	248	8	229	217–227	150 222	72 18	Gravel, sand Basalt	616.85	226.7	11–4–48	M	
36R1 46/42.5	T,	576.1	Dr	195	8	186.5		189	6	Ash, basalt	577.10	180 173.54	6–23–48 3–12–53	Th	L; rwl fig. 8.
T. 13 N., R. 27 E.															
3G1 HR10	T,	376.5	Dr	50	6	36				Sand	376.48			Th	Drilled by Ranney Water Collector Co.; slot-perforated casing set; test pumped at 60 gpm.
5B1	T,	394.5	Dg	19	24						395.0	18.2	11–18–52	O	Well No. 70 of Jenkins (1922).
7G1	T,	420	Dg	25	36							20.0	7–10–53	O	Well No. 66 of Jenkins (1922).
8B1	T,	397	Dg	24.5	10					Gravel, sand	399.5	17.89	3–15–43	D	Former farm well.
9K1	T,	391	Dg	39	24 30						391.0	24.27	11–15–52	O	Well No. 63 of Jenkins (1922).
10B1	T,	400	Dg	37.7	48						400.0	30.48	11–15–52	O	
13N1 CC133	T,	420	Dr	607	8	303	60–160 185–280	62 312	48 295	 Basalt		47.32	8–28–50	N	L; dd 140 ft after pumping at 75 gpm; known as Foster Ranch well; older, shallower well nearby.
15L2 S1683	T,	394.1	Dr	110	8	100	94–100	34 44 55 79	2 8 11 24	Sand, gravel do do do	396.3	31	9–1–44	Th	Backfilled with gravel to depth of 100 ft.
16G1	T,	405	Dr	84	8	83	65–74	53	22	Gravel		53	11–17–52	D	Ca; former army-camp well.
16R1 Hillman-USED.	T,	405	Dr	363	6	215		44 120	30 11	Sand, gravel Sand		44	4–1–43	N	L; casing pulled and well destroyed.
17J1 Sheep Ranch	T,	434.23	Dg	74.5	60					Gravel, sand	434.23	69.34	3–16–43	O	Rwl fig. 4; well No. 60 of Jenkins (1922).
21L1 Pistol Range	T,	414.2	Dg Dr	68	12	67	50–65	47	21	do	414.20	50.35	3–24–44	O	Dug 47 ft, drilled to 68 ft; dd 2 ft after pumping 1 hr at 500 gpm.
23R2 HD7W	T,	383.4	Dr	41.7	24	38	25–35	20	18	Sand, cobbles	384.32	20.5	9–18–43	PS	Dd 2.0 ft after 9 hr pumping at 1,100 gpm; old Hanford high school well.
25L3 HD2W	T,	392.0	Dr	100	12	100	22–45 67–90	35	65	Sand, silt	394.97	32.0	5–31–44	....	Casing pulled.
26F1 HD8W	T,	382.0	Dr	57	24	60	30–50	15	45	Sand, gravel	382.30	15.23	10–25–43	PS	Dd about 10 ft after 6 hr pumping at 1,080 gpm; temp of water 59°F.
26L4 HD24W	T,	408.9	Dr	140	16	122	50–90	45	49	do	409.90	45.84	5–31–44	PS	Dd 0.3 ft after 27 hr pumping at 1,500 gpm; temp of water 68°F.
28P1 50/30	T,	526.7	Dr	380	8	373.5	191–221	177 191 300 374	3 89 20 6	Sand Sand, gravel Sand Basalt	528.80	160	6–29–48	Th	L; rwl fig. 8; water in different strata has slightly different static levels.
30H1	T,	530	Dr	970	6 4.5 3.5	139 139–702 702–841				do		150	1923	D	Former Haynes stock well.
32K1 46/34	T,	473	Dr	107	8	102		75	27	Gravel, sand		80	8–24–55	O	Entered basalt at 102 ft.
35G1 HD22TH	T,	429.2	Dr	83	6	83					429.26	82.62	4–2–49	Th	
35N1 45/20	T,	521.5	Dr	337	8	333		160	40	Sand, gravel		162	9–22–55	O	
36G2 HD16W	T,	411.9	Dr	92	20	90	55–80	47	42	Gravel, sand, boulders.	411.40	47.73	3–20–44	PS	Dd 0.7 ft after 12 hrs pumping at 750 gpm; temp of water 58°F.
36G7 HD20TH	T,	410.1	Dr	102	6	92	76–88	19	73	Sand, gravel	410.35	48.12	3–21–44	O	
T. 13 N., R. 28 E.															
31F2	T,	382.1	Dr	45	2	33	18–33	18	15	Sand, gravel	386.65	17.83	7–3–43	O	
T. 14 N., R. 25 E.															
1D1 410–2	T,	659.0	Dr	938	20 16 12 10 8 6	894		224 625 895 934	2 5 5 1	Sand Basalt Sand "Rock"		195	5–1–52	D	Ca; log published by Walters and Grolier (1960, p. 394); dd 7 ft after 9 hr pumping 100 gpm; temp of water 78°F.
21B1 PSN525	T,	637	Dr	522	24 20	0–175 0–520		342	30	Sand, gravel		235	5–4–53	PS	Ca; log published by Walters and Grolier (1960, p. 394).
28E1	T,	860	Dr	648	24 20		492–503 550–560 593–600	547	22	do				PS	Log published by Walters and Grolier (1960, p. 395).
31N1 PSN515	T,	774	Dr	699	36 24 16	0–37 0–307 0–699	429–437 512–516 670–678	429 512 672	11 4 2	do do do		370	3–17–53	PS	Ca; log published by Walters and Grolier (1960, p. 395).

TABLE 1. — *Data on Wells of the Hanford Reservation*—Continued

Well No.					Casing			Water-bearing zone or zones				Water level			
USGS No.	Hanford Operations Office No.	Topography and altitude (feet)	Type of well	Depth (feet)	Diameter (inches)	Depth (feet below land surface)	Perforated interval (feet below land surface)	Depth to top (feet)	Thickness (feet)	Character of material	Altitude of MP (feet)	Feet below MP	Date	Use	Remarks
								T. 14 N., R. 26 E.							
11H1	HR-5	T, 388.4	Dr	77	6	47	....	6	41	Sand, gravel	....	5.06	5-17-43	Th	Screen set with bottom at 47 ft.
14A2	H-15	T, 401.5	Dr	75	6	30	....	16	21	...do	403.5	18.59	5-22-43	Th	
14M3	107D-2	T, 449.42	Dr	80.5	6	80.5	35-79	63	17.5	...do	447.92	56.5	6-12-52	O	
24F1		T, 410	Dg	41.0	60	....	....	....	....	....	....	25.24	1-23-53	O	Possibly well No. 177 of Jenkins (1922).
24P1		T, 405	Dg	27.5	60	....	....	....	....	Sand, gravel	405	15.24	3-15-43	N	
25A2		T, 405	Dg	45.4	48	....	....	....	....	....	....	43.22	1-23-53	O	
25M1	83/47	T, 450	Dr	150	8	150	35-50 65-100	50	50	Sand, gravel	....	47	4-24-57	O	
25P1		T, 415	Dg	26.0	8	....	....	....	....	....	....	23.18	11-17-52	O	Rebuilt No. 164 of Jenkins (1922).
31R1	RDA-DC6-1	T, 414	Dr	107	6	102.7	....	62	42	Sand, gravel	....	26	3-19-52	Th	L.
32P2		T, 460	Dr	159	12	160.0	118-134	....	....	...do	....	78.88	2-27-53	N	Pumped too much sand.
33L1	78/62	T, 470	Dr	150	8	135	70-120	87	33	...do	....	76	5-16-57	O	
36K1		T, 431	Dg	36	60	....	....	....	....	...do	....	33.70	3-15-43	D	Well No. 111 of Jenkins (1922).
								T. 14 N., R. 27 E.							
18H1	107H1	T, 403	Dr	75	6	57.8	25-74	40	10	Gravel, sand	417.27	40	3-27-52	O	
18J1	107H2	T, 418	Dr	386	6	363.1	....	355 380	10 6	Basalt	420.45	35.8	5-1-52	O	L.
24C1	PSN505	T, 860	Dr	1,396	20 16 12 10 8	1,396	1,370-1,393	1,373	22	...do	....	383 358	11-10-53 6-9-58	PS	Ca; log published by Walters and Grolier (1960, p. 395-396).
29D1		T, 410	Dg	42.0	48	....	....	....	....	....	....	40.54	11-17-52	O	Well No. 92 of Jenkins (1922).
30F1		T, 410	Dg	39.0	48	....	....	....	....	....	....	29.44	2-2-53	O	Formerly auxiliary water supply for White Bluffs.
30R1		T, 417	Dr	253.5	16	....	....	....	....	....	413.0	28.54	2-2-53	O	Well deepened in 1948 without increasing yield.
31G1	WBD1W	T, 402.1	Dr	53	16	50	19-36	4	36	Sand, gravel	404.54	14.14	9-30-44	PS	Dd 6.8 ft after 7 hr pumping at 187 gpm; temp of water 58°F.
								T. 14 N., R. 27 E. — Continued							
32R1	F-7-1	T, 395	Dr	150	8	146	20-25 78-100 130-140	130	10	Silty gravel	....	18	8-15-56	O	Gravel to 30 ft, mostly clayey siltstone below.
33D4	H-16	T, 403.5	Dr	62	2	....	....	42	17	...do	408.01	30	6-1-43	Th	
33F2	F-5-6	T, 405	Dr	191	8	191	154-191	35	34	Gravel, sand	....	35	8-13-56	O	
33G2	107F2	T, 411.37	Dr	100	8	100	25-35 80-100	25 73	10 27	...do Sand, gravel	412.49	34.26	5-15-53	M	
33M1	108F1	T, 410.27	Dr	115	8	115	65-105	....	....	....	....	35	2-18-53	M	
								T. 15 N., R. 27 E.							
32E1		T, 730	Dr	1,140	20-8	1,123	....	....	....	Basalt	....	261.5	10- -53	PS	Ca; log published by Walters and Grolier (1960, p. 403); temp of water 82°F.
34L2	500-1	T, 697.7	Dr	614	20 16 12	107 255 244 354	....	294 604	56 10	...do ...do	....	271 240	1-20-52 6-9-58	D	Ca; dd 170 after 3½ hrs pumping at 100 gpm; temp of water 74-76°F. Log published by Walters and Grolier (1960, p. 403-404).

TABLE 2.—*Logs of type wells on the Hanford Reservation*

[Stratigraphic designations by R. C. Newcomb]

Materials	Thickness (feet)	Depth (feet)
9/28-5C1 [City of West Richland. Driller's log]		
Alluvium:		
Sand and top soil	8	8
Glaciofluviatile and fluviatile deposits (mostly):		
Sand, gravel, and boulders, water-bearing	50	58
Ringold Formation:		
Clay, blue	17	75
Sand gravel, and boulders, water-bearing	7	82
Sand and Clay, water-bearing	8	90
Sand, blue	4	94
Gravel and boulders, water-bearing	9	103
Clay, brown	18	121
Sand and gravel, water-bearing	4	125
Clay	46	171
Sand, loose	2	173
Basalt of the Columbia River Group:		
Basalt, porous, black, water-bearing	8	181
Basalt, hard, dark	3	184
Basalt, porous, water-bearing	4	188
Basalt, hard, dark	3	191
Lava rock, "burned"	6	197
Basalt, hard, gray	3	200
Basalt, porous, water-bearing	5	205
Basalt, hard, gray	76	281
Clay, gray-green	59	340
Basalt, hard, gray	150	490
Clay, gray-green	35	525
Basalt, medium-hard, gray	5	530
Clay, gray-green	10	540
Basalt, gray	32	572

Materials	Thickness (feet)	Depth (feet)
9/28-15J1 [City of Richland. Drilled and recorded by A. A. Durand & Son, 1943]		
Alluvium:		
Sand, fine	18	18
Glaciofluviatile and fluviatile deposits(?):		
Silt and clay	10	28
Sand and gravel	4	32
Gravel, coarse	2	34
Sand	7	41
Sand, coarse, and gravel	4	45
Sand, fine, and coarse gravel	16	61
Gravel and boulders	9	70
Ringold(?) Formation:		
Clay	2	72

Materials	Thickness (feet)	Depth (feet)
10/28-10G1 [Drilling, sampling, and stratigraphic designations of samples by U.S. Geol. Survey. Leveling and altitude data by Gen. Elec. Co.]		
Alluvium:		
Sand, silty; about 40 percent quartz and 60 percent basalt; angular to subangular; poorly sorted—mostly coarse to fine sand with some ¼- to ½-in. diameter gravel and a few boulders; some artificial fill in places	3	3
Glaciofluviatile and fluviatile deposits:		
Gravel, sandy and bouldery; contains a small amount of silt; basalt predominates in the gravel and coarse sand and makes up 80 percent of the finer sand; sand is angular to subangular, and gravel is subrounded to subrounded	12	15
Gravel, sandy and slightly silty; pebbles, averaging 1 to 3 in. in diameter, are subrounded to subangular, about 40 percent basalt and 60 percent exotic types; material is about 40 percent gravel, 55 percent medium to very fine sand, and 15 percent silt	6	21
Gravel, sandy; gravel forms 60 percent of sample, sand 25 percent, and silt 15 percent; ratio of basalt to exotic types in gravel is about 65 percent–35 percent; sand is about 55 percent basalt and 45 percent exotics and quartz; gravel is subangular to subrounded and has 3-in. maximum diameter and 1-in. average diameter	4	25
Gravel, coarse to fine, and coarse sand; maximum diameter of gravel 4 in., average diameter 2 in.; pebbles form about 80 percent of bed; basalt component of pebble gravel about 40 percent at 30-ft depth, decreasing gradually to 20 percent at 50-ft depth; basalt in coarse to medium sand decreases gradually from 30 percent at 30-ft depth to 5 percent at 50-ft depth; almost no silt present	25	50
Ringold Formation:		
Gravel; mostly exotic rock types; fine to coarse from ¼ to 6 in. in diameter, although mainly pebbles with occasional cobbles, in a medium clean micaceous, quartzose sand matrix; upper 10 ft of this gravel is highly calcareous and gives strong reaction to acid; sand content increases to 55 percent of sample in 57- to 60-ft zone, remainder being gravel	13	63
Gravel, exotic-type, subrounded to subangular; has thin silt and clay zones in bottom foot of bed	4	67
Clay, light-tan; contains a few ½-in. angular pebbles	5	72
Clay, light-tan, finely micaceous, slightly silty	9	81
Clay, light-tan, slightly silty; has a few 1/16- to ¼-in. diameter rounded to subrounded indurated claystone nodules	3	84
Gravel, granule and pebble, in a silty clay matrix; approximate percentages: granule gravel, 75; pebble gravel, 15; silty clay, 10; rock particles are about half exotic and half basalt, all rounded to subrounded	3	87

TABLE 2.—*Logs of type wells on the Hanford Reservation*—Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
Siltstone, light-tan, clayey, very finely micaceous	4	91
Sand, quartzose and micaceous, medium to fine, well-sorted, over 90 percent siliceous, and gravel mainly of dark exotic types mostly about ½ to 1½ in. in diameter; gravel about 30 percent of sample in 91- to 96-ft zone increasing to 50 percent of sample in the 96- to 99-ft zone	8	99
Sand, silty and clayey, and gravel; gravel, maximum diameter 1 in., forms approximately 20 percent of sample; rude ⅛-in.-thick weathering rind on basalt pebbles	3	102
Sand, quartzose and micaceous, and gravel, as in 91- to 96-ft zone; good weathering rind on basalt	4	106
Gravel, sandy, as in 91- to 99-ft bed except that gravel component has increased to 80 percent of sample; gravel in lower 6 ft increases in size to maximum diameter of 4 in. and average diameter of 2½ in.; larger gravel is about 20 percent basalt having weathering rinds	10	116
Sand, quartzitic and micaceous, medium to fine, well-sorted; medium to heavy response to acid test	4	120
Siltstone, gravelly and slightly clayey; gravel of ¼-in. diameter forms 40 percent of bed in 120- to 123-ft zone, is absent in 123- to 126-ft zone and increases to 50 percent of sample in 126- to 130-ft zone, where the maximum diameter is 3 in.; gravel is mainly exotic types, and sand is siliceous	10	130
Sand, silty; contains about 3 percent subrounded granule gravel	6	136
Gravel, sandy and bouldery; gravel forms about 80 percent of bed, is 50 percent granules, and is composed mainly of dark exotic rocks; cemented sand coatings on pebbles and excellent ⅛-in.-thick rinds on basalts	5	141
Sand, fine to medium, micaceous; about 90 percent clear angular to subangular quartz, about 2 percent basalt, and estimated 1 percent calcareous grains; very reactive to acid test; a sand interbed in gravel of 136- to 165-ft unit	3	144
Gravel, pebble and boulder, in a clayey sand; subrounded gravel, mainly of exotic types, forms 50 percent of bed in 144- to 156-ft zone and increases to 80 percent in 156- to 165-ft zone	21	165
Gravel, boulder, cobble, and pebble; pebble gravel is mainly ½ to 1 in. in diameter	6	171
Silt, clayey, gray-tan; contains about 5 percent angular granules—both exotics and basalt; fewer rock particles in lower half of bed than in upper half	6	177
Clay, silty, gray-tan; has thin laminae of fine gray-white volcanic ash near bottom of bed	13	190
Clay, blue-gray, has some greenish laminae	2	192
Sand, basaltic; sand is 80 percent coarse to fine black basalt, with 10 percent quartz and 10 percent calcareous cement; some basalt and cemented fragments are ¼ in. in diameter; pyrite occurs as rare vesicle filling in basalt pebbles; water-bearing	2	194
Basalt of the Columbia River Group:		
Basalt, black, dense to vesicular; contains about 30 percent khaki banded and botryoidal opaline vesicle fillings, together with some clear feldspar and rounded and frosted quartz vesicle fillings; secondary minerals abundant in upper part of basalt; basalt is weathered and clayey in upper part but fresh and hard below 200-ft depth	18	212

10/28–17B1

[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium (wind-worked):		
Sand, mixed, very fine to coarse	12	12
Glaciofluviatile and fluviatile deposits:		
Sand, mixed, fine to coarse, quartz, exotic, and basaltic	4	16
Sand; same as just above, but with pods of clay	5	21
Sand and gravel, gray, fine to coarse	64	85
Sand and gravel	8	93
Sand and gravel; mixed grain sizes of a quartzose tan-white sand with 35 percent granule, pebble, and cobble gravel. Gravel consists equally of basalt and upriver exotic rock types; 93- to 128-ft zone is probably largely reworked Ringold material	35	128
Ringold Formation:		
Gravel and sand; granule and pebble basaltic and exotic gravel with 30 to 50 percent mixed quartzose sand; some basalt pebbles have iron-cemented sand coatings and weathering rinds	4	132
Sand and some gravel; medium and coarse brown-gray sand with 10 percent granule and pebble basaltic and exotic gravel	16	148
Sand and gravel	37	185
Silt, clayey; greenish-brown and bluish-gray laminated silt with some basalt pebbles and minor quantities of fine quartz sand; lowest 1 ft contains well-weathered basalt fragments	36	221

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Basalt of the Columbia River Group:		
Basalt, vesicular, porphyritic, partly decomposed	7	228
10/28-35H1		
[City of Richland. Drilling and sampling by Gen. Elec. Co. stratigraphic designation of samples by U.S. Geol. Survey]		
Rubble:		
Gravel and sand; well-rounded pebble and cobble gravel containing medium and coarse basalt and quartz sand; may in part be artificial fill	3	3
Glaciofluviatile and fluviatile deposits:		
Gravel and sand; mixed (mainly coarse) sand of quartz and basalt intermixed in pebble and cobble gravel that is 75 percent basalt	30	33
Ringold Formation:		
Gravel and sand; pebble and cobble gravel that is 75 percent upriver exotic rock types and 25 percent basalt; sand present to 30 percent in places and consists of medium subangular and subrounded quartz grains and siliceous exotic materials; some basaltic particles in top part of zone may have carried down from above; bed of clean sand 40–41 feet; sandy and clayey 41–45 ft	12	45
Silt, gray-green (blue when drilled)	34	79
Gravel, granule and pebble; exotic rock types (65 percent) and basalt (35 percent) with a little fine and medium quartzose sand	5	84
Sand, fine and medium; light-brown quartzose subangular sand with a few included coarse-sand (rounded), granular, and small-pebble streaks; almost all material is quartz, but larger grains include some basalt; thin silt bed at 85-ft depth	17	101
11/26-3G1		
[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Glaciofluviatile and fluviatile deposits:		
Silt, tan, and 40 percent fine quartzose sand	9	9
Sand, silt, and some clay; probably consists of Touchet Beds	68	77
Sand and silt; tan-gray fine to coarse quartzose sand with some silt that diminishes downward; probably also Touchet Bed material	4	81
Gravel and sand; granule, pebble, and cobble gravel with 30–50 percent medium dark basaltic sand; fine sand is higher in quartz; gravel is 70 percent basalt and 30 percent exotic types	15	96
Gravel, sand, and some tan silt; similar to zone just above, but the particles (even the sand) are chiefly exotic rock types and quartz, with basalt negligible	28	124
Glaciofluviatile and fluviatile deposits—Con.		
Sand, tannish-gray; poorly sorted quartzose and exotic sand with 20 percent tan silt	4	128
Sand, gravel, and some silt; sorted medium to fine quartzose and exotic-type sand with 15–25 percent pebble gravel of exotic rock types; zone 96–136 ft may be largely reworked Ringold Formation	8	136
Ringold Formation:		
Sand, brownish-white, subrounded, fine and medium, quartzose; has 5 percent mica	9	145
Gravel and sand; exotic-type gravel up to cobble size, with exotic-type sorted sand forming 40 percent of the material	12	157
Sand and some tan silt; very coarse to medium exotic-type brownish-gray sand with some pebbles	12	169
Sand, gravel, and silty clay; quartzose and exotic-type medium and coarse sand having 20–30 percent exotic-type pebble gravel and some silty clay	4	173
Clay-silt and a little sand and gravel; bluish-gray clay-silt having sand and gravel interbed	8	181
Gravel and some sand and silt; granule and pebble basalt and exotic gravel having 10 percent quartzose fine sand and tan silt	3	184
Silt, clayey and chalky, tannish-white when dry and bluish-green-white when wet; includes 10 percent scattered exotic-type and basalt granules and pebbles and quartzose fine sand	16	200
11/26-5B1		
[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Alluvium:		
Sand, silty, medium; consists equally of basalt and exotic types	13	13
Silt, sandy and clayey; khaki silt with fine and coarse quartz sand carrying basalt, mica, and exotic rock types	8	21
Glaciofluviatile and fluviatile deposits:		
Sand, gravel, and some silt; about 50 percent medium subangular basaltic sand with an equal amount of largely basaltic subangular caliche-coated pebble gravel that increases downward	24	45
Gravel, sandy; similar to lower part just above	8	53
Sand, silty; medium to coarse quartzose sand with fine and very coarse admixtures and some tan silt	12	65
Ringold Formation:		
Silt, clayey; stratified tan clayey silt having 10 percent sand of largely quartzose and exotic types	39	104
Sand, silty; medium to fine light-buff		

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
quartzose and exotic sand with 10 percent mica and no basaltic grains	5	109
Gravel, sandy; granule and pebble gravel whose particles consist of 40 percent basalt and 60 percent exotic rock types	4	113
Silt, sandy; tan silt with 40 percent fine quartzose iron-stained sand	8	121
Gravel, sandy; granule and pebble exotic-type gravel with about 40 percent medium quartzose sand; most basalt pebbles have 1/16- to 1/8-in. weathering rinds	12	133
Sand, well-sorted, medium to fine, rounded; 75 percent quartz, 15 percent exotic rock types, and 10 percent mica	4	137
Sand, gravelly; poorly sorted rounded coarse to fine quartzose buff-gray sand and pebble gravel whose particles are 75 percent exotic rock types and 25 percent basalt; many basalt pebbles have weathering rinds	24	161
Basalt of the Columbia River Group:		
Basalt, black, scoriaceous; has zeolite-filled vesicles	6½	167½

11/26–29B1

[Driller's log from files of owner. Drilled (deepened) in 1939. Stratigraphic designations by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
No record	40	40
Basalt of the Columbia River Group:		
Rock, broken, cavey	45	85
Hardpan (?)	10	95
Rock, broken	38	133
"Strange formation, very hot"	6	139
Basalt, broken uppermost 73 ft	82	221
Clay, soft, shaly	28	249
Rock, broken, cavey	3	252
Basalt, gray, black, and blue, water-bearing at 435 ft	445	697
Sandstone and shale	5	702
Shale	73	775
Basalt, porous; gas at 781 ft	25	800
Basalt, black and gray	80	880
Basalt, broken, porous	16	896
Basalt, gray, black, and blue	1,547	2,443
Sandstone	39	2,482
Basalt, gray and black	473	2,955
Shale	10	2,965
Basalt, black and gray	695	3,660

11/27–2Q1

[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium (windworked):		
Sand, silty, medium to coarse, rounded; consists about equally of basalt, exotic rock types, and quartz	3	3
Sand; mixture of all grain sizes; rock types equally distributed as above; some granular basaltic gravel and buff silt included	10	13
Glaciofluviatile and fluviatile deposits:		
Sand and gravel; medium to coarse quartz and basalt sand with 20 percent granule to cobble basaltic gravel	13	26
Sand, medium to coarse, clean, gray, basaltic; carries 5 percent rounded granules and pebbles of basalt	10	36
Sand, medium to coarse, partially cemented; consists of quartz 60 percent, basalt 35 percent, and exotic rock types 5 percent	28	64
Sand and gravel; medium to coarse quartzose and basaltic sand carrying 20 to 40 percent basaltic pebble and cobble gravel	39	103
Gravel and sand; pebble and cobble basalt and exotic-type gravel having a matrix of 30 percent poorly sorted quartz and basalt sand; predominantly sand in lowest 6 ft	24	127
Ringold Formation:		
Sand, fine to medium, iron-stained, high in quartz with some mica; includes some tan silt that was apparently an interbed	5	132
Sand and gravel; fine and medium light-buff sand high in quartz, with 5 percent mica and 10–40 percent pebble and cobble gravel largely of exotic rock types	12	144
Sand and gravel; pebble and cobble gravel predominantly of upriver exotic rock types with 50 to 90 percent sand that is largely fine to medium well-sorted quartz	4	148
Sand and gravel; fine to medium quartzose and micaceous sand with an equal amount of pebble and cobble gravel consisting of 70 percent exotic rock types and 30 percent basalt	11	159
Sand and gravel; mostly medium sand, but some fine and coarse, predominantly of quartz, some mica, and up to 10 percent pebble and small-cobble gravel consisting of 70 percent exotics and 30 percent basalt	19	178
Sand, gravel, and some tan silt; poorly sorted, or mixed beds of sorted fine to coarse, quartzose sand carrying up to 25 percent basalt and exotic pebble gravel and some silt	12	190
Silt, clayey, khaki; carries 10 percent fine sand	1	191
Sand and clayey silt; fine quartzose, micaceous sand with 25 percent khaki (apparently interbedded) clayey silt; zone is well laminated and partly indurated	9	200

TABLE 2.—*Logs of type wells on the Hanford Reservation*—Continued

Materials	Thickness (feet)	Depth (feet)
11/27-20M1		
[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Alluvium (windworked):		
Silt and sand; fine subrounded sand of about 80 percent quartz and exotic rock types; silt makes up about half of material	4	4
Glaciofluviatile and fluviatile deposits:		
Sand; 90 percent coarse sand having small amounts of granules and pebbles; finer grains largely quartz, and larger ones basalt	89	93
Sand, silty; similar to that just above, but largely medium to coarse; consists about equally of quartz and basalt; granule and pebble basaltic gravel interlayered	31	124
Silt and sand, buff; sandy silt carrying a few basalt granules and pebbles in the upper part	4	128
Sand and gravel, silty; fresh granular exotic and basaltic gravel in an unsorted fine to coarse gray-white quartzose sand having 25 percent tan-gray silt	8	136
Sand, gravelly, medium, and some silt; gravel almost entirely, and coarse sand largely, basalt	8	144
Basalt of the Columbia River Group:		
Basalt, gray, hard	25	169
Sand, tuffaceous; composed principally of volcanic glass shards, quartz, opal, feldspar, muscovite and biotite mica, basalt particles, and secondary gypsum	23	192
Tuff; weathered into silty and clayey material but containing identifiable particles of basalt, quartz, glass, mica, and feldspar	69	261
Basalt, hard, black, very finely crystalline and glassy	60	321
11/27-26D1		
[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Alluvium (windworked):		
Sand, well-sorted, light-brown, quartzose, medium to coarse; carries some fine and very coarse sand intermixed	19	19
Glaciofluviatile and fluviatile deposits:		
Sand and clayey silt	5	24
Sand and gravel; poorly sorted gray medium and coarse basalt and quartz sand carrying 20 percent granule and pebble gravel of basaltic type	3	27
Sand, mixed fine to coarse, gray, quartz and basalt; 10 percent tan silt interlayered	5	32
Sand and gravel; poorly sorted angular to subrounded gray quartz, basalt, and exotic-type sand carrying 15 to 20 percent granule and pebble basaltic gravel	8	40
Sand, poorly sorted, quartzose	27	67
Glaciofluviatile and fluviatile deposits—Con.		
Sand and gravel; poorly sorted basaltic sand having 25 percent basaltic granule to cobble gravel	9	76
Gravel and sand; basaltic pebble and cobble gravel having 25 percent basalt, quartz, and exotic sand	7	83
Sand; similar to 67- to 76-ft zone above	9	92
Gravel and sand; pebble and cobble basaltic gravel having 30 percent poorly sorted quartz, basalt, and exotic sand	8	100
Sand and gravel; poorly sorted gray quartz and exotic sand having 25 percent granule and pebble basalt gravel	7	107
Sand, medium to coarse, clean, white, gray	5	112
Ringold Formation:		
Sand and gravel; medium to coarse clean whitish-tan quartzose sand carrying 30 percent pebble and cobble gravel of predominantly exotic rock types	27	139
Sand, fine to medium, largely quartz but much exotic rock material in coarse sizes; has 10 percent mica	4	143
Sand and gravel; medium white quartz and mixed types of sand having 30 percent exotic and basaltic gravel	5	148
11/28-17D1		
[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Alluvium:		
Sand, buff-white, subrounded, coarse in upper 3 ft (wind-worked) and medium to fine below; sand is equally basalt and siliceous materials, but the few gravel granules are largely basalt	8	8
Glaciofluviatile and fluviatile deposits:		
Sand, gravelly, medium to very coarse, high basalt composition in coarser, and high quartz in finer, grains; about 15 percent granule and pebble gravel that is 75 percent basalt	4	12
Sand, clean, medium and coarse, basaltic and siliceous, gray, subrounded	32	44
Sand; similar to just above, but higher in basalt (50 to 75 percent)	12	56
Sand and gravel; mixed sand of average medium size; larger grains are basaltic, and smaller are siliceous; about 30 percent granule and pebble gravel is predominantly basalt without weathering rinds	39	95
Ringold Formation:		
Gravel and sand; granule and pebble exotic gravel having a matrix of medium siliceous sand; some basalt pebbles have weathering rinds	20	115
Sand, gravelly; medium and fine quartzose, exotic, and micaceous (5 percent) sand having granule, pebble, and cobble		

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
gravel that is predominantly of exotic rock types	5	120
Sand, clean, medium to fine, siliceous; contains granular largely exotic gravel	7	127
Gravel, sandy; granule and pebble exotic-type gravel having an equal amount of medium clean tan-gray siliceous sand; tan silt makes up 10 percent of material	8	135
Sand, gravelly; mixed, averaging medium, quartzose sand carrying 20 percent granule, pebble, and cobble gravel in which basalt forms 60 percent; some basalt pebbles have weathering rinds	8	143
Gravel, sandy; granule, pebble, and cobble gravel of about equal basalt and exotic types; medium sand, carrying fine and coarse, is predominantly siliceous material; some basalt pebbles have weathering rinds	4	147
11/28-29N1 [Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Alluvium (windworked):		
Sand, very fine to medium, buff, basaltic and exotic, and 25 percent silt	4	4
Glaciofluviatile and fluviatile deposits:		
Sand and some gravel; fine to coarse sand, but predominantly coarse, is equally basaltic and exotic rock types in coarser sizes and mainly siliceous in finer; the 15 percent granule and pebble gravel is predominantly basalt	40	44
Ringold Formation:		
Sand, fine to coarse but largely coarse quartz; exotic rock types make up about 80–90 percent of deposit; 10 percent is silt	8	52
Sand and gravel; medium to coarse tan-white quartzose sand having 10 percent granule and pebble gravel that is 70 percent exotics and 30 percent basalt	8	60
Sand, gravelly; fine to coarse, mainly medium, siliceous subrounded sand carrying 35 percent granule and pebble gravel that is 75 percent exotic rock types	9	69
Sand, fine to coarse in various beds, exotic rock types and quartz; 10 percent granule and pebble gravel is 70 percent exotic rock types; some silt is present	39	108
Clay, silty, blue-green and plastic when wet, grayish-green when dry	2	110
12/25-1A14 [Drilling, sampling, and stratigraphic designation by U.S. Geol. Survey]		
Alluvium:		
Silt and fine sand; has a little intermixed medium and coarse sand and 10 percent granules and pebbles up to ½ in. in diameter; pebbles and granules mostly basalt, finer sand sizes largely quartz, and coarser ones equally basalt and quartz	5	5
Glaciofluviatile and fluviatile deposits:		
Silt and gravel, dun; carries some varied sizes of sand together with scattered boulders and cobbles; material is similar to 0- to 5-ft bed, but with more gravel (40 percent); sand of all sizes makes up 30 percent	12	17
Sand, gravelly and silty, dun; sand of mixed sizes, coarse to fine, is mainly subangular quartz in fine sizes and up to 60 percent basalt in medium to coarse sizes; basalt and exotics are about equally represented in the granule, pebble, and occasional cobble gravels; basalt is fresh; light-gray Touchet-type silt is intermixed and forms 10–25 percent of samples	41	58
Sand, largely medium and coarse; contains granule and small-pebble gravel and silt; sand is mostly subangular to subrounded siliceous (milky and clear quartz); coarse sand and basalt granule gravel form 25–50 percent; pebble gravel in 80- to 85-ft sample is 75 percent basalt and 25 percent exotics	52	110
Ringold Formation:		
Silt, clayey and gravelly; 50 percent medium and fine sand is almost entirely quartz — 50 percent clear and 50 percent milky or stained; about 5 percent granule gravel is largely quartz and exotics; sample is tan-buff; some magnetite in the very fine sand	8	118
Sand, silty, fine, cream-buff; contains 5–10 percent intermixed coarse sand and granule gravel (to ⅛ in. in diameter); has some calcareous stemlike tubes and nodular concretions	25	143
Sand, medium to coarse, silty, and granule and pebble gravel; granule gravel and pebbles ½ to 1 in. in diameter form about 30 percent of deposit; as much as 75 percent of gravel is basalt with 1/16-in.-thick decomposition rinds; fine sand is mostly quartz, although basalt comprises much of the coarse sand; silt component forms 15–20 percent	32	175
Gravel and sand; a mixture of about 70 percent granule and pebble gravel with 30 percent medium quartz sand; gravel is 75 percent basalt	8	183
Sand, gravel, and silt; mixed sizes of sand, averaging medium, 20 percent		

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
granule and pebble gravel, and 20 percent silt; sand is normal Ringold type, subangular to subrounded, clear and milky quartz and siliceous exotics; gravel is ⅔ well-rounded basaltic material	8	191
Sand and gravel; medium to coarse siliceous sand having 50 percent granule and pebble gravel; gravel is largely exotic rock types	5	196
Sand, gravel, and silt, gray; much like the 191- to 196-ft bed; a thorough jumble of grain sizes; silt and fine sand is almost entirely quartz; medium to coarse sand includes increasing amounts of exotic rock types and basalt; gravel is about ½ basalt in granule sizes and ⅔ in pebble sizes	10	206
Sand, silt, and gravel, with boulders; fine sand and silt with some medium and coarse sand (10 percent ±) and 30 percent granule and pebble gravel to 1 in. in diameter; fine sand is almost entirely quartz, subangular, largely clear; coarser grades of sand are quartz, exotics, and a little basalt; gravel is 75 percent exotic and 25 percent basalt; silt is 10–15 percent	14	220
Sand, gravel, and silt; materials largely the same as overlying bed; rinds ⅛ in. thick on basalt pebbles; this remarkably uniform sand carrying gravel is apparently the same as the Ringold conglomerate in The White Bluffs	82	302
Sand and gravel, in part silty and clayey; sand is fine to medium, quartzose, and subrounded to subangular; gravel is mainly ½ to 2 in. in diameter, although in 315- to 320-ft zone sizes up to 4 in. in diameter are present; appproximately 3 percent basalt in gravel which forms 25 to 40 percent of bed; cemented coating of sand and mica on pebbles; some basalt pebbles have rinds	33	335
Gravel, sandy and silty; 60 percent gravel and coarse sand, 40 percent silt and fine sand; gravel is mostly less than 1 in. in diameter; sand is quartzose and lightly calcareous	10	345
Sand, silt, and gravel; fine to 1-in.-diameter pebbles; 70 percent sand and silt, 30 percent gravel; basalt less than 1 percent of sand component; pebbles mostly exotic types	26	371
Gravel, exotic, subrounded, up to 2 in. in diameter in a silty sand matrix; gravel forms about 75 percent of sample; very little basalt present	4	375
Gravel and sand, silty; gravel averages about 1 in. in diameter; sand is medium to fine and quartzose; white swelling sand at 375- to 380-ft depth; gravel, sand, silt comprise 50, 40, 10 percent respectively	25	400
Silt, sandy and gravelly; tan silt carrying gravel that is mostly ½- to ¼-in. diameter subrounded pebbles about 20 percent basalt and 80 percent exotic rock types — mainly light-colored quartzites; sand-gravel ratio is approximately 50–50; sand is about 80 percent quartz, 5 percent basalt, and 15 percent exotics; some basalt pebbles have weathering rinds	15	415
Gravel, medium to fine, in a matrix of silty sand; gravel forms about 70 percent of sample, is rounded to subrounded, averages ½ in. in diameter, and is mainly of exotic rock types	5	420
Sand, silty and gravelly, tan; gravel component about 10 percent in upper 10 ft of bed, with gravel-free medium to fine sand and silt in lower 8 ft; drilled like a "rotten sandstone" at 430–438 ft	18	438
Gravel in a matrix of silty sand; pebbles, predominately exotic rock types but a few basalt, are mostly 1 to 1½ in. in diameter and form approximately 50 percent of the bed; sand component is about 10 percent coarse sand, and remainder is silt and fine sand	22	460
Sand, coarse to fine, and silt; has about 15 percent medium to fine gravel	5	465
Sand, fine to coarse, and silt; carries about 30 percent gravel; sand is quartzose, but granule-size material contains about 30 percent angular basalt; some cobbles present	27	492
Sand, coarse to fine, silty; carries fine to coarse gravel and occasional cobbles and boulders; coarse sand and fine gravel is about 50 percent basalt; carbonized wood fragments of a low lignite rank lie in 500- to 505-ft zone; gravel comprises about 20 percent, sand 60 percent, and silt 20 percent	13	505
Sand, coarse to fine, silty and clayey, and gravel (10 percent); sample is about 70 percent basalt in coarse sand fractions and 30 percent basalt in fine sand and silt fractions; drilled material is sulfurous and rank smelling; basalt pebbles and cobbles have weathering rinds and have cemented sand on their surfaces	4	509
Basalt of the Columbia River Group:		
Basalt, black, vesicular, porous; contains clear to milky and greenish-brown opaline vesicle fillings	25	534

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
12/25-3D2		
[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Alluvium:		
Silt and fine sand; has some coarse and medium sand	13	13
Glaciofluviatile and fluviatile deposits (Touchet? Beds):		
Sand and silt, quartzose, yellow-buff, rounded; contains some medium and coarse sand and small amounts of granule gravel (basaltic) and clay	16	29
Silt, clayey, sandy, khaki; has 30 percent fine and medium quartzose sand and 15 percent medium to coarse quartz and (some) basalt sand	15	44
Sand and gravel; rounded medium to coarse siliceous (finer) and basaltic (coarser) sand, having equal amount of granule and pebble basaltic unweathered gravel; about 10 percent silt and clay gives sample an earthy appearance; much caliche coating and tubular-shaped material	28	72
Sand, gravel, and silt; like that just above but carrying 10 percent gravel and 20 percent silt	25	97
Ringold Formation:		
Sand, silty; mixed layers of fine to coarse basaltic (coarser) and siliceous (finer) rounded sand having 10 to 15 percent tan-brown silt and clay; a little gravel in lowest 4 ft	15	112
Sand, fine and medium, quartzose; has some coarse sand and some brownish silt	28	140
Sand and gravel, silty; subrounded to rounded siliceous fine to coarse sand having 20 percent gravel of granule to cobble sizes that are of exotic (70 percent) and basaltic (30 percent) types; exotic pebbles are rounded; basaltic pebbles are subangular, and some have weathering rinds; silt and clay present to 10–15 percent of deposit	105	245
Sand and minor gravel and silt; like the 140- to 245-ft zone just above, but with much less (5–10 percent) gravel	36	281
Sand and gravel; medium and coarse quartz sand, having a nearly equal amount of granule to cobble gravel largely of upriver exotic rock types; some silt and clay (10 percent) intermixed	12	293
Gravel; granule to boulder gravel (30 percent basalt and 70 percent exotics), carrying 15 to 20 percent coarse sand and silt; some basalt cobbles have weathering rinds	3	296
Sand, medium and coarse, buff quartzose; has minor amounts of gravel and silt	4	300
Ringold Formation—Continued		
Gravel, granule to cobble, well-rounded, largely exotic rock-type, and a minor amount of coarse well-rounded quartz sand	7	307
12/25-10N1		
[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U. S. Geol. Survey]		
Glaciofluviatile and fluviatile deposits (Touchet Beds):		
Sand, silty, medium to fine, micaceous, moderately well sorted, coarser toward bottom	44	44
Sand, silty, and gravel; silt and sand similar to overlying bed; pebbles subangular to subrounded, mostly basalt, coated with caliche	19	63
Ringold Formation:		
Sand, silty and clayey, fine	2	65
Clay, silty and sandy, plastic	8	73
Gravel, cobbly, and sand in tan silt matrix; pebbles and cobbles largely basalt, coated with caliche	12	85
Gravel, bouldery, sand, and tan-brown clayey silt; boulders are basalt, some of which is red and vesicular	34	119
Silt, clayey, and medium to fine sand, mottled with limonite	6	125
Silt, clayey, sand, and fine gravel; chiefly basalt; differs from overlying bed only in gravel content	10	135
Sand, silty, very fine to medium	7	142
Gravel, sandy and silty; pebbles and cobbles are fresh basalt, subangular to subrounded; a considerable number are quartzite, granite, gneiss, or other igneous rocks and are subrounded; some rocks show cemented sand on surfaces	41	183
Gravel, cobble and boulder, sand, and silt; differs from overlying bed only in cobble and boulder content	19	202
Gravel, sandy and silty; similar to 142- to 183-ft bed	33	235
Sand, silt, and gravel in respective percentages of 50, 25, and 25; caliche zone between 225 and 260 ft (?); about half the particles are basalt	91	326
Sand, medium to coarse, gravel, and tan-gray clayey silt; sand is arkosic, micaceous, subangular	14	340
Silt, sand, and gravel in approximate percentage proportion of 50, 25, and 25 respectively	18	358
Gravel, clay, silt, and sand in approximate percentage proportion of 40, 40, 10, and 10 respectively; fine fractions constitute a dark-brown matrix	17	375
Gravel, sand, and silt in approximate percentage proportion of 50, 30, and 20 respectively; sand is mostly white quartz	7	382

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
Sand, fine, white, quartz	2	384
Gravel and sand in weak matrix of silt and clay; pebbles are chiefly quartzite, granite, gneiss, and schist, with a few of basalt; includes numerous lenses and streaks of almost clean sand	25	409
Sand, silt, clay, and gravel; sand forms 70 percent, silt and clay 20 percent, and gravel 10 percent	13	422
Clay, gritty, heavy, plastic, light-greenish-gray; grit is about 20 percent of sample and is composed of metamorphic and igneous rocks	11	433
Clay, blue-gray, dense, sticky, impermeable	43	476
Sand, black, fine to coarse; 85 percent basalt, 15 percent quartz; a "quicksand" that "heaved" 50 feet into the well, carrying with it a few angular pieces of olive-black basalt up to 4 in. in length	7	483
Clay, gritty; contains very fine sand; blue-gray, plastic, "greasy"; grit similar to that in 422- to 433-ft bed	22	505
Volcanic ash and clay, light-brown, sandy; has shards of volcanic glass and small pebbles; clay is probably altered volcanic ash	21	526
Sand and silt, gray	11	537
Gravel, fine to coarse, in a matrix of sand and tan silt; many pebbles have a yellowish-tan coating of cemented sandy silt; sand is fine to medium and mostly quartz, feldspars, and mica	14	551
Sand, silty and clayey; sand is similar to overlying bed; silt and clay are greenish gray to brownish gray; silt is about 40 percent, clay 10 percent, and sand 50 percent of sample	14	565
Gravel, fine to medium, in a sandy, silty matrix	1	566
Sand, silty and clayey; similar to 551- to 656-ft bed	18	584
Gravel, sand, and tan-brown silt; proportions are approximately 50, 20, and 30 percent respectively	5	589
Sand and silt, tan, fine to medium, weakly cemented	25	614
Sand and silt, olive-brown, and a small amount of gravel	20	634
Sand and tan-brown silt in about equal proportions	2	636
Sand, gravel, and light-gray silt in approximate percentage proportion of 50, 20, and 30 respectively; gravel is fine to medium well-rounded particles; sand is fine to medium mostly light-colored minerals	13	649
Basalt of the Columbia River Group:		
Basalt, scoriaceous to dense, light-gray to black, jointed; zeolites occur in some of the vesicles	39	688

12/25-23K1

[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium (dune sand):		
Sand, silty, brown-tan, fine to medium	1	1
Glaciofluviatile and fluviatile deposits:		
Sand, silty, brown-tan; fine to coarse, averages medium; light-colored minerals predominate	32	33
Ringold Formation:		
Gravel, medium to coarse, sand, and silt; pebbles and cobbles principally quartzite and basalt; some samples contain only a trace of silt (as from 85 to 90 ft where aquagel was required to make a sludge); in others the silt fraction increases to nearly 50 percent of the whole; 33- to 38-ft zone contains caliche-coated pebbles and caliche-cemented sand	72	105
Gravel and sand in matrix of clayey silt; differs from overlying bed in its clay fraction	4	109
Basalt of the Columbia River Group:		
Basalt, talus(?)	36	145
Volcanic ash or tuff; carries angular basalt fragments	3	148
Basalt, black	6	154
Volcanic ash or tuff; carries angular basalt fragments	4	158
Basalt; has a few thin interbeds of ash or tuff; ranges from dense, black, and fresh to scoriaceous, gray, and devitrified; fresh basalt is jointed into small blocks	52	210
Tuff, altered in part to bentonitic(?) clay, light-gray, tan-brown, and greenish-brown; in part is sandy and contains considerable amount of glass shards, also some basalt fragments	108	318
Basalt, black and red, scoriaceous in part; lowest 4 ft is entirely scoriaceous and includes considerable ash	18	336

12/25-26M1

[Benson Ranch well. Driller's log by George E. Scott, 1929. Stratigraphic headings by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Undifferentiated:		
Clay	6	6
Sand, dry, loose	24	30
Sand, dirty	17	47
Sand, fine	11	58
Gravel, coarse	10	68
Gravel, cemented	6	74
Gravel, loose, coarse	6	80
Gravel, fine, pea-size	5	85
Gravel, dirty	41	126

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Undifferentiated—Continued		
Gravel, dirty, water-bearing at 127 ft; water level 100 ft	23	149
Ringold(?) Formation:		
Sand	151	300
Gravel	4	304
Clay, blue	41	345
Basalt of the Columbia River Group:		
Basalt, black and gray	113	458
Clay, white, sandy	12	470
Sand, white, sticky	11	481
Clay, blue, sandy	66	547
Basalt, black and gray	308	855
Shale, blue	31	886
Sandstone	7	893
Shale, blue, sandy	31	924
Basalt, black, gray, and red	277	1,201
Clay, yellow	2	1,203
Shale, blue, green, and brown; trace of sand in uppermost 46 ft	107	1,310
Basalt, gray and black; water level 210 ft below surface to end of drilling	128	1,438
Sandstone, fine-grained	12	1,450
Basalt, gray and black	90	1,540
Sandstone, fine-grained	13	1,553
Basalt, gray and black	447	2,000

12/26-2M1

[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Sand, silty, tan	7	7
Glaciofluviatile and fluviatile deposits:		
Gravel	3	10
Sand and gravel; sand grains largely quartz and feldspar, but some mica; probably reworked Ringold materials	9	19
Sand, very fine to coarse, and tan silt; silt content is 10 to 25 percent and increases with depth; coarser sand grains are largely basalt and quartz, finer grains are quartz and feldspar with some mica	36	55
Ringold Formation:		
Sand, silt, and clay; similar to overlying bed but contains clay	40	95
Silt, sandy, tan; similar to 19- to 55-ft bed	15	110
Sand, silt, and clay; similar to 55- to 95-ft bed	15	125
Silt, sandy, or silty sand, tan; sand grains predominantly very fine to medium light-colored materials	15	140
Sand, silt, and clay, tan; relatively low permeability	70	210
Sand, medium to coarse; about half basalt and half light-colored minerals	7	217
Gravel, bouldery	5	222
Sand, as in 210- to 217-ft bed	8	230
Sand, silt, and clay; similar to 140- to 210-ft bed	25	255
Gravel, sand, silt, and clay, tan	10	265
Ringold Formation—Continued		
Gravel, bouldery, and sand; contains diverse rock types	15	280
Gravel, granular, and sand; (silt in sample possibly is from soil added to make drilling sludge)	7	287
Sand, medium to coarse; about half is basalt and half is light-colored minerals	7	294
Clay, slightly silty, tan to dark-yellow, plastic, impermeable	6	300
Sand, very fine to medium; light-colored minerals predominate	10	310
Sand, gravel, and boulders; basalt is commonest in coarser particles, but quartz, feldspars, and mica predominate in finer particles	4	314
Sand, very fine to medium, gray	3	317
Sand, gravel, and boulders; similar to 310- to 314-ft bed	20	337
Sand, fine to coarse; coarser grains chiefly basalt, finer grains mainly quartz, feldspars, and mica	11	348

12/26-7Q1

[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium (dune sand):		
Sand, silty; basalt and quartz grains abundant; mica and feldspars common; subangular to angular	5	5
Glaciofluviatile and fluviatile deposits:		
Sand, fine to medium, silty; predominantly subrounded to angular basalt, quartz, and feldspar	15	20
Sand, silty, and fine to medium gravel; pebbles and sand grains, subrounded to rounded and apparently derived from Ringold Formation; includes some basalt particles which generally are angular to subangular	13	33
Sand, fine, and clayey silt	22	55
Ringold Formation:		
Silt, clay, and sand; sand grains are predominantly quartz, feldspar, and mica; basalt sand grains are medium to coarse, subangular, and less than 35 percent of the total; tan silt and clay comprise 35 to 60 percent of sample	120	175
Silt, sandy and clayey, tan, plastic; very fine to medium sand is less than 50 percent of sample	43	218
Sand and gravel; fine to coarse sand that is clean and permeable	13	231
Silt, clay, sand, and gravel in respective percentage proportions of about 40, 20, 30, and 10	19	250
Silt, sand, and gravel; differs from overlying bed by lack of clay	40	290
Silt, clay, sand, and gravel; similar to 231- to 250-ft bed	15	305
Silt, sand, and gravel; similar to 250- to 290-ft bed	10	315

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
Gravel, fine to coarse, and fine to medium sand, clean; fairly high permeability; mostly light-colored minerals	5	320
Gravel and sand; similar to overlying bed, but with clayey silt matrix; permeability relatively low	5	325
12/26-14D1 [Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]		
Alluvium (dune sand):		
Sand, silty, gray, very fine to very coarse, sharp to subangular; predominantly basalt	12	12
Glaciofluviatile and fluviatile deposits:		
Sand, silty, tan; chiefly angular to subrounded basalt grains; silt is about 30 to 50 percent of sample	13	25
Sand, silty, and fine to medium gravel; sand and silt as above; pebbles of varied rock types	5	30
Sand, silty, gray; similar to overlying bed (reworked Ringold(?) Formation)	10	40
Ringold Formation:		
Sand, silty, tan-gray; sand and silt fractions about equal	15	55
Silt, sandy, tan, semiconsolidated; sand is very fine to coarse, averages medium	5	60
Sand, silty, tan; silt ranges from about 30 to 50 percent of sample; in large part, probably lenses and an alternation of layers of almost clean silt with clean sand	120	180
Sand, silty; composition similar to overlying materials, but grains more firmly consolidated; (first drive-core sample, from 189 to 191 ft, dusty dry below the penetration of drilling water)	37	217
Silt, gravelly and gritty, gray-tan; pebbles and granules chiefly quartzite, granite, granodiorite, and basalt	5	222
Sand, silty and gritty, calcareous; core sample dusty dry; differs from overlying bed only in proportion of constituents	12	234
Gravel, fine to medium, very fine to very coarse sand and tan silt; silt is calcareous and makes 35 to 50 percent of sample	52	286
Clay, silty, plastic, tan-brown, damp	3.5	289.5
Silt, sandy, light-gray; contains granules and fine gravel	8.5	298
Gravel, fine to coarse, sandy and silty	2	300
Gravel, bouldery, in matrix of tan silty sand which is 45 percent of sample; pebbles and cobbles stream-worn, subrounded to rounded, chiefly light-colored	39	339
Gravel, sand, and tan silt; sand is very fine to medium — a "quicksand"; proportions are approximately 60, 30, and 10 percent respectively	2	341
Gravel and sand in a matrix of gray-tan silty clay; relatively impermeable matrix	10	351
Gravel, coarse, clean, well-worn, highly permeable	4	355
Sand, fine to medium, gray, permeable	2	357
Gravel and sand in a silty clay matrix, relatively impermeable	13	370
Gravel, clayey, fine to medium; pebbles are mostly quartzite; clay is silty and gritty; grit is very fine to coarse, sharply angular to subangular; low permeability	10	380
Sand, very fine to medium, clean, permeable	2	382
Sand and gravel, lenticular-bedded, iron-stained; clay and silt form less than 10 percent of sample; sand is gray, micaceous, largely quartz; medium permeability	4	386
12/26-19K1 [Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]		
Alluvium (dune sand):		
Sand, gray, clean, medium to fine, subangular to subrounded; dominantly quartz, feldspars, and basalt	5	5
Glaciofluviatile and fluviatile deposits (Touchet? Beds):		
Sand, silty, tan; sand as in member above; silt constitutes 20 to 30 percent of sample	75	80
Sand, silty and clayey; dominantly quartz, feldspars, mica, and basalt; very fine to medium, averages fine; clay sufficient to make sample slightly plastic	25	105
Sand, silty, tan-brown; composition as above, but grain size averages medium	20	125
Ringold Formation:		
Sand, clayey, brown, very fine and fine	5	130
Clay, sandy, brown	14	144
Gravel, clayey, pebble and granule; has caliche coatings	10	154
Clay, sandy, brown, and minor quantity of fine granular gravel	11	165
Sand, clayey, brown; similar to material from 125 to 130 ft	5	170
Sand, clayey, brown, and small amount of fine gravel showing caliche coatings	5	175
Sand, clayey, brown; has caliche fragments	12	187
Gravel, medium to coarse, in a matrix of brown clayey silt; pebbles subrounded and chiefly quartzite; probably boulders and cobbles from 200 to 215 ft	28	215
Gravel, sand, and silt; similar to bed above, but lacks the clay	11	226

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
Sand, gray, medium, clean, moderately well sorted; largely light-colored minerals; fairly permeable	5	231
Gravel, sand, and silt; pebbles chiefly quartzite, rhyolite, granite, gneiss, and basalt; subangular to subrounded; a few limonite concretions from 260 to 265 ft	54	285
Gravel and sand in a matrix of tan silty clay; pebbles as in bed above	5	290
Sand and medium to coarse gravel in a matrix of tan silt; pebbles and cobbles of diverse composition as above; subrounded; sand grains subangular, poorly sorted, mostly light-colored minerals	5	295
Sand and gravel in a matrix of brown clayey silt; differs from overlying bed only in clay content	20	315
Sand and gravel in a matrix of tan-brown silt; similar to 290- to 295-ft bed	19	334
Sand, clayey, fine, mottled reddish-brown by limonite	4	338
Sand, fine to medium, and fine to coarse gravel, almost free of silt; gravel and sand are subangular to rounded and most commonly quartzite and basalt	122	460
12/27-3P1 [Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]		
Alluvium (dune sand):		
Sand, silty	1	1
Glaciofluviatile and fluviatile deposits:		
Cobbles, coarse to fine gravel, and sand; predominantly basalt	43	44
Sand, silty and clayey, medium to fine	14	58
Gravel, granular, and sand; mostly basalt	32	90
Ringold Formation:		
Gravel, fine to medium, and sand in a tan silt matrix	30	120
12/27-18C1 [Drilling and sampling to 130 ft by Gen. Elec. Co.; deepened and changed to 6-in. diameter by U.S. Geol. Survey, 1953. Stratigraphic designations by U.S. Geol. Survey]		
Alluvium (dune sand):		
Sand; fine to very coarse, averages coarse; mostly basalt	3	3
Glaciofluviatile and fluviatile deposits:		
Sand and tan silt; sand mostly basalt, fine to very coarse	30	33
Sand with minor amount of silt; sand mostly basalt, fine to medium	7	40
Gravel, sand, and tan silt; gravel and sand mostly basalt	2	42
Gravel, boulders, sand, and minor amount of tan silt; largely basalt; very high permeability	25	67
Boulders, coarse gravel, sand, and minor amount of silt; differs from overlying bed in larger proportion of boulders and cobbles	19	86
Sand, coarse; principally basalt; sample shows gravel, which probably is "carry-down" from overlying bed	4	90
Boulders, finer gravel, sand, and silt; similar to 67- to 86-ft bed	20	110
Boulders and finer gravel; mostly basalt	2	112
Sand, fine to coarse; principally basalt	5	117
Sand and gravel, with boulders; mostly basalt	13	130
Sand and gravel	5	135
Boulders	3	138
Gravel and sand; very clean and free of silt in lower 10 ft, wood fragments in lower 1 ft	28	166
Boulder, large	1	167
12/27-27J1 [Drilled and sampled by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]		
Alluvium:		
Sand, silty, and some fine gravel; coarse particles chiefly basalt	5	5
Glaciofluviatile and fluviatile deposits:		
Gravel, fine, and fine to very coarse sand; slightly silty in part but generally clean and fairly permeable; coarse particles chiefly basalt, angular to subrounded	50	55
Ringold Formation:		
Sand, silty, tan-gray, subangular to subrounded; very fine to coarse, averages medium; about 50 percent quartz, feldspars, and mica and 50 percent basalt	25	80
Gravel, sand, and some silt and clay; pebbles are chiefly quartzite and basalt, subrounded to rounded; sand is very fine to coarse, averages medium, and is largely quartz, feldspar, mica, and basalt; both sand and silt are tan	45	125
Sand, silty, and some fine gravel; sand is chiefly quartz and feldspars and carries a minor amount of basalt; size ranges from fine to coarse and averages medium; pebbles generally well rounded; mostly quartzite, granitoid and gneissoid rocks, and basalt	10	135
Gravel, medium to coarse, and fine to coarse sand, slightly silty; mostly quartzite and granitoid rocks, generally subrounded; may include cobbles or boulders from 145 to 154 ft	23	158
12/28-18D1 [Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Alluvium (dune sand):		
Sand, fine and medium, clean; quartz and exotic rock types with 10 percent mica; about 5 to 10 percent silt-size material present	4	4

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Glaciofluviatile and fluviatile deposits:		
Sand and gravel; principally medium dark basaltic sand with much pebble and cobble basalt gravel that makes up 30–50 percent of the zone	41	45
Sand, medium, dark-gray, basaltic; contains some interbedded gray clayey silt and a few basalt pebbles	4	49
Sand and gravel; mixed sand of basalt materials with basaltic pebble and cobble gravel making up 25–40 percent of deposit	15	64
Sand, mixed, dark; consists of 60–80 percent basalt; the zone at 74 to 77 ft is a scabland-bar type of deposit similar to those in the Scooteney channels eastward across the river	13	77
Sand and clayey silt; fine to medium tan-gray quartz and basalt sand in which some brown clay silt beds are interlayered	11	88
Sand and gravel; medium, but mixed, exotic and basaltic light-gray-tan sand that is about equally quartz and basalt with 30 percent granule, pebble, and cobble gravel in which exotic rock types predominate over basalt; the zone may be either fluviatile reworked Ringold materials or Ringold strata	28	116
Ringold Formation:		
Silt, sandy, light-tan	1	117
Sand and gravel; mixed, but average medium, tan-gray mainly quartz sand accompanied by 25 percent granule to cobble gravel that is 80 percent exotic rock types and 20 percent basalt	16	133
Silt, clayey; gray siliceous silt carrying fine quartz sand and some clayey material	4	137
Sand and gravel; medium quartz sand having 20 percent granule and pebble exotic-type gravel	11	148
Sand, medium, quartzose; contains an occasional pebble layer	17	165
Silt, clayey, gray; carries 10 percent fine sand near the top	11	176

12/28–24N1
[Driller's log, by N. C. Jannsen Company, 1921. Stratigraphic designations by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Sand	18	18
Ringold Formation:		
Gravel, cemented	67	85
Clay	20	105
Clay and gravel	22	127
Gravel	28	155
Boulders and finer gravel	6	161
Clay, black and blue	35	196
Sand	9	205
Basalt of the Columbia River Group:		
Rock, black	29	234
Rock, black, and shale	6	240
Shale	17	257
Rock, black	151	408
Basalt	63	471
Clay and gravel	16	487
Shale	9	496
Rock	39	535
Basalt	2	537
Rock	2	539
Shale, black and blue	25	564
Basalt	103	667
Basalt, porous	10	677
Basalt, scoriaceous, water-bearing	15	692
Shale, blue	19	711
Sandstone, gray	9	720
Basalt, creviced, water-bearing	35	755

12/28–31H1
[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Glaciofluviatile and fluviatile deposits:		
Sand, gravelly and silty; medium to coarse basalt forms 60–90 percent of the coarse, and 25–50 percent of the fine, grains; granule and pebble gravel is largely basalt	32	32
Gravel and sand, gray, subrounded; about equally basalt and exotic pebbles and granules carrying fine to coarse basaltic sand and 10 percent siliceous silt	4	36
Ringold(?) Formation:		
Sand, fine to medium, quartzose, tannish-white, and layers of siliceous and basaltic granule and pebble gravel	4	40
Gravel and sand; has 10 percent tan silt; rounded granule and pebble gravel of 60 percent exotic rock types and 40 percent basalt accompanied by about 50 percent quartzose whitish-gray subrounded medium sand	21	61
Sand; has gravel and silt layers; medium to coarse light-tan and gray quartz and basalt sand; includes layers of silt and pebble gravel that each forms about 20 percent of the zone	7	68
Ringold Formation:		
Sand; largely medium sand, but having much fine and some coarse sand, is gray, quartzose, and subrounded; some layers of granule and pebble siliceous gravel as well as some gray silt	12	80
Silt, clayey and sandy; buff silt and clay carrying some layers of siliceous sand and gravel	17	97
Gravel and sand; subrounded granule, pebble, and cobble gravel that is equally basaltic and exotic; about 50 percent of material is medium quartzose, arkosic, and basaltic sand	8	105

TABLE 2.—*Logs of type wells on the Hanford Reservation*—Continued

Materials	Thickness (feet)	Depth (feet)
13/25-1N2 [Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Glaciofluviatile and fluviatile deposits:		
Gravel, bouldery and sandy; carries some cobbles and pebbles; largely basaltic	15	15
Gravel, bouldery and silty	10	25
Gravel, coarse, sandy	18	43
Gravel, coarse, silty; water at 44 ft	13	56
Ringold Formation:		
Gravel, pebble, sandy	3	59
Gravel, up to 4 in. in diameter	4	63
Gravel, coarse, silty	2	65
Gravel, coarse to fine, sandy	7	72
Gravel, sandy; 75 percent gravel and 25 percent sand	6	78
Gravel, ⅛- to ½-in.-diameter, sandy	3	83
Gravel, ½- to 3-in.-diameter	4	87
Sand, fine, gray; contains gravel ¼ to 4 in. in diameter	8	95
Sand, medium to coarse, and coarse gravel; sand 75 percent, gravel 25 percent	7	102
Sand, fine to coarse, and some pea-sized gravel	3	105
Gravel, coarse, sandy	25	130
Gravel, sandy; 50 percent gravel, 50 percent sand	7	137
Gravel, fine to coarse, sandy	3	140
Gravel, fine to coarse	3	143
Gravel, ½- to 5-in.-diameter, sandy and clayey	5	148
Sand, gravelly, fine; sand 70 percent, gravel 30 percent	5	153
Sand, tan, silty	20	173
Sand, silty, and thin clay strata	15	188
Gravel, coarse, sandy; gravel 50 percent, sand 50 percent	9	197
Sand, silty; has caliche from 217- to 230- and 240- to 253-ft depths	60	257
Sand, fine, tan	7	264
Sand, fine to coarse, and fine to coarse gravel; sand 50 percent, gravel 50 percent; gravel near the 267-ft depth between 1 and 5 in. in diameter	11	275
Gravel, coarse	3	278
Gravel, fine to coarse	4	282
Sand, gravelly	8	290
Gravel, sandy; gravel up to 2 in. in diameter makes up 75 percent, and sand is 25 percent	5	295
Sand, fine, tan, silty	10	305
Sand, medium to fine, tan, and alternating silt and clay strata	12	317
Gravel, fine, sandy; gravel 75 percent, sand 25 percent	3	320
Gravel, fine to coarse, sandy	13	333
Gravel, bouldery and sandy	1	334
Sand, coarse, and fine to coarse gravel; basalt pebbles have rinds	9	343
Gravel, coarse, and some sand	7	350
Ringold Formation—Continued		
Sand, fine, and some coarse gravel; sand flows into well	9	359
Sand, fine, gravelly; sand 50 percent, gravel 50 percent; bouldery gravel in 365- to 375-ft zone	17	376
Clay; has sand and gravel strata	2	378
Sand, silt, and clay strata	10	388
Clay, brown	29	417
Clay, gray	10	427
Sandstone; water shut off by clay parting at 388-ft depth and reappeared at 430-ft depth; water level 57 ft below land surface	8	435
Clay; has sand beds and caliche	10	445
Sand, coarse to fine, and clay beds	5	450
Clay, brown, plastic, and a few pieces of ⅛- to ½-in. gravel	12	462
Clay, dark-brown, and fine intermixed gravel	3	465
Clay, brown, and alternating silt beds	15	480
Clay, blue-gray, and some ⅛-in. granules	16	496
Clay, blue-green, plastic	5	501
Clay, gray-brown; has a few pockets of yellow sand	10	511
Clay, blue, silty	39	550
Clay, blue, silty; plastic clay at 555- to 575-ft depth, and some caliche at 580- to 585-ft depth; water level 78 ft below land surface	43	593
Clay, blue and black, and about 35 percent gravel ¼ to 2 in. in diameter, sandy	2	595
Sand, gravelly, and a few clay strata; water level 67 ft below land surface	16	611
Clay, tan; water shut off at 611 ft and reappeared at 620-ft depth, rising to 74 ft from land surface	9	620
Sand and tan clay; carries gravel in 630-ft zone	10	630
Sand, medium to fine; water 75 ft below land surface	2	632
Sand, gravelly	6	638
Sand and alternating beds of tan clay	10	648
Clay, brownish-black; water shut off at 648-ft depth	8	656
Basalt of the Columbia River Group:		
Basalt, black, vesicular; water from upper part of basalt has level 287 ft below land surface, but no water entered from 675- to 764-ft depth	81	737
Basalt, gray, hard	8	745
Basalt, black, medium-hard; a few small vesicle fillings in the 763- to 765-ft zone	20	765
Basalt, gray; water entered at 764 ft, rising to 255 ft from land surface in 1 hr and to 238 ft after drilling at 765-ft depth	4	769
Clay, blue and white, and pieces of basalt	4	773
Ash, gray, crumbly; breaks into ⅛-in. granules	5	778

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Basalt of the Columbia River Group—Con.		
Sand, medium to fine, white, quartzitic; water rose to within 106 ft of land surface when sand was penetrated and to 73 ft from land surface when drilled to 780-ft depth; at 785-ft depth water level was 38 ft from land surface	9	787
Sandstone, red; water temperature 130° F; bailing at 100 gpm lowered water level from 34 to 51 ft below land surface and lowered water temperature from 130 to 90° F; in 30 minutes after bailing ceased, water level recovered 7 ft, and water temperature recovered to 98° F; at completion of well, after bailing sand 5 days, water level was 41.4 ft from land surface with water temperature 73° F at well bottom and 86° F at the top	3	790
13/25-16J1 [Drilling and sampling by Gen. Elec. Co. Stratigraphic designations from samples by U.S. Geol. Survey]		
Glaciofluviatile and fluviatile deposits:		
Gravel, bouldery, sandy, and slightly silty	22	22
Sand, basaltic, medium to coarse, angular to subangular	3	25
Sand, basaltic, fine, angular to subangular	13	38
Gravel, sand, and silt; has an occasional cobble or boulder; mostly basalt, subangular to subrounded	24	62
Sand, medium, mostly basalt, subangular; slightly silty in part	8	70
Sand, silty, as above; carries fine to coarse gravel; silt is gray tan	54	124
Gravel and sand in clayey silt matrix; materials suggestive of Ringold Formation, but coarser particles are preponderantly basalt; probably reworked Ringold Formation mixed with basaltic detritus	11	135
Ringold Formation:		
Gravel in a matrix of silty and clayey sand; pebbles about half basalt and half light-colored rocks; subrounded to rounded; some coated by cemented sand; sand is very fine to coarse, commonly quartz, feldspars, and mica; approximate proportions: gravel, 65 percent; sand, 20 percent; silt, 10 percent; clay, 5 percent	103	238
Basalt of the Columbia River Group:		
Basalt, gray to black, dense to vesicular, jointed into small blocks, water-bearing	15	253
13/25-23A2 [Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]		
Glaciofluviatile and fluviatile deposits:		
Gravel, bouldery, in silty sand matrix; pebbles and cobbles subrounded to rounded, chiefly basalt; sand is fine to very coarse and predominantly basalt	29	29
Sand, silty, fine to medium; predominantly basalt	7	36
Gravel and sand, silty; chiefly basalt; pebbles subrounded to subangular	9	45
Sand, medium to fine, subangular, clean; chiefly basalt	5	50
Pebbles, subrounded; particles chiefly basalt	5	55
Sand, medium, slightly silty; grains subrounded to subangular; basaltic	7	62
Gravel, medium, and fine to coarse sand, slightly silty, basaltic; pebbles subrounded	12	74
Ringold Formation:		
Sand, medium, subangular, clean; proportions of light and dark minerals equal	2	76
Gravel in compact matrix of brown silty medium sand	19	95
Sand, medium, and medium to fine gravel; sand is poorly sorted and subangular	5	100
Sand, coarse, moderately sorted, clean; chiefly quartz, feldspar, and basalt	10	110
Gravel in a matrix of tan-brown silty sand; much mica in the sand	15	125
Gravel, medium to coarse, and sand in a clayey silt matrix; pebbles and cobbles subrounded, of diverse rock types, and commonly coated with cemented sand	40	165
Basalt of the Columbia River Group:		
Volcanic ash and tuff, clayey and gritty; contains angular fragments of basalt and quartzite of fine-gravel size; apparently water laid or reworked; color ranges from pale bluish to greenish gray, mottled with rusty streaks and spots	12	177
Basalt, dense to scoriaceous, black to gray, water-bearing	21	198
13/25-30G1 [Driller's log by Frank R. Lawson, 1927. Stratigraphic designations by U.S. Geol. Survey]		
Surficial material, silt, etc	22	22
Ringold(?) Formation:		
Clay and boulders	316	338
Clay, blue, green, and yellow	240	578
Basalt of the Columbia River Group:		
Basalt, black, with soft seams	34	612
Clay, blue, hard, sandy	10	622
Clay, sticky, blue	48	670
Shale, soft, and "soapstone float"	10	680
Rock, water-bearing	25	705
Basalt, black; increase in waterflow	115	820
Basalt, broken; increase in waterflow	4	824
Clay, soft, with "broken rock" (no water)	26	850
"Lakebed with wood"; layers of green clay	10	860
Basalt, black, broken; increase in waterflow	65	925

TABLE 2.—*Logs of type wells on the Hanford Reservation*—Continued

Materials	Thickness (feet)	Depth (feet)
Basalt of the Columbia River Group—Con.		
Basalt, hard, black	25	950
Basalt, black, "broken"; increase in waterflow	25	975
Basalt, broken; increase in waterflow	15	990
Basalt, broken	8	998
Sand, fine; "heavy flow" of water	1	999
Porous rock; "heavy flow" of water	101	1,100
Sand, fine	10	1,110
13/25-33D1 [Driller's log (1943) with approximate stratigraphic designations by U.S. Geol. Survey]		
Soil	5	5
Glaciofluviatile and fluviatile deposits:		
Sand and some gravel	3	8
Sand and coarse gravel	4	12
Boulders, with sand and finer gravel	8	20
Gravel, cemented	50	70
Gravel, clay, and sand (dry)	16	86
Ringold Formation:		
Sand, clay, and sandstone	9	95
Sandstone	30	125
Sand, loose, caving	20	145
Sandstone (caving 194–200 ft)	105	250
Sand, gravel, and some clay	38	288
Gravel, cemented (probably top of Ringold conglomerate zone)	54	342
Gravel, pea-size, sand, and a little clay	7	349
Sand and pea gravel, loose (dry)	16	365
Sandstone	26	391
Sand and pea gravel, water-bearing; static water level 390 ft below land surface	12	403
Sandstone	26	429
Sand and gravel	1	430
Sandstone and pea gravel	23	453
Sand and gravel	8	461
Sandstone (washed cuttings are quartz, feldspar, basalt, and mica; drills into greenish-brown sludge)	10	471
Sandstone, hard	9	480
Sandstone and pea gravel	12	492
Clay, sandy, brown	20	512
Sand and gravel	5	517
Sand and pea gravel	23	540
13/25-36D1 [Drilling and sampling by Gen. Elec. Co. Stratigraphic designation of samples by U.S. Geol. Survey]		
Glaciofluviatile and fluviatile deposits:		
Gravel, fine, with cobbles, boulders, sand, and some tan silt; predominantly basalt	19	19
Sand, silty, fine to coarse	6	25
Gravel, medium to coarse, clean	2	27
Sand and tan silt; sand is fine to coarse, mostly quartz, feldspars, and mica, and makes about 60 percent of sample	8	35
Gravel, fine to medium, in a matrix of tan silty sand; pebbles are of diverse rock types, well rounded to rounded; sand is of same material, very fine to coarse	9	44
Sand and silt, as in 27- to 35-ft bed	6	50
Gravel, sandy and silty, as in 35- to 44-ft bed	20	70
Sand, tan, silty, micaceous, mostly light-colored minerals, very fine to medium	40	110
Sand and medium gravel, silty; sand as in overlying bed; pebbles well rounded; 50 percent basalt, 50 percent diverse light-colored rocks	20	130
Sand, silty, as in 70- to 110-ft bed	5	135
Gravel, coarse sand, and trace of silt	20	155
Ringold Formation:		
Sand, fine to medium, and tan silt; has 1-ft layer of fine gravel at 159 ft	8	163
Gravel, fine to coarse, granules, coarse sand, clean, highly permeable; diverse rock types; pebbles well rounded	30	193
Gravel in a sandy, silty matrix; single boulder from 232–237 ft; gravel is diverse rock types, fine to coarse, subangular to well rounded, and about 50 percent of sample; sand and silt are about 25 percent each	97	290
13/26-5D2 [Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]		
Alluvium:		
Silt, grayish-brown, sandy and gravelly	3	3
Glaciofluviatile deposits:		
Gravel, sandy and slightly silty; contains boulders up to 3 ft in diameter, mostly basalt; gravel ranges from ½ to 10 in. in diameter	12	15
Gravel and sand, mostly basalt, subrounded to rounded; gravel 60 percent, sand 40 percent	14	29
Sand, tan, silty, mostly fine, micaceous; contains grains having a higher than usual percentage of limestone and gneiss, schist, and metasediments rather than a predominance of quartz grains	9	38
Sand, silty, as above, and slightly gravelly; sand is 95 percent of deposit and gravel averaging 1 in. in diameter is 5 percent	7	45
Ringold Formation:		
Gravel, sandy; ¼- to 5-in.-diameter rounded to subrounded mostly metamorphic pebbles in a coarse to fine angular micaceous sand matrix; a few basalt pebbles have thin weathering rinds	35	80
Gravel, coarse to fine, and sand; weathering rinds on basalt pebbles; sand is medium to fine, micaceous, largely siliceous; gravel forms 50 percent of bed, and sand 50 percent; first water noted at 83 ft	4	84

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
Sand, gravelly, gray-tan, fine to coarse; forms 75 percent of bed; gravel forms 25 percent, is rounded to subrounded, and is largely metamorphics and granitics ranging in diameter from ¼ to 3½ in. and averaging 1½ in.	5	89
Gravel, cobble and pebble, subrounded to rounded; forms 80 percent of bed; maximum diameter of 4 in. and all intermediate grade sizes give an average diameter of about 1 in.; sand 20 percent, coarse to medium, subangular to subrounded; basalt pebbles have weathering rinds; water at this depth cut off by casing	2	91
Sand, gravelly; sand is coarse to fine and forms 80 percent of bed; gravel, pebbly, has average diameter ½ in. and forms 20 percent of bed	2	93
Sand, coarse to fine, mainly quartzitic, micaceous, and only rare pieces of gravel; sand forms over 95 percent of bed; depth to water 77.2 ft below land surface; sand caves easily and rises in pipe	4.5	97.5
Sand, gravelly; 60 percent sand, 40 percent gravel	.5	98
Gravel, sandy; 60 percent gravel, 40 percent sand; diameter of gravel ranges from 5 down to ½ in.; 50 percent of gravel ranges from 2½ to 3½ in. in diameter	3.5	101.5
Sand, gravelly and slightly silty; 95 percent sand, medium to fine, micaceous, largely siliceous; gravel forms 5 percent of bed and has a maximum diameter of 4 in. and a minimum of ¼ in.; gravel is composed of 75 percent upriver exotics, mainly metamorphic rocks, and 25 percent basalt, much of which has thin weathering rinds; pebbles are subrounded to rounded; sand in this stratum runs freely into well	.5	102
Sand, gravelly; 70 percent coarse to fine sand, micaceous, siliceous; gravel, mainly pebbles and occasional cobbles, averages 1 in. in diameter and forms 30 percent of bed	2	104
Gravel, sandy; 70 percent medium to fine gravel, 30 percent coarse to fine siliceous, micaceous sand	2	106
Sand, gravelly; sand 95 percent, gravel 5 percent; sand rises in well	.5	106.5
Boulders, basaltic, and a few cobbles and pebbles	1.5	108
Gravel, pebble and cobble, in a coarse to fine micaceous, quartzitic sand matrix; maximum diameter of the occasional cobbles present is 4 in.; pebble gravel 2 in. in diameter forms 50 percent of gravel component; gravel forms 70 percent of bed, sand 30 percent; 15 percent of gravel is basalt, 17 percent granitics and felsites, and 68 percent metamorphic rocks; a cemented gravel stratum having a sandy matrix with calcareous cement was penetrated; a bailer test utilizing an 8-in. dart bailer was made at 112-ft depth; 40 gpm were bailed during a 15-min test with a 16-ft drawdown; depth to water before bailing was 73.25 ft below land surface	16.5	124.5
Gravel, granule, pebble, and cobble, rounded to subrounded; has a maximum diameter of 5 in. and average diameter of 2 in.; about 30 percent of gravel is ¾ to 1 in. in diameter in a siliceous, micaceous angular coarse to fine sand matrix; weathering rinds, manganese stains, and cemented micaceous sand on basalt pebbles; gravel 90 percent, sand 10 percent	8	132.5
Sand, coarse to medium; has about 20 percent granule gravel and 5 percent pebble gravel averaging 1 in. in diameter; sand is mainly siliceous and angular	1	133.5
Gravel, cobble, pebble, and granule; forms 90 percent of bed; a 10-min bailer test at 139-ft depth produced 45 gpm with a 6-ft drawdown	6.5	140
Sand, tan, medium to coarse, siliceous, micaceous; forms 80 percent of bed; pebble gravel, average diameter 1 in. with maximum diameter 2 in., forms 20 percent of bed	7	147
Gravel, pebble and granule; has a few cobbles in a medium to coarse sand; gravel 50 percent, sand 50 percent; maximum gravel diameter 3½ in. with 60 percent of the gravel near the 2-in.-diameter size	5	152
Gravel, cobble to pebble, well-rounded, average diameter 1 in., in a granule gravel to coarse sand matrix; gravel 70 percent, sand 30 percent	12	164
Claystone, silty, cream, indurated; contains angular granules and small pebbles ⅙ to ½ in. in diameter, with a few larger pebbles and cobbles, mainly basalt, averaging 2 in. in diameter and having a maximum diameter of 7 in.	5.5	169.5
Sandstone, cream streaked with yellow-brown iron stains, medium- to fine-grained, indurated	1	170.5

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

13/26–19R1
[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Glaciofluviatile and fluviatile deposits:		
Silt, tan, and bouldery gravel; materials are mainly basalt	5	5
Gravel and sand, with boulders; has minor amount of silt; cobbles and boulders are 90 percent basalt	20	25
Boulder, basalt	5	30
Gravel and sand, with boulders	15	45
Gravel, sand, and clay, with boulders (largely reworked Ringold? Formation)	5	50
Ringold Formation:		
Gravel, sand, tan silt, and bluish-gray clay; pebbles and coarser sand about 50 percent basalt; the remainder, also the silt and clay, are chiefly light-colored minerals; considerable mica in the sand	30	80
Gravel and minor amount of silt and clay, with boulders; gravel is 50 percent basalt	3	83
Gravel and clay	2	85
Sand and gravel in a matrix of indurated gray-tan clay	36	121
Clay, light-brown; contains some sand and fine gravel	34	155
Sand and granules in a light-brown clay matrix	10	165
Clay, light-brown, plastic, impermeable	16	181
Clay, gravelly, light-brown, plastic, impermeable	1	182
Sand, clayey; contains fine gravel	8	190
Clay, light-brown; contains granular and pebble gravel	6	196
Clay, bouldery and sandy, light-brown	4	200
Basalt of the Columbia River Group:		
Basalt, black, dense, water-bearing	5	205

13/26–25A1
[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Sand and tan silt; sand is fine to coarse, is mostly basalt, and forms 75 percent of sample	14	14
Gravel, granule, and sand; larger particles mainly basalt	3	17
Gravel, sand, and tan silt, with boulders; mostly basalt	36	53
Gravel, sand, and silt; chiefly basalt	7	60
Ringold Formation:		
Gravel, boulders, silt, and clay; driller's log lists "coarse sand, rocks, and boulders"; gravel and sand are of diverse rock types, with basalt forming less than 35 percent	14	74
Gravel, sand, silt, and clay; differs from overlying bed mainly in lack of boulders in driller's log; sample marked "90 feet" appears to be from shoulder of bit (not mixed) and is about 50 percent silt and clay drilling sludge	18	92
Ringold Formation—Continued		
Clay, silt, sand, and some gravel, dark-grayish-brown; silt and clay are 85 percent of sample, sand 10 percent, gravel 5 percent; sand is predominantly light-colored minerals	8	100
Clay, silty and sandy; clay is 80 percent, silt 10 percent, sand 10 percent	28	128
Sand, light-gray, and minor amount of tan silt; sand is very fine to medium; principally quartz, feldspar, and mica (some flakes of mica are 1 mm across); differs from overlying bed mainly in lack of clay	12	140
Clay, gritty, gray-tan; driller's log lists "clay and a little gravel"	5	145
Clay, gray-tan	30	175
Clay, silty and sandy, light-tan; similar to 100- to 128-ft bed	13	188
Clay, gray-tan; probably an altered water-laid volcanic ash	14	202
Basalt of the Columbia River Group:		
Basalt, black, dense, jointed; probably more permeable than overlying sediments	8	210

13/26–33K1
[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Sand, silty, tan	3	3
Glaciofluviatile and fluviatile deposits:		
Sand, and fine gravel, chiefly basalt; silt present both as lenses and throughout the bed	45	48
Sand, fine to coarse, subangular to subrounded, and granule gravel; both sand and gravel about 50 percent basalt, with remainder exotics	17	65
Gravel, fine to coarse, and sand, basaltic; contains tan silt and clay; basalt forms about 70 percent of gravel and 50 percent of sand	17	82
Gravel and sand; differs from overlying bed in lack of silt and clay	33	115
Gravel, fine, in a silty sand matrix; granule and pebble gravel is mainly subrounded basalt; sand is about ½ basalt; some caliche present	40	155
Sand and fine gravel in a gray-brown clayey silt matrix	7	162
Sand, coarse to very fine, basaltic, fairly clean and permeable; possibly reworked Ringold materials	5	167
Gravel and sand, basaltic, in a dark-gray clayey silt matrix; possibly reworked Ringold materials	36	203
Ringold Formation:		
Sand, medium to very fine; contains little clay; about 30 percent basalt present, with remainder quartzose material	3	206

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
Gravel; much like 167- to 203-ft bed	4	210
Sand, coarse to fine, and a small amount of granule gravel	8	218
Gravel, medium to fine, sandy and silty	22	240
Gravel, medium to fine, silty and sandy; has caliche coatings on some pebbles; sand is very fine to coarse	37	277
Basalt of the Columbia River Group:		
Basalt, dark-gray, jointed	8	285

13/26-36R1

[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Sand, silty, tan	2	2
Glaciofluviatile and fluviatile deposits:		
Gravel, sand, and silt, with boulders, mostly basalt	13	15
Boulders, finer gravel, and sand, mostly basalt	10	25
Gravel and sand, almost clean, about 90 percent basalt	9	34
Sand, fine to very coarse, basaltic	1	35
Gravel and sand; similar to 25- to 34-ft bed	15	50
Gravel, granular, and sand in a matrix of tan silt and clay; at 75 ft materials characteristic of the Ringold Formation were penetrated; these are probably reworked	35	85
Ringold Formation:		
Sand, silty, tan, fine to very coarse; mostly light-colored minerals but part basalt	5	90
Sand, granules, silt, and clay; sand is fine to very coarse, about 50 percent light-colored minerals, 50 percent basalt	25	115
Gravel, sand, and silt; differs from overlying bed chiefly in presence of gravel and absence of clay	10	125
Gravel, sand, and tan silt, with boulders	7	132
Sand, fine to very coarse; contains minor quantities of granules and tan silt	8	140
Gravel, boulders, and sand; coarser grained than overlying bed	5	145
Gravel, granules, and sand; lacks boulders of overlying bed	10	155
Gravel, fine to medium, and sand in a silt and clay matrix	5	160
Clay, dark-gray, silty; includes sand and granules	15	175
Basalt of the Columbia River Group:		
Basalt, reddish, rubbly, ashy	15	190
Basalt, black, dense, jointed	5	195

13/27-13N1

[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Soil, silt, clay, and fine sand	4	4
Ringold Formation (possibly disturbed to 48-ft depth):		
Silt, sandy, clayey; about equally quartz silt (40 percent) and fine and very fine quartz sand (40 percent) with some clay and some medium pale-buff sand	22	26
Sand and silt; medium to very fine, average fine, quartz sand (60 percent) with quartz silt and some clay; pale-buff; silt and clay are more prominent in lowest few feet	22	48
Claystone, silty, tan grading downward into greenish-tan and blue; contains claystone nodules and concretions up to 1 in. in diameter; "chalky" layer at 63 ft is water bearing	42	90
Claystone; silty and sandy like that just above, but contains more fine sand (up to 15 percent increasing downward); has concretionary nodules up to ½ in. in diameter; dark-buff	30	120
Sand, silt, and clay; medium to very fine sand that is 90 percent quartz; contains silt and clay (up to 40 percent at top) decreasing downward	25	145
Silt, sand, pebbles, and cobbles; gray-buff; has 10 percent sand and 15 percent gravel (up to 4-in. cobbles) interbedded in silt	5	150
Sand, medium to fine, and silt, pale-buff, well-sorted, friable, quartzose and micaceous; poorly consolidated sandstone	45	195
Silt, sandy, quartzose, gray-tan, and 25 percent fine quartz sand	10	205
Siltstone and claystone; dark-brown quartzose compact silt and some clay with concretionary nodules of claystone	10	215
Sand, medium to very fine; gray-tan quartz sand having 25 percent quartzose silt; a few basaltic pebbles present in the 220- to 225-ft zone	18	233
Siltstone and claystone; brown quartzose siltstone and clay having a few white and brown claystone nodules; a few basalt and exotic rock pebbles are present in 256- to 280-ft zone	72	305
Sand, coarse and medium, quartzose (80 percent)	5	310
Sand and gravel; medium and coarse gray sand having about 25 percent basaltic gravel	5	315
Basalt of the Columbia River Group:		
Basalt, gray, unweathered	4	319
Shale, black, tuffaceous	5	324
Basalt, dark-gray, slightly vesicular; a large fragment or thin flow	6	330
Tuff, dark-gray, "gravelly"	26	356
Basalt, black, glassy, hard	9	365
Sandstone, tan, tuffaceous, quartzose	5	370
Basalt, medium-gray; has thin interbeds of shaly tuff and sandstone	80	450

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Basalt of the Columbia River Group—Con.		
Tuff, sandstone, and breccia; mainly olive-green sandy tuff containing large and small basalt fragments in places	38	488
Basalt, gray, scoriaceous at top	26	514
Tuff, tan	6	520
Basalt, gray, massive	87	607

13/27-16R1

[Drilled and log recorded by unknown driller, 1943. Stratigraphic designations by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Soil	2	2
Glaciofluviatile and fluviatile deposits:		
Sand, loose, and some gravel	18	20
Gravel, cemented ("hard pan")	24	44
Sand and pea gravel, water-bearing	30	74
Ringold Formation:		
Clay, sticky	46	120
Sand, coarse grading to fine, light-red, water-bearing	11	131
Sand, fine (some clay?)	24	155
Clay	25	180
Sand, fine	12	192
Gravel; "basaltic" rocks and fragments	3	195
Clay	21	216
Clay, soft, silt, and sand (gravel at bottom)	24	240
Clay, sticky, bluish-gray; has streaks of light-yellow fine sand	117	357
Gravel, pea-size, and sand	6	363

13/27-28P1

[Drilling and sampling by Gen. Elec. Co. Stratigraphic designations of samples by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Sand, silty, tan	2	2
Gravel and sand; contains gray silt and clay; gravel and sand about 70 percent basalt, remainder of diverse rock types	23	25
Ringold Formation:		
Clay, silty, tan; contains very fine sand	40	65
Gravel, sand, silt, and clay; pebbles and cobbles of quartzite, granite, gneiss, and schist; well-rounded to subrounded	23	88
Boulders, gravel, sand, silt, and clay; differs from overlying bed in presence of boulders	12	100
Sand, very fine to fine, in a matrix of gray silt and clay; sand grains mostly light-colored minerals	12	112
Sand, silty; differs from overlying bed in lack of clay	26	138
Sand, silty and clayey, as in 100- to 112-ft bed	27	165
Gravel, sand, and silt; some basalt pebbles show matrix of cemented sand and silt	9	174
Sand, gray-tan, very fine to medium	4	178
Gravel, sand, and silt, as in 165- to 174-ft bed	20	198
Ringold Formation—Continued		
Gravel and very coarse to fine sand; contains tan silt and clay	12	210
Sand, silty, tan	10	220
Silt, clayey, and very fine sand	10	230
Sand, silty, very fine to fine; grains angular to rounded, of diverse mineral types, and weakly cemented by silt	15	245
Gravel, sand, silt, and clay; pebbles and sand grains generally rounded to subrounded, comprised of light-colored minerals, and weakly cemented by clayey silt	20	265
Sand, silty and clayey; similar to overlying bed but lacks the gravel	8	273
Gravel, sand, silt, and clay, as in 245- to 265-ft bed	7	280
Clay, silty, or clayey silt	20	300
Sand, silty, highly micaceous, very fine to medium	10	310
Silt, clayey, gritty, gray-tan; grit is angular and largely basalt	15	325
Clay, gritty, gray-tan mottled with blue, plastic	5	330
Clay, gritty, blue, plastic; a few angular basalt pebbles	5	335
Clay, dark-gray, nodular	32	367
Sand, coarse to very coarse, basaltic, highly permeable	7	374
Basalt of the Columbia River Group:		
Basalt, black, broken into small blocks; yields water freely	6	380

14/26-31R1

[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Alluvium:		
Silt, grayish-tan, finely micaceous, slightly calcareous	10	10
Silt, tan, finely micaceous; more tan than bed above	5	15
Ringold Formation:		
Gravel, fine to medium; has subrounded metamorphic and granitic pebbles up to 2½ in. in diameter in a sandy silt matrix	21	36
Gravel, sandy; gravel forms about 60 percent of sample, sand 40 percent; pebbles are about 80 percent metamorphic and granitic types and 20 percent basalt, some of which have thin weathering rinds; subrounded to subangular gravel, averaging 1½ in. in diameter and having a maximum diameter of 3 in., lies in a tan well-sorted medium to fine quartzose sand matrix	7	43
Gravel, granule to pebble, sandy and silty; granule and small-pebble gravel makes up about 50 percent of zone, with remainder a quartzose sand	13	56

TABLE 2. — *Logs of type wells on the Hanford Reservation* — Continued

Materials	Thickness (feet)	Depth (feet)
Ringold Formation—Continued		
Sand, gray, coarse to fine, gravelly and clayey	4	60
Gravel, sandy and silty	7	67
Gravel, sandy; gravel up to 5 in. in diameter and averaging 2 in. is subangular to subrounded, is in part stained black, and has a matrix of coarse to fine quartzose sand; basalt pebbles have well-developed weathering rinds	3	70
Sand, coarse to fine, tan, quartzose; contains a gravel stratum	5	75
Gravel, coarse to fine, 60 percent upriver exotic rock types, subrounded to subangular; lies in a sand matrix which becomes silty in lower part	7	82
Sand, as in the 70- to 75-ft zone	8	90
Gravel, sandy and clayey becoming more clayey near bottom	13	103
Silt, tan, clayey	1	104
Clay, white to cream, gravelly; alternately thin beds of sand and gravel in thicker gravelly clay strata; one clay stratum contains rounded 1- to 3-in. pebbles and cobbles; sand is medium to fine, gray	3	107

14/27–18J1

[Drilling, sampling, and stratigraphic designations by U.S. Geol. Survey]

Materials	Thickness (feet)	Depth (feet)
Glaciofluviatile and fluviatile deposits:		
Gravel, sandy and silty	10	10
Gravel, sandy; warm water encountered at 36½-ft depth	27	37
Sand, medium to fine; contains gravel	18	55
Sand, gray-tan	4	59
Ringold Formation:		
Silt, reddish-tan; water shut off by casing	10	69
Clay, poorly indurated, sandstone, and sand, light-red; in alternating beds; has caliche in 70- to 75- and 93- to 95-ft zones	26	95
Clay, sandy; has silt beds containing a few basalt chips; has caliche in 114- to 125-ft zone	40	135
Clay, silt, and sand beds; has some intermixed gravel and chips	15	150
Clay, silt, and sand beds	15	165
Clay, sandy, and silt beds; contains basalt chips	5	170
Clay, reddish-brown	4	174
Clay, yellow, sandy; contains gravel up to 2 in. in diameter at 190- to 192-ft depth	18	192
Silt, brown, sandy; has a few 1-ft-thick gray sand beds	12	204
Silt, tan, sandy; contains some rock chips	3	207
Sand, brown, silty	3	210
Sand and silt; contains caliche	25	235
Sand and silt; contains basalt chips	14	249
Clay, plastic, sandy, and a few sandstone and shale beds; water level was 75 ft, but bailing lowered water level 35 ft	21	270
Ringold Formation—Continued		
Clay, blue; contains embedded gravel; a white sandy clay bed occurs at 272- to 274-ft depth	5	275
Clay, green; contains fine gravel	5	280
Clay, blue-black, semi-indurated; has a 1-ft-thick shale stratum at 299–300 ft; water shut off by casing	45	325
Shale, gray-black, hard	15	340
Shale, green; contains black and white clay beds and white sand beds containing basalt chips	15	355
Basalt of the Columbia River Group:		
Basalt, vesicular; in part decomposed; at 365-ft depth, the depth to water was 325 ft	15	370
Ash, sand, blue clay, shale, and gravel interbeds; water rose to ½ ft above land surface when drilling was at 380-ft depth	11	381
Basalt, black	5	386

TABLE 3. *Analyses of waters from the Hanford Reservation*

[Chemical constituents in milligrams per liter]

Well No.	Date of collection	Temperature (°F)	Temperature (°C)	Total dissolved solids at 180°C	Silica (SiO_2)	Iron (Fe) when analyzed	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Boron (B)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness as $CaCO_3$ (calculated)	pH	Percent sodium	Specific conductance (micromhos at 25° C)	Radium activity based on radon measurement (curie/liter)[1]	Beta-gamma activity in dry residue (curie/liter)[1]
10/26-11D1	Mar. 24, 1959			270	51	0.68	38	21	13	4.8	......	176	43	7.5	0.2	4.5	[2]182	7.7	....	397	....	....
10/28-17B1 (USGS 12)[4]	June 15, 1951			119	18	.05	9.2	3.8	25	4.8	0.06	[3]90	2.1	10	1.0	.3	39	9.2	55	206	1×10⁻¹²	100×10⁻¹²
11/26-3G1 (USGS 3)	Aug. 13, 1951			168	24	2.7	23	11	12	4.6	......	126	20	5.9	.4	1.8	103	8.0	19	258	1×10⁻¹²	100×10⁻¹²
11/26-5B1 (USGS 4)	Aug. 14, 1951			202	41	5.2	30	10	12	4.6	......	143	22	4.5	.4	1.7	116	8.2	18	270	1×10⁻¹²	100×10⁻¹²
11/26-34R1	Mar. 24, 1959			146	38	.02	22	9.8	7.1	2.1	......	111	11	3.2	.2	4.7	95	7.5	....	216	....	....
11/27-2Q1 (USGS 5)	June 14, 1951			212	22	.10	37	8.3	17	8.0	.07	147	33	8.0	.2	5.8	126	7.9	21	321	1×10⁻¹²	100×10⁻¹²
11/27-5Q1 (USGS 2)	do			223	25	.03	39	9.0	17	6.1	.03	151	40	6.5	.3	5.5	134	7.9	21	343	1×10⁻¹²	100×10⁻¹²
11/27-20M1 (USGS 7)[4]	June 15, 1951			245	46	.06	36	9.9	17	10	.04	162	40	6.1	.3	.1	130	7.9	20	343	1×10⁻¹²	100×10⁻¹²
11/27-26D1 (USGS 6)	May 16, 1951			260	31	.03	39	11	29	9.1	.06	199	15	26	1.0	1.0	143	7.4	29	418	1×10⁻¹²	....
11/28-17D1 (USGS 8)	May 15, 1951			222	31	.04	36	10	16	6.9	.01	158	33	7.0	.4	4.3	131	7.5	20	338	1×10⁻¹²	300×10⁻¹²
11/28-29N1 (USGS11)	Sept. 12, 1951			194	24	.04	29	7.6	20	7.2	......	136	32	6.0	.5	.8	104	8.0	28	281	1×10⁻¹²	100×10⁻¹²
12/25-3D2 (USGS 13)	Feb. 5, 1953			133	4.3	.01	22	6.1	14	3.9	.04	80	31	11	.3	1.4	80	8.3	26	182	0.43×10⁻¹²	100×10⁻¹²
12/25-29NE¼[5]	Sept. 12, 1960			154	36	.03	22	10	7.2	1.7	......	114	11	2.8	.3	4.5	96	7.8	....	221	....	....
12/26-25Q1 (USGS 1)	Aug. 19, 1953			200	20	.01	34	9.6	16	6.8	.06	150	32	7.2	.1	.8	124	8.2	21	318	....	....
12/28-18D1 (USGS 10)	Sept. 12, 1951			170	10	.19	28	8.8	17	7.7	......	145	30	6.8	.3	.3	106	7.8	24	284	1×10⁻¹²	100×10⁻¹²
12/28-31H1 (USGS 9)	Feb. 6, 1953			233	30	.02	42	10	13	4.8	.02	149	35	8.4	.3	16	146	7.8	....	351	....	....
	June 10, 1953			244	19	.0	47	9.5	14	5.2	.12	158	34	11	.3	14	156	7.6	16	374	0.61×10⁻¹²	100×10⁻¹²
13/25-1N2	Sept. 21, 1953	130–78	54–25	216	39	.05	19	11	22	11	.05	143	23	8	.4	0	93	7.6	....	296	....	....
13/25-7M1	Sept. 2, 1953	60	16	128	25	.03	26	6.7	3.5	1.8	......	100	15	1.5	.2	1.1	92	7.5	....	191	....	....
13/25-30G1 (McGee)	Dec. 1, 1951	81	27	225	62	.02	17	9.4	30	9.9	.05	181	1.6	4.8	.6	.1	81	7.8	41	277	1×10⁻¹²	100×10⁻¹²
	Sept. 2, 1953	87	30	216	64	.05	18	10	30	6.3	......	180	2.1	5.2	.7	.2	86	7.7	....	289	....	....
	Oct. 28, 1954	84	29	214	67	.04	17	9.4	30	7.7	......	178	2.1	5.1	.6	0	81	7.4	....	291	....	....
	Oct. 24, 1956	70	24	207	62	.05	17	9.3	30	8.2	......	178	.4	4.8	.7	.2	81	8.0	....	286	....	....
13/26-5D2	Oct. 3, 1952			181	34	.02	31	9.7	9.3	4.9	.05	144	16	2.7	.2	2.1	117	7.8	14	266	7.68×10⁻¹²	100×10⁻¹²
13/26-13R2	Apr. 6, 1954	64	18	202	39	.00	23	10	23	4.8	.06	150	18	3	.5	4.5	98	8.2	....	292	....	....
13/27-16G1	Oct. 25, 1956	58	14	431	36	.01	77	20	34	6.6	......	239	113	22	.3	6.0	274	7.7	....	647	....	....
14/25-1D1	Aug. 7, 1952[6]	70	24	265	75	.22	12	4.5	47	19	......	157	25	9.7	.4	1.1	48	7.9	....	330	....	....
	Oct. 28, 1954	82	28	229	61	.16	24	9.3	20	12	......	142	27	6.2	.5	.1	98	7.7	....	291	....	....
	Oct. 28, 1959			228	59	.00	28	11	19	6.0	......	154	21	5.2	.3	1.9	114	7.7	....	310	....	....
14/25-21B1	Sept. 3, 1953	65	18	243	70	.05	28	11	22	6.5	......	155	26	7.0	.4	2.2	115	7.8	....	319	....	....
	Oct. 28, 1954	70	24	250	69	.02	28	11	21	6.7	......	156	25	7.4	.3	1.8	115	7.6	....	313	....	....
	Jan. 7, 1958	72	22	239	50	.07	30	9.6	21	6.4	......	154	23	7.0	.3	2.0	114	7.8	....	318	....	....
	Mar. 24, 1959			232	67	.03	30	9.8	20	6.9	......	157	24	7.2	1.0	2.1	115	7.8	....	324	....	....
14/25-31N1	Sept. 3, 1953	65	18	184	43	.02	25	11	11	5.5	......	127	24	4.0	.3	3.8	108	7.8	....	262	....	....
14/27-24C1	Mar. 23, 1959			316	64	.07	7	.8	80	26	......	216	28	12	1.2	.1	20	8.1	....	451	....	....
	Oct. 28, 1959	86	30	322	63	.00	7	.4	80	26	......	216	28	12	1.2	.5	19	8.0	....	457	....	....
15/27-32E1	Oct. 28, 1954	62	17	231	54	.29	21	8.8	26	12	......	146	25	5.8	.6	.1	89	7.9	....	298	....	....
15/27-34L2	Jan. 7, 1958	71	22	262	57	.07	13	6.0	40	18	......	152	26	8.2	.4	2.5	57	7.8	....	330	....	....
	Mar. 24, 1959			249	73	.02	14	6.1	35	19	......	150	27	7.5	.5	2.7	60	7.6	....	327	....	....

[1]To convert to microcuries per milliliter, multiply by 1,000.
[2]Includes 38 mg/l noncarbonate hardness.
[3]HCO_3 includes 16 mg/l CO_3.
[4]Sample from basalt aquifer.
[5]Rattlesnake Spring.
[6]Sample taken during drilling and before pumping and developing.

U. S. GOVERNMENT PRINTING OFFICE : 1972 O - 478-552