UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

GEOLOGY AND HYDROLOGY OF RADIOACTIVE SOLID-WASTE BURIAL GROUNDS AT THE HANFORD RESERVATION, WASHINGTON

Open File Report 75-625

Prepared in cooperation with the Energy Research and Development Administration (formerly the U.S. Atomic Energy Commission)

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Abstract

The geology and hydrology of radioactive solid waste burial grounds at the Hanford Reservation were investigated, using existing data, by the U.S. Geological Survey as part of the waste management plan of the Richland Operations Office of the Energy Research and Development Administration. The purpose of the investigation was to assist the operations office in characterizing the burial sites as to present environmental safety and as to their suitability for long-term storage (several thousand to tens of thousands of years) of radioactive solid wastes.

The burial ground sites fall into two classifications: (1) those on the low stream terraces adjacent to the Columbia River, mainly in the 100 Areas and 300 Area, and (2) those lying on the high terraces south of Gable Mountain in the 200 Areas. Evaluation of the suitability of the burial grounds for long-term storage was made almost entirely on hydrologic, geologic, and topographic criteria. Of greatest concern was the possibility that radionuclides might be leached from the buried wastes by infiltrating water and carried downward to the water table.

The climate is semi-arid and the average annual precipitation is 6.4 inches at the Hanford Meteorological Station. However, the precipitation is seasonally distributed with about 50 percent occurring during the months of November, December, January, and February when evapotranspiration is negligible and conditions for infiltration are most favorable. None of the burial grounds are instrumented with monitoring devices that could be used to determine if radionuclides derived from them are reaching the water table.

Burial grounds on the low stream terraces are mainly underlain by permeable materials and the water table lies at relatively shallow depths. Radionuclides conceivably could be leached from these burial grounds by percolating soil water, and radionuclides might reach the Columbia River in a relatively short time. These sites could also be inundated by erosion during a catastrophic flood. For these reasons, they are judged to be unsuited for long-term storage. Local conditions at several of these burial grounds are particularly unfavorable from the standpoint of safety. Depressions and swales at some burial grounds, such as numbers 4 and 5 in the 300 Area in which runoff can collect, enhance the possibility of water infiltrating through the buried wastes and transporting radionuclides to the water table. Also, during a high stage of the Columbia River, the water table conceivably could rise into burial grounds 1 and 2 of the 100 F Area. Most of the burial grounds on the low terraces contain either (1) reactor components and related equipment bearing activation products, principally cobalt-60, or (2) less hazardous radioactive materials such as uranium. The inventory of activation products in these burial grounds will decay to a safe level in a relatively short period of time (about 100 years), according to estimates made by C. D. Corbit, Douglas United Nuclear, Inc., 1969. The inventory of radionuclides is not considered by the ERDA staff to be complete, however. At these burial grounds containing activation products or less hazardous materials, investigations should be made of the radioactivity in soil and ground water beneath selected representative sites to verify that radionuclides are not migrating from the burial grounds. If migration is detected, field investigations should be made to determine the source or sources of the radionuclides and the desirability of removing the source wastes.

Other burial grounds on the low terraces contain plutonium and fission products, which require long-term storage. Both the 300 WYE and the 300 North burial grounds are reported to contain plutonium in large quantities. Burial ground no. 1 in the 300 Area reportedly also contains plutonium. The inventory records of any other burial grounds on the low terraces suspected of containing plutonium should be reviewed to determine if plutonium could be present in large enough quantities to be hazardous should it reach an uncontrolled part of the environment. Any plutonium present in hazardous quantities in these burial grounds should be removed as its long-term containment is not assured.

Two filled burial pits in the 213 Area south of Gable Mountain contain plutonium. The pits may be subject to erosion and, in addition, plutonium could migrate from them through the ground-water system. The plutonium should be removed from these pits.

The burial grounds on the high terrace in the 200 Areas are underlain by considerable thicknesses of low permeability material and the water table is at a depth of 200 feet or more. Vadose water movement is slow beneath these burial grounds, and the soil and some near-surface deposits have a large capability for ion exchange that would delay the movement of radionuclides. However, these burial grounds contain plutonium and fission products in such large quantities that containment would be necessary for several thousands or hundreds of thousands of years before the activity decays to a safe level. The suitability of these sites for such long-term storage has not yet been determined. Definitive information is needed on water movement and radionuclide transport through the soil and other earth materials beneath the burial grounds. Such information would be difficult and expensive to obtain owing to the complexities of measuring unsaturated flow in, and sorptive properties of, natural porous media. Because it is possible that these sites may be suitable for long-term storage and as removal of waste materials from these burial grounds would be extremely costly, further studies are warranted. It is suggested that the environmental studies that are planned in connection with the long-term tank storage of high-level wastes in the 200 Areas be broadened to include an appraisal of the suitability of the solid-waste burial grounds for long-term storage.

GEOLOGY AND HYDROLOGY OF RADIOACTIVE SOLID WASTE BURIAL GROUNDS AT THE HANFORD RESERVATION, WASHINGTON

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Introduction

Large volumes of solid radioactive wastes are buried within designated burial grounds in the Hanford Reservation. Most of the burial grounds are within the 100, 200, and 300 facilities areas shown in figure 1. A few, such as the 300 WYE and 300 North burial grounds, are remote from the main facilities areas. The burial grounds typically are rectangular-shaped areas in which a series of trenches were excavated to receive the wastes, which were then covered with soil materials. A few special type facilities for storing solid wastes are also discussed in this report. The wastes consist of process wastes and trash from plant operations, laboratory wastes of many types, scrapped equipment, and some liquids that were packaged. Radionuclides present in the wastes are varied, according to Karagianes (1972). Important ones from the standpoint of the volume of wastes containing them are:

(1) the transuranium element, plutonium, and the fission products strontium-90 and cesium-137, obtained mainly from processing of irradiated fuel elements, plutonium fabrication, and laboratory work;

(2) uranium and thorium from reactor fuel fabrication; and

(3) activation products, mainly cobalt-60, in scrapped equipment that has been irradiated in reactors and fuel separation plants.

The Richland Operations Office of the Energy Research and Development Administration (formerly Atomic Energy Commission) (ERDA) as part of its waste-management plan is making an overall evaluation of solid waste disposal that will include a characterization of the burial grounds as to their suitability for the long-term storage of solid radioactive wastes (several thousands to tens of thousands of years).

This report gives the results of an examination made by the U.S. Geological Survey of the hydrology and geology of solid waste burial grounds in support of ERDA's evaluation of their suitability for long-term storage of radionuclides. It stresses the geohydrology pertaining to the burial grounds, because the principal mechanisms by which radionuclides can leave the burial grounds appear to be transport in water percolating through the ground. The study was financed by the Richland Operations Office and was done from December 1972 to June 1973. It made use of existing data from previous investigations by AEC contractors and the U.S. Geological Survey on geology, ground-water hydrology, and radionuclide concentrations in ground water. No new data were collected. Except for field inspections of the solid radioactive waste burial grounds, the entire effort consisted of synthesizing and presenting as complete a description of the geohydrology as was possible from the available data.

In order to compile the illustrations in this report, it was necessary to examine a large number of engineering drawings for locations of burial grounds and facilities and for detailed topography of the sites. A list of pertinent Hanford engineering drawings is given in Appendix I. One of the difficulties in determining locations at the Hanford Reservation is that four separate coordinate systems have been used for surveying facilities--the Hanford plant, 100 K, 100 N, and Richland coordinates. The Hanford plant coordinate system is the system most extensively used. Conversion factors for translating coordinates in each of the other systems to the Hanford plant coordinates were obtained from Paul F. Pritchard, Vitro Engineering Division, who is responsible for field surveys, so that all locations could be referred to the Hanford plant coordinate system. Figure 2 of this report shows the Hanford plant coordinates in relation to the land nets of the U.S. Geological Survey 1:62,500-scale topographic maps. The cross sections showing the geohydrology of burial sites were compiled from well data supplied by Battelle Northwest Laboratories and from data in the report by Newcomb, Strand, and Frank (1970).

Geography

The Hanford Reservation occupies about 560 square miles in south-central Washington between latitudes 46°15' and 46°45'N and longitudes 119°10' and 119°45'W. The larger part of the reservation, in which all major facilities are located, lies south and west of a large bend of the Columbia River through a river length of about 45 miles. Most of the Hanford Reservation is on river terraces of low relief between altitudes of about 350 to 800 feet. The reactors (100 Areas) and fuel fabrication plant (300 Area) are on low terraces near the river. The fuels reprocessing plants (200 Areas) are on higher terraces near the center of the Reservation. Gable Mountain, which rises to an altitude of 1,125 feet, and Gable Butte are the only features of strong relief other than the hills fringing the Reservation. Figure 2 shows the topography of the Hanford Reservation and the surrounding area.

The climate of the Hanford region is semi-arid with a wide seasonal range of temperature. At the Hanford Meteorological Station (fig. 1) precipitation averages 6.4 inches per year. The heaviest rainfall of record was 1.68 inches during a 6-hour period in October 1957. According to a climatological analysis provided by Washington Public Power Supply Corp. (written communication, 1973), about 50 percent of the average annual precipitation has been distributed through the four months of November, December, January, and February, when temperatures are lowest and evapotranspiration is negligible. The maximum observed depth of snow on the ground during these months is 12 inches. November and December are the wettest months, each having average precipitations of almost 0.9 inch. July and August are markedly drier than the other months of the year, each having average precipitations of about 0.15 inch. Temperatures during any one year generally range from below 0°F to above 100°F. Mean daily temperatures for the winter months are about 32°F and for the summer months about 74°F.

The only large communities in the immediate environs of the Hanford Reservation are Richland, about 3 miles to the south on the west bank of the Columbia River, and the downstream neighboring communities of Kennewick and Pasco. The Tri-Cities area encompassing these communities has a population of about 70,000. The operations at the Hanford Reservation comprise the most important industrial enterprise of the Tri-Cities. Other industries are food and meat processing and light manufacturing. North of Pasco and to the east and north of the Columbia River, irrigated farming is practiced widely on lands developed as part of the U.S. Bureau of Reclamation's Columbia Basin Irrigation Project. Farms are relatively small and the farming population is relatively large. Southwest of the Hanford Reservation, in the Yakima River Valley, irrigated farming is also practiced. South of the Yakima River Valley, in the Horse Heaven Hills, population is sparse and dryland wheat farming and grazing are the important economic activities.

Geomorphology and General Geology

The Hanford Reservation is in the Columbia Plateaus physiographic province, which is formed by a thick accumulation of basaltic lava flows that extend from central Washington eastward into Idaho and southward into Oregon. In south-central Washington, the lava flows have been deformed, giving rise to a broad basin, the Pasco Basin, in which the Hanford Reservation lies. The Pasco Basin is bounded on the west by uplands formed by a series of eastward- and southeastward-trending ridges, which rise to altitudes of 2,000-3,000 feet (fig. 2). Umtanum and Yakima Ridges terminate at the western margin of the Pasco Basin. The Saddle Mountains and Rattlesnake Hills persist eastward from this upland and form the northern and southwestern borders of the basin, respectively. The Rattlesnake Hills end at the Yakima River, about 5 miles north of Benton City, but their topographic trend is continued by a southeasterly trending line of hills, which include Red and Badger Mountains, and which mark the border of the basin. This line of hills merges with the Horse Heaven Hills south of Kennewick. The eastern margin of the Pasco Basin is not strongly delineated by topographic features. The basin merges to the east of the Columbia River with a broad southwestward-dipping monocline that extends into east-central Washington.

Drainage from the region is entirely through the Columbia River, which flows generally southeastward to Wallula Gap and then makes a broad turn through the Horse Heaven Hills and flows westward to the Pacific Ocean. The Yakima River is the only other perennial stream in the immediate vicinity of the Hanford Reservation, which it closely approaches at Horn Rapids. The Yakima flows southeastward from there into the Columbia River south of Richland.

The Pasco Basin, in common with the rest of south-central Washington, is underlain by the Yakima Basalt of the Columbia River Basalt Group of Miocene and Pliocene age. Successively overlying the Yakima Basalt are the Ringold Formation of Pleistocene age and glaciofluvial deposits of Pleistocene age. Figures 3, 4, 5, 6, and 7, which are diagrammatic geologic cross sections, show the relationships of these geologic units in the region. Lines of section are shown in figure 2.

The Yakima Basalt consists mainly of basaltic lava flows, 10 to 200 feet in individual thicknesses. Intercalated between some flows, particularly in the upper part of the formation, are volcanic ash, palagonite, and some sedimentary rocks. The thickness of the formation is probably about 4,500 feet in the Pasco Basin. Underlying it are about 6,000 feet or more of older rocks of the Columbia River Basalt Group. More information on the lithology of the Yakima Basalt at the Hanford Reservation is available in Newcomb, Strand, and Frank (1972, p. 8); Bingham, Londquist, and Baltz (1970); and La Sala and Doty (1971, pp. 10-17).

The Ringold Formation overlies the Yakima Basalt. The formation consists of nearly horizontal beds of silt, sand, clay, gravel, and a little volcanic ash. The most common type of material is weakly lithified siltstone in beds up to 10 feet thick, with some interbedded fine sand. Detailed descriptions of the formation are given by Newcomb, Strand, and Frank (1972, pp. 10-15). The stratigraphic thickness of the Ringold may be as much as 1,200 feet. Actual thickness varies greatly depending on configuration of the basalt surface and the history of deposition and erosion.

Three distinct lithologic zones have been defined in the Ringold Formation.

(1) The lowermost unit is the so-called "blue-clay" zone, which consists mainly of silt and clayey silt and which

may be as much as 300 feet thick. This unit contains some interbedded gravel and sand, which at places predominates over the silt.

(2) The middle unit is a conglomerate, which may be as much as 400 feet thick. It generally consists of weakly cemented gravel composed of well-rounded pebbles and cobbles in a matrix of fine to medium sand. Beds of sand also are common within the gravel.

(3) The uppermost unit, which has a stratigraphic thickness of about 500 feet, consists of the bedded sand, silt, and clay exposed at the type locality in the White Bluffs at Ringold. The uppermost unit has been largely eroded away from the main part of the Hanford Reservation east of the Columbia River.

Overlying the Ringold Formation are glacial stream and lake deposits of late Pleistocene age called glaciofluvial deposits in this report as the stream-laid deposits predominate. Recent stream deposits of the Columbia River overlie the glaciofluvial deposits. They are not sufficiently thick or different in character from some of the glacio-fluvial deposits to warrant differentiation in this report. Also over-lying the glacial deposits is dune sand, which occupies large areas in the southern half of the reservation and, at places, loess, a windblown cover of silt.

The glaciofluvial deposits of late Pleistocene age are predominantly stream-laid lenticular beds of granule and pebble gravel, cobble gravel, and some boulders (Newcomb, Strand, and Frank, 1972, p. 16). The gravel generally is openwork, and only locally has a sandy matrix. Sand, generally coarse, also occurs in separate beds and lenses. Silt and fine sand of a lacustrine facies (Touchet Beds of Flint, 1938) occur within or on the gravel deposits at places, mainly in the western part of the reservation.

The major geologic structural features of the Hanford Reservation are developed in the basaltic rocks. The Pasco Basin is an extensive downwarping of the basalt having two main elements, the Pasco and Cold Creek synclines (Newcomb, 1970). These synclines are separated by the anticline forming Gable Mountain. The ridges and hills bounding the Hanford Reservation are all formed by tightly folded anticlines which have undergone little erosion. Bingham, Londquist, and Baltz (1970) and Newcomb, Strand, and Frank (1972) discuss the structural features of the basalt in detail.

Deformation of the basalt probably was still occurring during deposition of the Ringold Formation. The lowermost unit ("blue clay") was deposited in a lake, which formed in the sagging Pasco Basin. An interval of stream deposition followed in which the middle (conglomerate) unit was laid down on the lower lake deposits which had filled the lake. Further subsidence of the basin or uplift of its margins again led to lake conditions in which the uppermost unit was laid down. Newcomb, Strand, and Frank (1972, p. 15) note that the lower and middle units of the Ringold are warped whereas the upper unit is underformed.

The glaciofluvial deposits were laid down following a period of erosion by the ancestral Columbia River in which the upper part of the Ringold Formation was removed from the main part of the Reservation. This accounts for the later glaciofluvial deposits lying at lower altitudes than the upper part of the Ringold, which forms the White Bluffs east of the Columbia River. The source of the melt water and much of the sediment, which came down the Columbia River channel, was a lobe of the last ice sheet, which lay in the Okanogan Valley 100 to 150 miles to the north of the Reservation. This interval of erosion and glaciofluvial deposition probably spanned the period from about 60,000 to less than 9,000 years ago. Newcomb, Strand, and Frank (1972, pp. 16-18) give an explanation of the glacial history of the Reservation.

Hydrologic Characteristics

The hydrology of the Hanford Reservation is marked by these salient features:

(1) Very low precipitation and high summer temperatures, which lead to soil moisture deficiencies and a resulting low rate of ground-water recharge by direct infiltration.

(2) A large ground-water reservoir in the Ringold Formation and glaciofluvial deposits.

(3) Uplands to the west of the Reservation from which runoff recharges the ground-water reservoir.

(4) The Columbia and Yakima Rivers, through which runoff from Canada and mountainous areas of Washington and Idaho cross the Reservation.

Infiltration

The surficial materials of the Hanford Reservation are sand and gravel of the fluvial and glaciofluvial deposits, dune sand, and fine sand or silt of the lake deposits or loess. On Gable Mountain and on the ridges surrounding the Reservation, there are large areas of bare or thinly covered basalt, much of which is fractured. In general, the surface materials of the region generally are capable of receiving direct infiltration from precipitation at a high rate, particularly on the flat landscape of the main part of the Hanford Reservation. Much of the precipitation that falls on the Hanford Reservation doubtless infiltrates directly, but probably is used mainly to replenish deficiencies in soil moisture at relatively shallow depths, which result mostly from sparse precipitation and a high rate of evapotranspiration during the summer months.

The amount of infiltration and the depth to which water will percolate under the various conditions occurring at the Hanford Reservation are not known. Some field studies of soil (vadose) water movement have been undertaken by Battelle Pacific Northwest Laboratories in recent years, notably the installation in 1970 of a 310-foot-deep well instrumented with soil psychrometers; and 2 lysimeters, about 60 feet in depth, in 1971. (See, for example: Hsieh, Warner, and Rising, 1972; Hsieh, 1972b; Reisenauer, 1972; for discussions and data.) The term "soil" in the following discussion of infiltration is used in the sense preferred by the cited authors to mean all unsaturated materials above the water table. These installations are at a site about 2 miles southeast of the 200 East Area which is underlain by fine-grained lake deposits, where the depth to the water table is about 300 feet. The lysimeters are about 8 feet in diameter and are cased. One of them, called the closed lysimeter, has a steel plate in the bottom to prevent upward or downward movement of water. It is the authors' understanding that the investigators hoped to distinguish any upward flux of water through the soil by a comparison of the records from the two lysimeters. It was theorized that the soil in the closed lysimeter should be drier than that in the open lysimeter if the flux of soil water is mainly upward. The soil below a depth of 20 feet in the closed lysimeter has been drier than that in the open lysimeter, since soil moisture measurements were begun in March 1972. However, the data from the lysimeters must be interpreted in detail within the overall framework of the zone of aeration, water table, structure of the lysimeters and of the replaced soil in them, the initial moisture content of the soil that was replaced, and the weather conditions. For example, the suction, or soil-moisture tension, that develops in a soil depends partly on the depth to the water table. It can be expected, therefore, that the open and closed lysimeters by reason of their construction will develop different soil moisture tensions that will cause water to move differently in each of them.

The studies have been handicapped by difficulties with field instruments, uncertainties about laboratory column studies designed to determine soil parameters, and difficulties in restoring soil materials in excavated holes. Theories of soil moisture movement are also inadequate for analyzing the data that have been collected. For the instrumented site, Hsieh (1972a) computed a downward water flux of 0.022 mm/yr due to gravity and the psychrometric gradient (matric potential), and an upward flux of 0.019 mm/yr due to the thermal gradient for a net downward Darcian flux of 0.003 mm/yr. (Darcian flux here is in terms of millimeters of water, not actual flow distance.) However, Hsieh states that other investigators have indicated that the method used for computing thermal flow may give results that are too low by one or two orders of magnitude. He points out that if the computed thermal flux is increased by an order of magnitude the net flux would be 0.108 mm/yr and in an upward direction. It would appear, therefore, that the present theoretical approaches to the analysis of the soil moisture data are inadequate even for determining the direction of movement.

Changes in relative moisture content from February 1971 to December 1971 were investigated by Hsieh (1972a) for soils in the deep well instrumented with soil psychrometers for depths from 13-310 feet. He used psychrometric data obtained at the well and laboratory determinations of soil parameters as a basis for his computations. The soil moisture was computed to have remained unchanged at 15 depths, was reduced to 14 depths, and was wetter at 4 depths. These computed changes did not occur in any consistent pattern. The wetter zones for instance were at depths of 15, 90, 130, and 240 feet. It would appear from these calculated results that either the psychrometric measurements in the well or the soil parameters measured in the column studies, or both, are not accurate enough to present a consistent picture of soil moisture movement at the low moisture contents, low hydraulic conductivities, and velocities existing in the soil at the instrumented site.

Infiltration on lower terraces near the river is a different matter than on the high terraces where the 200 Areas are located. The depth to water table beneath the low terraces is much less and the materials in the unsaturated zone are generally coarser than they are in the 200 Areas. Infiltration in the areas of low terraces probably does produce some recharge to the ground-water body, mainly in times of high precipitation or a snow melt when local runoff can collect in depressions or swales. Newcomb, Strand, and Frank (1972, p. 28) report that the records of water-level fluctuations in wells indicate that there have been no appreciable accretions to the ground-water body by this mechanism. However, the water level fluctuations in wells in the low terraces on the reservation are dominated by liquid waste disposal and water that enter the ground-water reservoir from the Columbia River. Unless accurate, continuous water-level records are obtained on an intensive basis in carefully selected wells together with soil moisture and matric potential measurements, accretions to the ground-water body from direct infiltration are not likely to be recognized.

In general, infiltration at the Hanford Reservation is small in amount, but probably is a large percentage of the precipitation, because

(1) much of the precipitation occurs in the winter months when temperatures are low and evaporation is negligible, (2) the land surface is underlain by permeable materials that encourage infiltration, and (3) runoff is negligible because of the low land slopes, depressions, and flat-bottomed swales. Studies of infiltration have not been made until recent years and are presently restricted to the high terrace where the 200 Areas are located.

Runoff

Runoff from the reservation itself is negligible, but the upland areas to the west of the Hanford Reservation do provide some runoff. Most of this runoff occurs in Cold and Dry Creeks. Newcomb, Strand, and Frank (1972, p. 28) estimate the average annual flows of these streams as 600 acre-feet (0.83 cfs) and 200 acre-feet (0.28 cfs), respectively. Runoff through Cold Creek rarely reaches the Reservation. The flow through Dry Creek rarely extends beyond Rattlesnake Springs in the western part of the Reservation. A flash flood at Rattlesnake Springs reached a peak flow of about 200 cfs in March 1952, as reported by Newcomb, Strand, and Frank (1972, p. 28).

The Columbia River carries mainly runoff from Canada and the mountainous areas of Washington and Idaho and has a mean annual flow of 120,000 cfs. Water is diverted from the Columbia at Coulee Dam, 150 miles north of the Reservation, to provide an irrigation supply to the U.S. Bureau of Reclamation's Columbia Basin Irrigation Project. This water is sent southward through Grand Coulee and an irrigation canal network through lands lying east of the Columbia. The most southerly of these irrigated lands are just north of Pasco. Some irrigation waste water is returned to the Columbia River in its course through the Hanford Reservation along its east bank through waste ways and by seepage from the ground.

The Yakima River carries runoff originating mainly on the eastern flank of the Cascade Mountains. The river is intensively developed for irrigation. Flow near the Reservation at Kiona (Sec. 20, T9N, R27E) generally averages 2,000-4,000 cfs annually.

Occurrence of Ground Water

Ground water in the Hanford region occurs in interflow zones and fractures in the basaltic rocks under artesian conditions, and in intergranular openings in the glaciofluvial deposits and Ringold Formation mainly under water-table conditions.

In the Yakima Basalt, the most permeable water-bearing units are thin zones of rubbly or fractured rock along the contracts of basalt flows and sediments interbedded with basalt flows. The interiors of individual flows, even though fractured, are of low permeability. This contrast in hydraulic properties leads to confinement of ground water in the basalt and encourages movement parallel to the dip of the rocks. In figures 3-7, it can be seen that confinement of water in the basalt also results in the water levels in wells tapping the basalt standing at altitudes different than those of the water table at any particular location. Water-bearing properties of the basaltic rocks and measurements of hydraulic conductivities are discussed in detail by La Sala and Doty (1971, pp. 22-49) and La Sala, Doty, and Pearson (1973, pp. 17-26).

In the Ringold Formation the most permeable deposits are composed of sand and gravel. The clayey silt and fine sand phases of the formation are much less permeable. Bierschenk (1959) indicates that the hydraulic conductivity of the Ringold Formation on the Hanford Reservation ranges from about 1 foot per day for the finest grained deposits to about 80 feet per day for the coarse-grained deposits.

The glaciofluvial deposits contain the most permeable water-bearing materials. Bierschenk (1959) indicates that hydraulic conductivities may exceed 6,500 feet per day in the openwork gravels. They are considerably less for the fine-grained lake deposits, however.

Ground-Water Recharge and Discharge

Natural recharge to the unconsolidated deposits and the Yakima Basalt occurs from precipitation that infiltrates the ground directly and from runoff that infiltrates in stream channels, such as occurs in Cold and Dry Creeks. At the Hanford Reservation water also enters the ground-water reservoir from the Yakima River downstream from Horn Rapids and from the Columbia River at times of high stages. The annual range of stage of the Columbia is about 20 feet, with the highest stage occurring in the late spring. Water from the Columbia enters the ground in large quantities in the main part of the Hanford Reservation, which causes a rise in ground-water levels in the unconsolidated deposits 2 or more miles from the river (Newcomb and Brown, 1961; Newcomb, Strand, and Frank, 1972, pp. 26-28, figs. 3 and 4; Tillson, Brown, and Raymond, 1969).

Natural recharge in the main part of the Hanford Reservation and in the Columbia Basin Irrigation Project is greatly overshadowed by artificial recharge by waste water pumped originally from the Columbia River. Discharge to the ground of cooling and waste water from fuel reprocessing plants in the 200 East and 200 West Areas have been as great as 2,000 and 4,000 gallons per minute (gpm), respectively, for extended periods of time. Large discharges of cooling water in connection with treatment of wastes in evaporators are planned. Veatch (1971) discusses this anticipated discharge and summarizes information on past discharges. The discharge of water to the ground in the Hanford Reservation has caused the buildup of large ground-water mounds beneath the 200 Areas and smaller mounds in the reactor areas and the 300 Area.

The highest recharge mound is beneath the 200 West Area. This has been built up by water from disposal ponds which entered the ground at the following rates: 0.8 billion gallons per year (bg/yr) from 1945 to 1950, 3.3 bg/yr from 1951-1955, a declining rate of from 2.4 bg/yr to 1.5 bg/yr during the period 1956 to 1959, and 1.5 bg/yr from 1960 to 1970. The water table near the center of the mound rose 25 feet between 1944 and 1951, and an additional 55 feet between 1951 and 1956. From 1956 to 1970 the height of the mound fluctuated slightly, but did rise overall to an altitude of more than 480 feet in 1967. Discharge of additional water at the rate of 1-1.2 bg/yr from evaporators designed to concentrate high-level liquid wastes would cause further growth in this cone until 1980, when the evaporators would be shut down.

On the east side of the Columbia River, ground-water levels have risen considerably from seepage into the ground of water being transported in irrigation ditches, coulees, and disposal ditches, or applied to the fields. Water levels have risen as much as 100 feet or more since 1952 in some wells finished in basalt.

The discharge of ground water in the region occurs mainly by subsurface flow into the Columbia River. Part of the large volume of water added to the ground at the 200 Areas could be discharging to the river mainly downstream of the old townsite of Hanford and to reaches of the river north of Gable Butte.

Discharge of ground water by evapotranspiration is said by Newcomb, Strand, and Frank (1972, p. 31) to be negligible within the reservation. They mention only a few places within the area of the low river terraces where the water table is close enough to the surface for evapotranspiration to be effective.

The Water Table and Ground-Water Movement

Under natural conditions, the water table in the unconsolidated deposits at the Hanford Reservation reflected the recharge received from runoff at the western margin of the Reservation, principally through Cold and Dry Creeks, and the discharge of ground water to the Columbia River. The water table was relatively high adjacent to Rattlesnake

Mountain and the two creek valleys and reached a maximum altitude of about 425 feet in the upper part of Cold Creek Valley. The slope of the water table generally was about 5 feet per mile toward the Columbia River. The water table also sloped diagonally away from the Yakima River easterly toward the Columbia River in the reach of the Yakima between the Horn and Richland, indicating that water was short circuiting through the ground from the Yakima to the Columbia. Newcomb, Strand, and Frank (1972, p. 35, pl. 1) present a map and discuss the natural water table as it was before the Reservation was developed.

On the part of the Hanford Reservation north of the Columbia River, the water table sloped southerly away from the Saddle Mountains to the Columbia River. East of the Columbia River the water table sloped southwesterly in the general direction of the land surface toward the Columbia River from recharge areas in the coulees.

With the construction of the Hanford Works and later the irrigation works of the U.S. Bureau of Reclamation on the north and east sides of the Columbia River, natural recharge was overshadowed by artificial recharge; consequently, the water table has risen and has been considerably modified in shape.

At Hanford the discharge of cooling water pumped from the Columbia River to the ground caused the buildup of ground-water mounds around disposal sites in and near the 100, 200, and 300 areas. In the 100 and 300 areas, leakage of water from detention basins had relatively local effects because of proximity to the Columbia and the relative ease with which water could move through the permeable deposits back to the river. Near the 200 Areas, however, the effects of waste discharges were much larger because the deposits are less permeable and the distance to the Columbia River is great. By January 1973, the water table had risen a net of 30 feet due to water discharged from the 200 East Area and a net of 60 feet due to discharge from the 200 West Area. The water table has been considerably modified from its natural shape in the central and western parts of the Hanford Reservation. A recent water-table map prepared by Battelle Pacific Northwest Laboratories is shown in figure 8.

The movement of ground water in the unconsolidated deposits is in the general direction of the slope of the water table. In general, the movement of water from a particular location can be traced as a smooth flow line that proceeds to an area of discharge by crossing normally water-table contours of successively lower altitude. A water-table map is a valuable tool for predicting flow paths of ground water. However, water-table maps should not be considered as precise representations of the water table. At the Hanford Reservation, water levels are monitored in an exceptionally large number of wells but data are insufficient to show in detail the slope of the water table. In drawing any water-table map, therefore, interpretations must be made based on the best information available on the geohydrology as it controls the character of the flow system. The water-table map (fig. 8), which is drawn for January 1973, shows Gable Butte and Gable Mountain as ground-water barriers. An interesting feature of the January 1973 map (fig. 8) is the appearance of a small ground-water mound rising to an altitude of 405 feet on the north side of Gable Mountain. To the authors' knowledge, this is the first appearance of a mound in this area on a Hanford water-table map. Good evidence for it is presented by Kipp (1972, pp. 4.1-4.4). The origin of this mound may be runoff that has percolated into the ground in the low swales in the land surface at the site. Or the mound may be residual from the die away of bank storage that entered the ground from the Columbia River.

Movement of Contaminants in the Ground Water

Movement of wastes through the ground-water system reflect directions of ground-water flow. The wastes are dispersed in the ground water due to (1) the kinetic dispersion inherent in the movement of a solution through a porous medium, (2) divergence of ground-water flow paths due to variations in hydraulic conductivity of the water-bearing materials, (3) transient changes in water level due to variations in natural and artificial recharge and Columbia River stage, and (4) changes in the quantities and locations of waste discharges.

Maps showing the distribution of radionuclides and nitrate in the ground water are contained in a series of semi-annual reports. Figures 9 and 10 are maps from a late report in this series, which is currently the responsibility of Battelle Pacific Northwest Laboratories (Kipp, 1973, figs. 2 and 3). A large plume of low-level contamination spreads southeasterly and easterly from the 200 East area toward the Columbia River. Lobes on this plume apparently follow preferential directions of ground-water movement where the deposits are relatively permeable. This plume has been reported on in semi-annual reports at least since 1959. Some of the reports show this plume closely approaching Gable Mountain, but it has never been known to transgress Gable Mountain. This is further evidence that Gable Mountain is a barrier to ground-water flow as shown on the current water-table map. The waste maps (figs. 9 and 10) indicate that ground water from the 200 West area moves easterly to join with ground water flowing away from the 200 East area mound. The water table contours and waste distribution indicate that water from the 200 West area also flows northward. However, the movement is relatively slow, presumably because of the low permeability of the deposits in the vicinity of the 200 West area.

North of Gable Butte and Gable Mountain some wastes have moved generally easterly from the 100 K and 100 N areas and generally westerly and southerly from the 100 F area. Doubtless, most waste waters discharged to the ground in the reactor areas moved directly to the river during low or normal stage because all waste discharge facilities are close to the river. Some wastes would move inland because of ground-water gradients on water-table mounds created by waste-water discharge. Also, the effect of seasonal high stages in the Columbia River is to cause ground-water gradients near the river to slope away from the river periodically. As the river stage declines, ground-water gradients are reversed and slope again toward the river. Ground water can be moved toward and away from the river in a complicated way by this mechanism.

Dispersion brought about by such ground-water movement may account for the tritium in the ground water at the west end of Gable Butte. Although the tritium in the 200 Areas is not shown as being connected with the tritium north of Gable Butte and Gable Mountain, it is conceivable that tritium could move into this area by ground-water flow around the west end of Gable Butte northward through the gap between Gable Butte and Gable Mountain. The Columbia River water that enters the ground is unlikely to be the source of the tritium concentrations that are mapped. The river water has a tritium concentration on the order of 2 pico curies per mililiter (pCi/mℓ) (Bromson and Corley, 1972, p. 1), whereas wells 699-72-88, -72-92-0, -72-98, which define the extent of tritium contamination at the east end of Gable Butte have water with tritium concentrations of 20 to 30 pCi/mℓ (Kipp, 1973, p. 22).

Conditions at the Solid Waste Burial Grounds

The burial grounds and other solid waste storage sites can be divided into two categories: (1) those lying in the low terraces adjacent to the Columbia River mainly at the 100 Areas and the 300 Area, and (2) those lying on the high terrace south of Gable Mountain in the 200 Areas. The burial grounds in the first category are inactive except for 2 sites in the 100 F Area, one in the 100 K Area, and one in the 300 Area where mainly laboratory wastes are being buried, and the 100 N Area where fuel element spacers are stored. Most solid wastes are now being buried in the 200 Areas.

The waste material contents (including radionuclide activity) of the burial grounds are not well known for all burial grounds, because precise records of disposed materials were not kept until recent years. Karagianes (1972) describes the inventory of radionuclides in the solid wastes on the basis of records and indirect estimates.

Included in the present report, as appropriate, for each area containing burial grounds, are:

(1) Site maps of production areas, showing facilities, which were obtained from Vitro Engineering Division. Added to these maps by the authors were burial grounds, wells and test borings, water-table contours, lines of geologic sections and grid lines for the Hanford Plant and other special coordinate systems. These site maps, as obtained, are not accurate as to scale. They are not available for those burial grounds outside of production or laboratory areas.

(2) Plan drawings showing grid lines, burial grounds, wells, and lines of cross sections, which were used as a basis for constructing geologic cross sections.

(3) Geologic cross sections showing profiles of the land surface and water table, and the character of the geologic materials as indicated by well records.

Monitoring well data on ground-water contamination are also discussed. These data were reviewed with the intention of determining their suitability for defining the movement of radionuclides that may occur from solid waste burial grounds. Monitoring well data for the period 1967 to the present are tabulated in the Battelle Northwest files by well number and were available to the project. Prior to 1967, the data are recorded on laboratory analytical reports by sample batches. Most of the monitoring data collected prior to 1957 had been placed in permanent storage in a federal records repository at Seattle, Washington. None of these data in permanent storage was inspected. It proved impractical to follow the monitoring history of more than a few selected wells in detail through the period 1957 to the present because of the difficulty of extracting data for individual wells from the records.

Some general observations can be made on the utility of the monitoring data with regard to the solid waste burial grounds. The monitoring wells on the Reservation were constructed with the intention of detecting movement of radionuclides from cribs, swamps or sumps, and other liquid waste disposal facilities. However, with the exception of 9 monitoring wells (designated by the prefix S6-E4) near the 300 North Burial Ground, where a crib is also located, the placement of a monitoring well near a solid waste disposal site was only by happenstance, or the result of geographic proximity or superposition of solid and liquid waste disposal areas. Only about 5 wells (other than the S6-E4 and 200 Area wells) are situated so as to intercept contaminants leached from the solid waste burial grounds. It appears, however, that any contaminants that may have been leached from solid waste burial facilities are masked by the contaminants from liquid waste disposal.

At few wells was monitoring carried through a long period of time for more than one chemical constituent or type of radioactive determination.

The records are fragmentary apparently because multiple types of analyses were only continued long enough to trace the passage of a particular plume of contaminants that was anticipated to pass a well. The number of analyses was reduced as the level of concentration of the contaminant decreased. Tritium content, beta activity, and nitrate concentration are the most commonly analyzed characteristics or constituents. The detection limits of tritium and beta activity have varied over the years making comparisons within one record difficult. Tritium should be an indicator of liquid wastes from both reactor and fuel reprocessing plants. Beta activity may have either liquid or solid wastes as the source. Alpha activity, which is only selectively analyzed near some cribs, may be from either solid or liquid wastes. Nitrate in large concentrations is associated with liquid wastes, but is naturally present in the ground water in low concentrations. Some nitrate may also be present from agricultural fertilizers, used mainly prior to building of the Hanford Works. The spectrum of analytical data appears to be inadequate to define selectively the materials that may be leached from the burial grounds.

100 B Area

The 100 B Area, the most westerly of the reactor areas, is approximately centered on Hanford coordinates N70,000 and W80,000. It contains three burial grounds, one east of the 105-B reactor, one east of the 105-C reactor, and in the southwestern part of the area (fig. 11). The burial ground east of the 105-C reactor is considered terminated and is monumented. The other two burial grounds are unused but as of January 1973 were not officially considered terminated. The locations shown for these latter two burial grounds are approximate within an error of about 50 feet.

Surficial materials in the 100 B area are sand and coarse gravel and the burial grounds are backfilled with the same material. The two burial grounds east of the 105-B and 105-C reactors are on flat or gently sloping ground with no prominent surface drainage.

At the burial ground in the southwestern part of the area, individual burials are marked by concrete posts with brass identification plates. The general land slope is to the north. There are no prominent surface drainage features at or near the burial ground. A small area immediately north of the burial ground is 6-8 feet higher than the northern end of the burial ground. It is possible that runoff could accumulate on the surface at the north end of the burial ground and infiltrate into the ground.

Water-level data are insufficient to define the slope of the water table and the direction of ground-water movement. Although the figure 8 water-table shows no contours in this area, the approximate position of the 400-feet water contour is shown in figure 11. The regional direction of flow is generally toward the river in a northern or northwesterly direction. During times when the Columbia River is at high stage, bank storage entering the ground reverses the gradients and water flows away from the river.

The geologic units underlying the 100 B area along section F-F (fig. 12) are shown in figure 15.

The burial grounds are 50 to 70 feet above the water table, which lies within the glaciofluvial deposits as shown in figure 13. Except when the river is at high stages, it is probable that radionuclides carried downward to the water table by percolating soil water, would move to the Columbia River through the permeable glacial deposits. The Yakima Basalt lies at altitudes of about 100 to 200 feet below sea level. There is a 500- to 600-foot thickness of Ringold sediments including the lowest "blue clay" zone between the glaciofluvial deposits and the Yakima Basalt. It is unlikely that radionuclides from the 100 B Area burial grounds would enter the basalt in the immediate area before being discharged to the Columbia River.

Ground-water samples to monitor radionuclide concentrations were collected at wells 199-B-3-2 and 199-B-4-4. At well 199-B-3-2, 4 water samples collected in 1956-57 showed Beta activity on the order of 10^3 pCi/ℓ, which probably was the detection limit at that time. A later series of samples beginning in 1967 and collected at intervals varying from monthly, quarterly, to semi-annually, with an 18-month period of no record during 1967-69, showed maximum concentrations of about 5×10^3 pCi/ℓ which declined during 1969 and 1970 to about 10^{-2} pCi/ℓ. Several samples taken since 1962 contained 1 to 3 ppm nitrate. As this well is close to a crib and detention basins (107-B, 107-C), it is presumed that the radioactivity resulted from reactor cooling water which entered the ground. At well 199-B-4-4 Beta activity was monitored beginning in 1968. Conceivably well 199-B-4-4 could show from the burial grounds east of the reactors. However, at this well, fluctuations in Beta activity followed a similar pattern to that in well 199-B-3-2 and this would indicate that activity at well 199-B-4-4 also resulted from liquid waste discharges rather than from the burial grounds. Beta activity was at a higher level at well 199-B-4-4 (as much as 2×10^4 pCi/ℓ) than at 199-B-3-2. This difference in Beta activity may be explained either by well 199-B-4-4 also intercepting wastes originating from a leaky pipe line between the 105-C reactor and the 107-C detention basins, or by wastes discharged to a crib, a few hundred feet north of 199-B-4-4.

The monitoring data from these two wells reflect contamination only from liquid waste discharges. In addition, both wells are too far from the burial grounds to be useful in obtaining data on the possible migration of radionuclides from the solid wastes.

100 D Area

The 100 D area is approximately centered on Hanford coordinates N92,000 and W53,000 (fig. 14). Burial ground no. 1 is about 1,000 feet south of the 105-DR reactor building. Burial ground no. 2 is in the southwestern part of the area. Burial ground no. 3 is just east of the 105-DR building. Burial ground no. 4 consists of seven discrete segments, of which segments A-F are southeast of the 105-D reactor building. Segment G is south of the 105-DR building. The DR Gas Loop site south of the 105-DR building is also considered as a solid-waste burial by Karagianes (1972, fig. 14).

Surface materials at all burial grounds in the 100 D area are sand and coarse gravel, containing cobbles, with a sparse vegetation of weeds. Burial ground no. 1 is marked by monuments, and surface drainage is east and northeast to a swale southeast of the 105-DR building. Burial ground no. 2 is monumented. Its surface is smooth to gently rolling and has no prominent drainage features. Water could collect in subtle depressions on the surface. In general, surface drainage from burial grounds no. 3 and 4 would be southerly to a swale southeast of 105-DR building. Within burial ground no. 3 are bladed-up mounds of soil and an apparently active trench at its east end.

The water-level data for 2 wells in the area indicate that the water table slopes northerly (fig. 16). Ground water that receives any radionuclides from the burial grounds should move to the Columbia River within a few thousand feet of the burial grounds during low and normal stages. When the 107-D and 107-DR detention basins were operated, a ground-water mound doubtless was built up to sufficient altitude to cause ground water to move easterly and southeasterly to the Columbia River at the opposite side of its bend around the reservation.

The character of the materials underlying the area along section line G-G' (fig. 15) are shown in figure 16. The bottoms of the burial grounds are about 55-65 feet above the water table. The saturated zone extends 5-15 feet above the base of the glaciofluvial deposits. Radionuclides reaching the water table from the burial grounds would move to the river mainly through the glacial deposits. The surface of the Yakima Basalt is indicated to be at an altitude of about 100 feet by Brown (1962, fig. 6). It is unlikely that radionuclides leached from the burial grounds would enter the basalt at or near the 100 D area before the ground water discharges to the Columbia River.

Wells 199-D-2-5 and -D-5-12 have been monitored for Beta activity, tritium, and nitrate in the ground water. These wells possibly intercept radioactivity moving from burial grounds nos. 1, 3, and 4. Beta activity at well 199-D-2-5 was monitored on a monthly to quarterly basis from 1967-69. A single sample taken prior to this monitoring period had a Beta activity of about 5×10^4 pCi/ℓ. This and two samples taken during March and April 1967 showed a greater level of Beta activity than the other samples, which consistently had a Beta activity of about 10^2 pCi/ℓ. At well 199-D-5-12 Beta activity was monitored from mid-1967 to present. Unfortunately, the record at this latter well does not extend back through the period when the relatively high Beta activity was obtained at well 199-D-2-5. The character of the fluctuations in Beta activity at 199-D-2-5 suggest either that a minimum of two small slugs of contaminants passed that well in a short period of time or that the samples were contaminated during collection. The Beta activity at well 199-D-5-12 has been rather uniform within the range >10^2 to 5×10^2 pCi/ℓ. The tritium and nitrate content of water samples from these two wells were determined for 1971 and 1972. At well 199-D-2-5 tritium rose from about 4×10^3 to 10^4 pCi/ℓ and nitrate rose from 2 to about 75 ppm during 1971 and 1972. At well 199-D-5-12 tritium fluctuated between 6×10^3 and 10^4 pCi/ℓ during 1970-1972 and nitrate rose from about 10 to about 65 ppm from 1971-1972. Both monitoring wells almost certainly are intercepting wastes moving northeastward from the 100 N area where a ground-water mound has been built up by discharged waste water. Such a direction of movement is indicated by figures 9 and 10. It appears that the contaminants reaching these wells from the 100 N Area make the record obtained from them of little value in evaluating the possibility that radionuclides may be entering the ground water from the solid waste burial ground.

100 F Area

The 100 F Area is on the eastern limb of the bend of the Columbia River at Hanford Plant coordinates N79,000 and W31,000. Terminated and monumented burial grounds nos. 1, 2, and 3 are in the southwest quarter of the area (figs. 17 and 18). Battelle Pacific Northwest Laboratories operates a burial ground for radioactive refuse from biological experiments at the south side of inactive burial ground no. 1. Battelle PNL also operates the so-called Sawdust Repository, east of the 100 F area, where litter from animal pens containing small amounts of radioactivity is buried as a land fill.

The soil material at the inactive burial grounds is sand and coarse gravel. Vegetation is sparse. The surfaces of the burial grounds are graded fairly smooth. At burial ground no. 2, the land surface is several feet above swales and linear depressions bordering it. Wind deflation appears to have removed some of the soil cover from an area on burial ground no. 2.

The water table is not clearly defined by the ground-water level information for the area but it appears to slope northeasterly toward the Columbia River. There may be a low ground-water mound built up in the vicinity of the 107 basin as a result of waste water discharge from the Battelle laboratory operation.

The water table lies within the glaciofluvial deposits, as shown in figure 19, and is within 10 feet of the land surface at the southwest part of the 100 F area. The depth to water increases northeasterly across the area, mainly because of a rise in the land surface. The water table is close to the surface in the area where burial grounds nos. 1 and 2 are located. Conceivably the water table could rise into burial ground nos. 1 and 2 as a result of a high stage of the Columbia River. Burial ground no. 3 and the Sawdust Repository are on higher ground and the depths to the water table are somewhat greater. The water table lies within the glaciofluvial deposits, through which the ground water from the vicinities of the burial grounds can move freely to the Columbia River within distances of a few thousand feet. The Yakima Basalt lies at about sea level beneath the 100 F Area, and 300 feet or more of the Ringold Formation lies between it and the glaciofluvial deposits. It is unlikely that radionuclides leached from the burial grounds would enter the basalt before reaching the river.

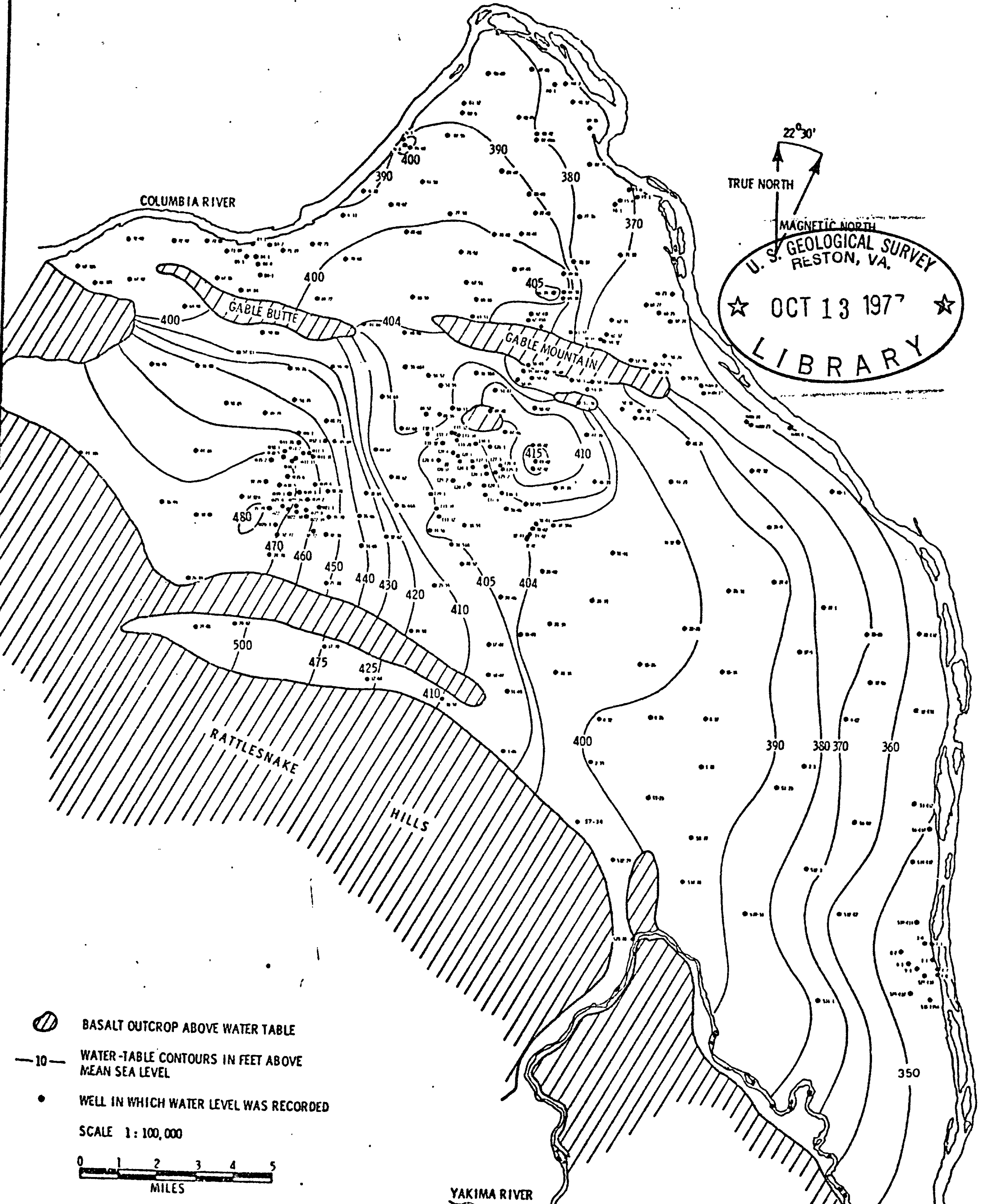
Monitoring records of radioactivity at wells 199-F-5-1 and 199-F-8-1 were inspected. Water sample analyses on both these wells are sparse. Thirteen samples analyzed for Beta activity from well 199-F-5-1 from 1956 to 1962 indicate that some contaminants reached this well in 1958 and persisted through 1962. Source of these radionuclides probably was the 107 detention basin or a nearby crib. Samples analyzed for Beta activity in 1967-68 were at laboratory detection levels. Tritium and nitrate analyses for 1971-72 indicate that negligible concentrations, if any, of these contaminants were in the ground water at this well. It is improbable that continued surveillance would provide any data useful in evaluating the burial grounds. The well is too far from the abandoned burial grounds and not in the path of ground water moving below the Sawdust Repository, but samples from it may show if radionuclides move away from the crib.

Well 199-F-8-1 is near burial ground no. 3 but the well appears to have been installed to monitor liquid waste discharge to a crib between it and well 199-F-8-2. Few analytical data were found for this well. Four analyses for nitrate in 1962-63 indicated that the water in the well was contaminated (11 ppm) in June 1962, but the other 3 samples contained about 1 ppm. A later series of analyses for 1971-72 showed nitrate concentrations varying between 55 and 75 ppm.

Tritium content for this same period was fairly constant at about 2×10^4 pCi/ℓ. Well 199-F-8-1 reflects the contaminants in a large body of polluted ground water which partly underlies the 100 F area. This body of polluted ground water is shown in figures 9 and 10. The source of the polluted water may not be the 100 F area. This water may have moved eastward from the reactor areas on the western limb of the bend on the Columbia River, or it may have moved northward between Gable Butte and Gable Mountain from the 200 Areas and then eastward. Monitoring records of nitrate north of Gable Mountain are too few to define the source of this body of water. Beta activity was not determined for the wells in the 100-F Area so it is not known if radionuclides other than tritium are associated with the high nitrate concentrations. The value of well 199-F-8-1 is suspect in monitoring radionuclide movement from the burial grounds because of the possibility that contaminants from another source have moved into this area.

100 H Area

The 100 H Area is the most northerly of the reactor areas and is well within the bend of the Columbia River. The Hanford plant coordinates N95,000 and W40,000 intersect within the area (fig. 20). Burial grounds nos. 1 and 2 are about 1,000 feet southwest and about 1,200 feet west, respectively, of the 105 reactor building. Both of these burial grounds have been terminated and are marked by monuments. They are built up a few feet above the apparently original land surface by a fill



(Map from Bettelle Pacific Northwest Laboratories)

Figure 8.--The water table at the Hanford Reservation, January 1973

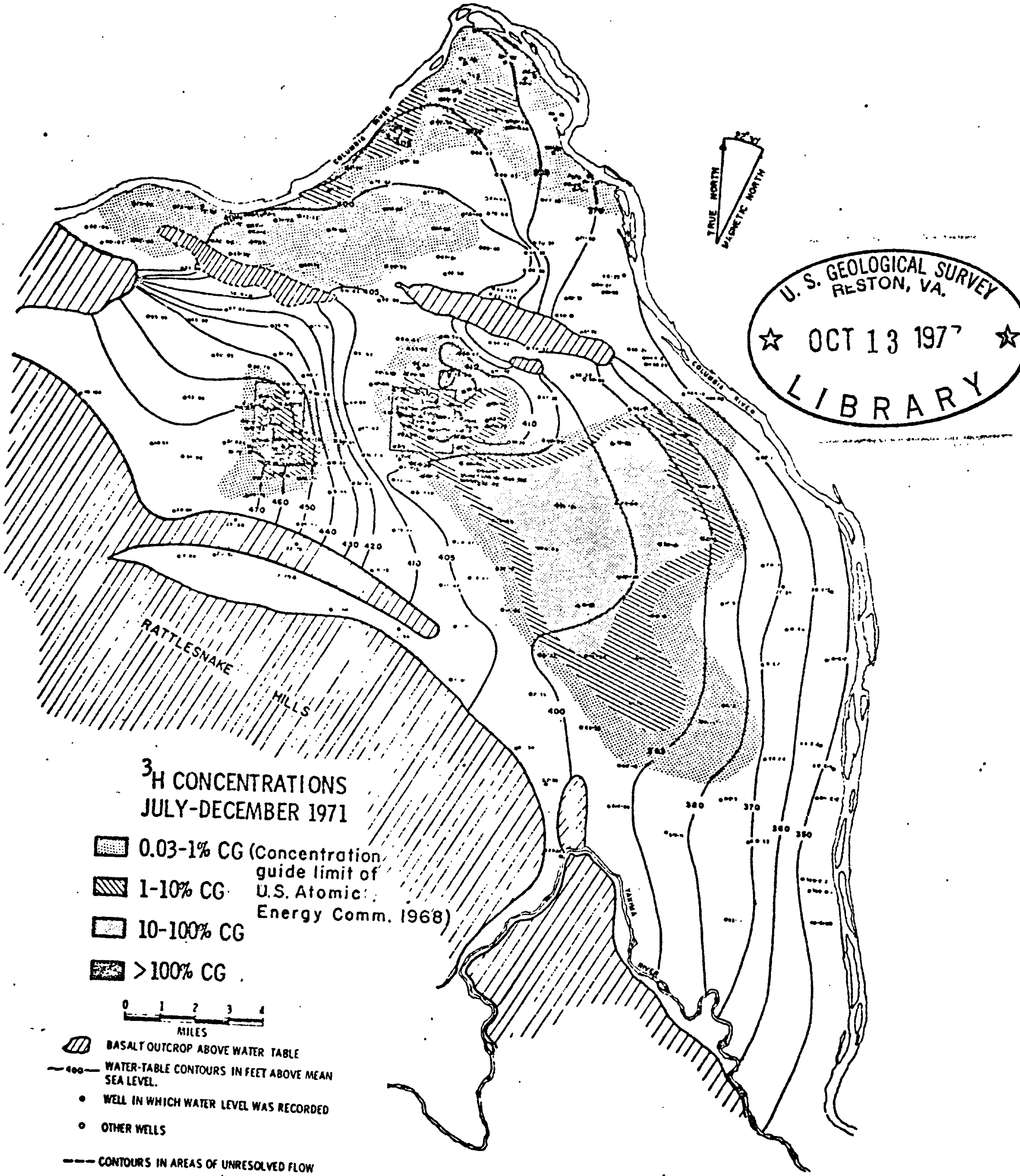


Figure 9.--Average tritium concentrations in ground water, July to December 1971 (from Kipp, 1973).

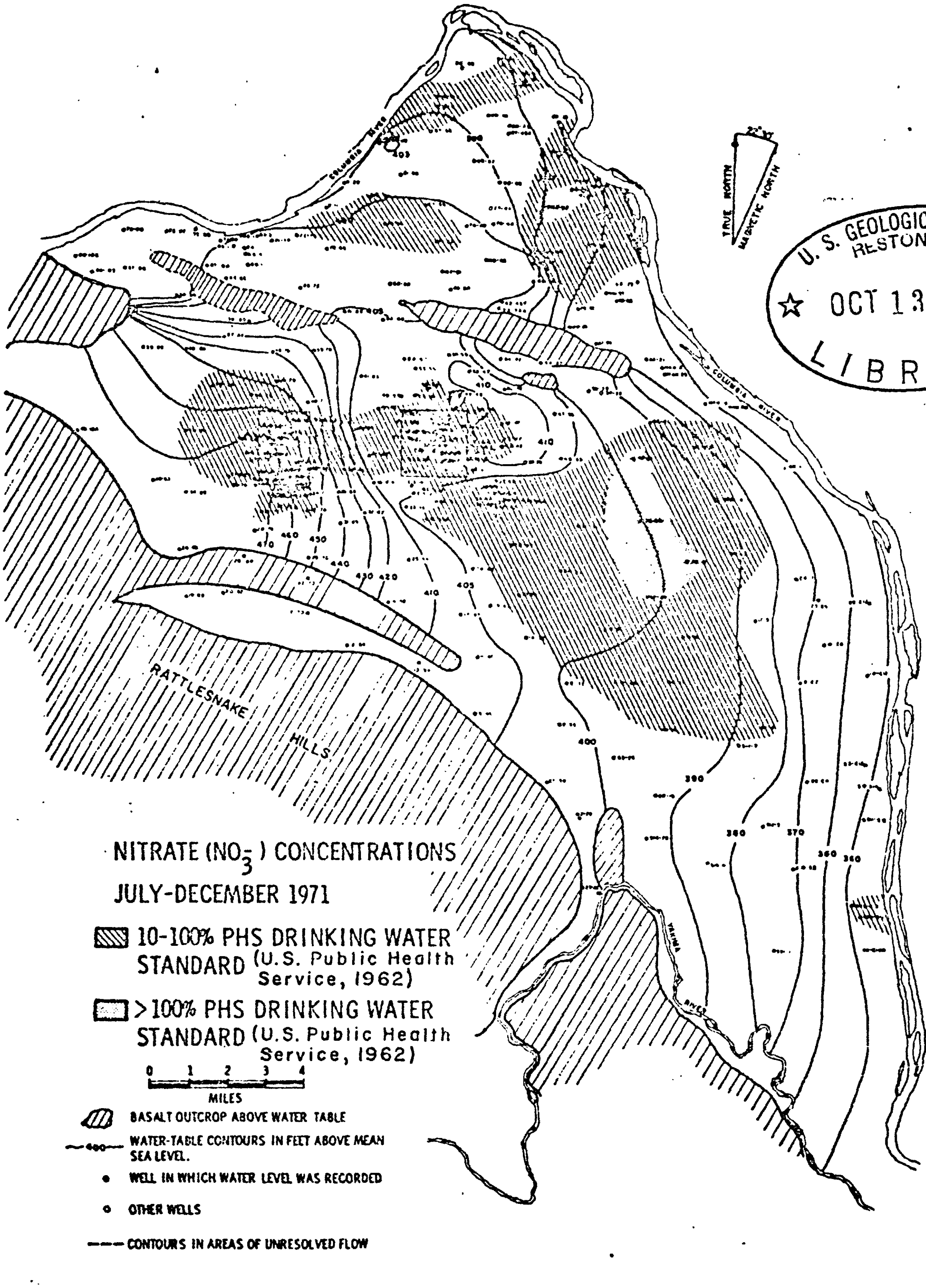


Figure 10.--Average nitrate (NO_3^-) concentrations in ground water, July to December 1971 (from Kipp, 1973).

of sand and coarse gravel. Burial ground no. 1 is bounded by broad swales. Shallow closed basins have been formed in these swales by artificial fill for a road cutting across the burial ground and by fill for the railroad line to the east. Burial ground no. 2 is in a flat area which appears to have been modified from the original topography. A few small shallow depressions lie along its margins.

The geologic materials along a line J-J' across the area (fig. 21) are shown in cross section in figure 22. The slope of the water table is not defined by the limited water-level data in the area. The water table probably is at about an altitude of 375 feet and lies within the glaciofluvial deposits. A significant ground-water mound was built up by water discharged to the 107 detention basin in years prior to 1965. Only two wells (199-H-3-1 and 199-H-4-2) are presently monitored for water-level altitude. Well 199-H-4-2, the deeper of the two, is described by K. L. Kipp, Jr. (written communication, 1973) as tapping confined ground water, presumably water in the Yakima Basalt. The water-level altitude in this well appears to be significantly higher than the water table.

The depth to the water table beneath the burial grounds is about 10 to 20 feet. Under present conditions, any radionuclides reaching the water table would generally follow a direct easterly course to the Columbia River through a distance of 3,000 to 4,000 feet. At times of high river stage, however, the direction of ground-water movement may be reversed for a time.

There is a scanty radiological monitoring record available for well 199-H-3-1. However, data from this well are not significant with regard to the solid-waste burial grounds. Ground water flowing beneath the burial grounds would not reach this well as long as the former ground-water mound existed around the 107 basin. Three analyses made during 1962-63 showed tritium to be about 10^5 pCi/ℓ and nitrate to be 10 ppm which probably were caused by local waste discharges. Beta activity, based on 10 samples, during 1967-68, was 10^2 pCi/ℓ, with one sample of 3×10^3 pCi/ℓ, which probably was contaminated during collection or was poorly analyzed. Samples were again taken from the well during 1971-72 for tritium, which was about 10^4 pCi/ℓ and nitrate, which was about 8-10 ppm. It would appear from figures 11 and 12 that these recent samples contain contaminants that entered the 100 H area by moving northeastward from the 100 N area.

100 K Area

The 100 K Area is located at Hanford plant coordinates N76,000 and W69,000. Facilities within the area have been surveyed by a land grid specific to the area. Both the Hanford plant and the 100 K grids are shown in figures 23 and 24. There is one large burial ground in that area at Hanford coordinates N77,000 and W67,000. This burial ground is not in use but is considered active and is fenced.

The burial ground is on the high river terrace on which the principal facilities of the 100 K Area are located. The surface materials and backfill at the burial ground are mainly sand and coarse gravel. These materials have been graded to a fairly smooth surface, which drains northward toward a large effluent basin. There is a burning pit a short distance north of the southeast corner of the burial ground. This burning pit is 20-25 feet deep at its center.

The water table is inadequately defined by two observation wells in which water levels are monitored. With the shutdown of the 105 KE in January 1971 and 105 KW reactors in February 1970, the ground-water mound built up by discharge of waste water to the ground began to decay. An experiment during 1973 at the 100 K Area required the pumping of a large quantity of river water. If any of this water were discharged to the ground, the water table was again modified. It is possible that, at the burial ground, the water table lies at an altitude of about 390 feet, which is about 60 feet below the bottom of the burial ground. The water table is in the conglomerate zone of the Ringold beneath the southern part of the burial ground and in the glaciofluvial deposits beneath its northern part (fig. 25). Radionuclides reaching the ground water would have a direct flow path about 2,000 feet long, northerly or northwesterly to the Columbia River through the most permeable part of the Ringold Formation and the glaciofluvial deposits (figs. 25 and 26). At least a 450-foot thickness of the Ringold Formation intervenes between the water table and the Yakima Basalt. The blue clay zone in the lowermost unit of the Ringold appears to have been reached by wells 199-K-10 and 199-K-11 at about a depth of 300 feet. It is unlikely that radionuclides from the burial ground would enter the basalt before reaching the river.

Radiological monitoring of ground water was done at wells 199-K-11 and 199-K-20. Neither of these wells is placed so as to intercept radionuclides that may move from the burial ground through the ground-water body. Well 199-K-5, which is within the burial ground, was drilled for subsurface information and its casing was removed. This well was never used for monitoring. Unless this well was refilled with care to prevent circulation through it, it may be an avenue of downward movement of radionuclides from the buried wastes.

The radionuclides in the ground water at the 100 K Area apparently were from local sources such as the effluent trench near well 199-K-20. This well was sampled 13 times for Beta activity from November 1956 to October 1959 and showed a general rise to about 10^4 pCi/ℓ. Another series of Beta activity determinations for the years 1968-72 showed levels of about 10^6 pCi/ℓ which declined throughout 1970, after waste discharges ceased, to about 10^2 pCi/ℓ. Beta activity at well 199-K-11 was low, about 10^2 pCi/ℓ during the period 1967-69 but the well was not otherwise sampled for Beta activity. Tritium apparently was released to the ground locally within the 100 K Area. Tritium determinations for the two monitoring wells are few and were made mainly during 1971 and 1972. These tritium data, though inconclusive, suggest that some tritium-bearing ground water moved southward when waste water was discharged to the ground, then moved northward toward the Columbia River as normal gradients were restored. A large body of nitrate contaminated ground water is south and southeast of the 100 K Area (fig. 10) and may move northward through the area to the Columbia River. The possibility that wastes originating outside the 100 K Area may move into the area should be considered if monitoring of the burial ground is undertaken.

100 N Area

The 100 N Area is located at Hanford coordinates N85000 and W61000. Surveying within the area based on a local 100 N grid, which is shown on figures 27 and 28 along with the Hanford grid. The only radioactive solid wastes stored in the 100 N Area are used fuel element spacers, which are stored in a concrete subsurface structure containing three silos northwest of the 105-reactor building. The spacers may be retrieved through hatches in the tops of the silos. There is no likelihood of radioactivity from the spacers entering the soil materials as long as the storage structure is intact.

The surficial materials in the 100 N Area are principally sand and coarse gravel of the glaciofluvial deposits. These are underlain at an indefinite depth by the middle conglomerate unit of the Ringold Formation. The upper surface of the Ringold may range from about an altitude of 350 feet near the Columbia River to about 400 feet in the eastern part of the 100 N Area (figs. 29 and 30). At well 699-86-60, where the top of the Ringold is at an altitude of about 400 feet, the top of the blue clay unit is at an altitude of about 360 feet.

A large ground-water mound has been built up to an altitude of more than 400 feet, more than 20 feet above normal river stage, where waste water is discharged to the ground in the northeastern part of the area. Ground water has moved in all directions from this mound. The eastward moving ground water probably has carried contaminants into the 100 H and 100 F Areas. Radionuclides entering the ground-water body from the spacer storage will move toward the Columbia River under the influence of the high artificial ground-water gradient from this mound. If waste-water discharge were stopped and the mound decayed completely, movement of ground water beneath the spacer storage facility would still be toward the river but at a lower velocity. However, at times of high stage of the Columbia River, there would be a movement of water eastward beneath the spacer storage facility. In fact, during high stages, water might move in the subsurface across the part of the reservation enclosed by the bend of the river and eventually enter the river (after it had returned to normal stage) in the reach that includes the 100 H and 100 F Areas.

Although several completed wells are in and near the area of waste discharge, only test boring data are available on the subsurface materials in the southern two-thirds of the 100 N Area. Samples for radiological monitoring are collected regularly at wells 199-N-3, 199-N-4, and 199-N-10 near the waste discharge. Beta activity, tritium, and nitrate concentrations are available and originate from reactor liquid wastes.

300 Area

The 300 Area is in the southeastern part of the Hanford Reservation at S 24000 and E 13000 of the Hanford plant coordinate system. Facilities in the 300 Area are referenced to the Richland coordinate system. Both systems of coordinates are shown in figures 31 and 32.

The burial grounds in or near the 300 Area are designated no. 1, 2, 3, 4, 5, 7, 8, and 300 West. Of these burial grounds, only no. 7 is still receiving solid wastes. Burial ground no. 1 is east of the 333 building at plant coordinates S 24000 and E 13400 and is marked by monuments. Part of its surface is paved with asphalt and the remainder is graded smooth. Two small steel buildings are on it.

Burial ground nos. 2 and 3 are side by side a short distance north of burial ground no. 1 and are marked by monuments. Surficial materials are sand and gravel. A few minor depressions occur in the surface. Surface drainage is to the north.

Burial ground no. 4 is north of the 300 Area and is marked by monuments. Surface materials are sand and gravel. It is in a broad shallow swale that drains eastward to the Columbia River. Fill placed in the burial ground has blocked drainage through the swale and created a surface depression centering on the burial ground. The depression may also be partly caused by compaction of buried materials. With the present condition, runoff can collect on the burial ground and seep through it. The burial ground may also be susceptible to erosion by runoff, if the fill is washed out.

Burial ground no. 5 is also located in a swale about 1,000 feet southeast of burial ground no. 4. A burning pit, the use of which was discontinued in 1973, is within the monumented confines of the burial ground. Excavation and backfilling for the burials has considerably modified the natural drainage. The swale has been blocked by fill at the downstream end of the burial ground and an excavation was made on the upstream end. As with burial ground no. 4, burial ground no. 5 may collect runoff that will infiltrate through it, and it may be eroded by surface water.

Burial ground no. 7 is northwest of the main facilities sector of the 300 Area. It is marked by steel posts and a chain. Surficial materials are sand and coarse gravel. Natural topography consists of rolling prairie with 8-10 feet of relief. Operations at the burial ground have considerably modified the surface at places. In January 1973, a trench was open in the northern part of the burial ground in which a variety of solid wastes had been placed. These wastes contained such items as stainless steel and aluminum vessels, a tank truck body, machine equipment, a wooden ladder, and various packaged wastes. Presumably these materials were only slightly contaminated by radioactivity as access to them was controlled only by radiation signs.

The 300-West burial ground is about 1000 feet southwest of burial ground no. 7 (fig. 32) and is marked by monuments. It is a small burial ground about 20 by 140 feet in dimension. The surficial materials are sand

and gravel. The topography of the burial ground and surroundings is gently rolling. The 300 West burial ground contains uranium-bearing solvent in steel drums which were buried in 1955-56.

The water table beneath the 300 Area is affected by waste water discharges to the north and south process ponds. A low ground-water mound has formed beneath the ponds (fig. 31). This mound causes ground water that normally would move beneath the burial grounds, to follow circuitous courses to the Columbia River. The water-level data on the 300 Area are insufficient to allow the flow paths from the burial grounds to be traced. If waste-water discharges were stopped, ground water should flow easterly directly to the river after the mound decayed. All of the burial grounds are close enough to the river, so that ground-water flow beneath them is reversed when the Columbia attains high stage in late spring.

The relationships of the burial grounds to the geologic materials and the water table are shown in the cross sections of figures 33 and 34.

Within the 300 Area, the water table lies at a general altitude of about 342 feet. The more easterly burial grounds are about 20 feet above the water table; the westerly burial grounds are about 40 feet above it. The water table lies in the glaciofluvial deposits, which are underlain by the middle conglomerate unit of the Ringold Formation. Hydraulic data show that the water-bearing materials in the 300 Area have a high transmissivity and the movement of water to and from the Columbia occurs at a high rate (Tillson, Brown, and Raymond, 1969). The surface of the

Yakima Basalt is at an altitude of about 200 feet. There is a saturated section of about 140 feet of Ringold Formation and glaciofluvial deposits above the basalt. The Yakima Basalt probably is involved little, if at all, in the movement to the river of wastes originating in the 300 Area.

Radiological and chemical monitoring data are available for 14 of the wells shown in figures 31 and 32. Tritium was not determined but alpha activity and Cr^{+6} and F^- concentrations, as well as beta activity and nitrate concentrations, were measured in ground-water samples.

Apparently all of the contaminants observed at these wells are locally introduced by liquid waste discharges, principally to the process ponds. The concentrations of contaminants observed at wells decrease in a general way with distance of the well from the process ponds. Radioactivity in the ground water is caused mainly by uranium (Kipp, 1973, p. 23). Beta and alpha activities generally are low. In wells near the ponds, beta activity occasionally reaches levels of 10^4 pCi/ℓ or somewhat higher, but generally is not much higher than 10^2 pCi/ℓ. Nitrate is the principal chemical contaminant having reached concentrations greater than 100 ppm in the ground water near the ponds. Nitrate determinations on wells 399-8-1, 399-8-2, and 399-8-3 indicate that wastes from the process ponds probably have moved beneath even the most distant burial grounds.

300 North Burial Ground

The 300 North burial ground is about 2-1/2 miles north-northwest of the 300 Area at Hanford plant coordinates S 6000 and E 3000 (fig. 35). Its boundaries are delineated by monuments. The burial ground is in an area of undulating topography with 10 to 20 feet of relief between swales and hillocks. There is no plant topographic map for this area. Altitudes are available for wells and the corners of the burial ground (fig. 35). The profile of the topography shown in figure 36 was based on the U.S. Geological Survey topographic map of the Richland quadrangle (contour interval, 20 feet).

Surficial materials are sand and coarse gravel. Surface drainage from this area is eastward to the Columbia. However, the burial ground has been graded with earth-moving machines, is poorly drained, and may be in a closed basin. Seven wells were drilled east and southeast of the burial ground. Five of these wells were found in 1973 to be still in existence. Apparently one of the wells was a production well which supplied water to wash out truck bodies after wastes were delivered to the burial ground. It was reported that this wash water was disposed of in a crib adjacent to the burial ground.

The ground-water level is monitored near the burial ground at well 699-S6-E4C. This record indicates the water table to be at an altitude of about 370 feet. The water table is within the permeable glaciofluvial deposits, as shown in figure 36. The water table is about 45 feet beneath the bottom of the burial ground. The Hanford water-table map (fig. 8) indicates that ground water moves easterly from the burial ground to the river. The map of tritium concentrations in ground water (fig. 9) shows that there is a preferential movement indicated by the most southerly segment of the waste plume extending from the 200 West Area. In general, the direction of ground water should roughly approximate the line of section of figure 36. The length of the flow path from the burial ground to the river is on the order of 2 miles.

Monitoring of ground water at wells 699-2-3, 699-S6-E4C, and 699-S11-E14 indicate that wastes from the 200 West Area have appeared at all three wells. At well 699-2-3 tritium reached a level of $>10^3$ pCi/ℓ in 1969, indicating that contaminants were present. Tritium increased to 2×10^4 pCi/ℓ by October 1972. Nitrate content at this well increased in 1970 to 16 ppm and has been rather erratic in concentration since, but at levels generally of 7.5 to 10 ppm. Beta measurements were discontinued at this well before the arrival of the tritium.

At well 699-S6-E4C piezometers O and P have been sampled. Piezometer O is 148 feet deep and piezometer P is 460 feet deep. The shallow ground water is not monitored at this site. Beta activity has not been determined since 1969. However, tritium and nitrate appear to have been present as contaminants in small concentrations. In the shallower piezometer, nitrate was as high as 6 ppm in 1969. Tritium has fluctuated in recent years from 5×10^2 to 10^3 pCi/ℓ. In the deeper piezometer, tritium fluctuations were similar but nitrate did not rise above a maximum of about 2 ppm.

At well 699-S11-E12 nitrate concentrations rose to 6 to 11 ppm during 1971 and 1972, which definitely indicate the arrival of wastes. Beta activity was not monitored. Tritium was reported at low levels during 1971 and 1972, except for one measurement of 7.7×10^4 pCi/ℓ, which probably resulted from a contaminated sample or a poor measurement.

300 WYE Burial Ground

The 300 WYE burial ground is about 7-1/2 miles northwest of the 300 Area and 3-1/2 miles west of the Columbia River (fig. 1). The burial ground is inactive and is marked with monuments. The WPPSS (Washington Public Power Supply System) Hanford No. 2 generating plant is under construction to the east of the burial ground.

The burial ground is on one of the lower river terraces with an altitude of 440 feet and with a topography characterized by areas of rolling prairie and intervening broad, flat meadows. There is no plant topographic map of the burial ground area. The authors have drawn contours of the area, shown in figure 37, on the basis of altitudes obtained by WPPSS in its site investigation for the Hanford No. 2 generating plant. Land surface profiles shown in figures 40 and 41 were drawn on the basis of the topography shown on the U.S. Geological Survey topographic map of the Richland quadrangle. A low medial ridge, 4-5 feet high, trends east-west through the burial ground. Drainage from the burial ground is locally north and south of this ridge and generally eastward to the Columbia River. There are some shallow depressions at the west margin of the burial ground.

Surficial materials at the burial ground are sand and gravel of the glaciofluvial deposits. These extend downward about 45 feet, as shown in figures 38 and 39, to the middle unit of the Ringold Formation. However, the base of the glaciofluvial deposits is not definitely known in this area, and it may really lie at a greater depth of about 40 feet below the bottom of the trenches at the burial ground. There are some tubular-shaped caissons that reportedly received considerable solid radioactive wastes in the burial ground, which extend to greater depths than the trenches.

Ground water moves easterly from the 300 WYE area to the Columbia River. The lobate fronts of the waste plumes from the 200 East Area, shown by tritium and nitrate concentrations of ground water (figs. 9 and 10) indicate that ground water flow is more rapid to the north and south of the 300 WYE burial ground. These differences in the rate of ground-water flow probably result from the different transmissivities of materials in the upper part of the zone of saturation from place to place on the Reservation.

No monitoring wells are near enough to the 300 WYE burial ground to have any utility in determining if contaminants from the solid wastes are reaching the water table. Wells 699-17-5 and 699-9-E2, the closest monitoring wells, are each about a mile from the burial ground. Soil borings by WPPSS, listed on figure 39, were drilled recently. WPPSS reportedly may monitor two of these borings for water levels and radioactivity but probably in connection with liquid waste discharges or for possible leaks from the Hanford No. 2 generating plant. The monitoring record for well 699-17-5 indicates that wastes from the 200 Areas recently (1972) may have reached that well. Occasional nitrate concentrations above background concentrations have been observed at that well since 1967. These may be accounted for as due to contaminated samples or poor laboratory analyses. In 1972, nitrate contents of 5.9, 11, < 0.5, and 7.7 ppm were observed in the months of February, May, July, and September, respectively. Three of these determinations are indicative of contamination.

200 Areas

The 200 East and 200 West fuels separations areas are spaced about 3 miles apart in the central part of the Hanford Reservation on a high terrace with an altitude of about 700 feet. The 200 East Area is approximately centered on Hanford coordinates N 42000 and West 52000 and the 200 West Area on Hanford coordinates N 42000 and W 74000.

The solid waste burial grounds and regulated storage sites in the 200 Areas contain most of the radioactive solid wastes from the operations at Hanford. There are 27 solid waste burial sites and 9 regulated equipment storage locations (L. L. Lundgren, Atlantic-Richfield Hanford Co., written communication, January 26, 1971). Many of the burial grounds coalesce into large areas of solid waste burials. The Atlantic-Richfield Hanford Company is presently updating drawings and maps showing the various burial grounds and other solid waste storage. Most of the burial grounds are shown in figures 40 and 41. Wastes generally have been placed in trenches in the burial grounds which were backfilled with the excavated soil material. There is also contaminated or radioactive equipment in various storage facilities. The largest such facility consists of two railroad tunnels in which are stored flat cars containing large radioactive equipment items from the Purex plant (the 202-A building in figure 40). Such stored equipment is presently retrievable.

The topography of the 200 Areas is flat or gently sloping. In the 200 East Area the slope of the land and the natural drainage is northeasterly. In the 200 West Area the land slopes and natural drainage are mostly westerly and southwesterly. Both of the 200 Areas are intensively developed and drainage is now controlled along the networks of roads and railroads, the waste-water canals and ponds, and other structures. The 700-foot altitude of the 200 Areas would seem to place them well above any conceivable extreme flood levels of the Columbia River. Unruh (1970, p. 25) states, "....a coincident failure of Grand Coulee Dam and the simultaneous arrival of breech (sic) flows from upper Canadian storage projects.....would produce a flow of only 10 million cfs past Hanford. Even this flow rate would raise the surface waters to an elevation only 560 ft. above sea level...."

The surficial materials in the vicinity of the 200 Areas are mainly sand and gravel of the glaciofluvial deposits. In the 200 West Area the surficial materials are a finer grained facies of the glaciofluvial deposits and consist mainly of sand and silt. The subsurface geology of the 200 Areas has been described by Brown (1959). Figure 42 is a topographic map of the 200 Areas taken from Brown's report and shows lines of geologic cross sections that Brown prepared. Figures 43, 44, 45, 46, and 47 are copies of Brown's cross sections and show the character of the geologic materials at depth in the vicinity of the 200 Areas.

The glaciofluvial deposits are much thicker beneath the 200 East Area than they are beneath the 200 West Area. As a result of waste water discharge, the water table has risen into the glaciofluvial deposits beneath the 200 East Area. The water table has risen considerably higher beneath the 200 West Area, but it is well within the Ringold Formation. Because the glaciofluvial deposits are much more permeable than the Ringold Formation, wastes in the ground-water system move away from the 200 East Area much more rapidly than they do from the 200 West Area. The extent of waste movement and the direction of ground-water flow from the 200 Areas is indicated by the bodies of wastes originating in these areas and moving principally easterly and southeasterly as a large plume and northerly toward the Columbia River (figs. 9 and 10).

Radiologic monitoring of ground water has been intensive in the 200 Areas and immediate vicinity. However, this monitoring has been conducted to provide operating information for liquid waste discharge facilities, consisting of cribs and ponds, and to provide information on the movement of radionuclides from liquid wastes through the ground-water system. The monitoring wells are not located to detect if materials from solid wastes have entered the soil or the ground water beneath the burial grounds.

In recent years, a considerable effort was made at Hanford to develop a predictive computer model of waste transport through the soil and ground-water system. Cearlock (1971) describes the features of this computer model system. De Mier (1972) described the use of the model relative to ground-water flow and indicates that the predictive capability of the model is poor, except for the region of the tritium plume extending southeast of the 200 East Area and shown on figure 9. The modeling of waste movement through the soil at Hanford is still in the development stage. Further laboratory and theoretical studies are necessary to determine the intereactions of wastes and soil materials and to develop suitable mathematical relationships (Battelle Pacific Northwest Laboratory, 1972, p. 2).

213 Area

The 213 Area is located on the south flank of Gable Mountain at Hanford coordinates N 54000 and W 35000 (fig. 1). It includes a concrete structure containing two vaults formerly used for storing the plutonium product of the Hanford Works and two small burial pits in the yard south of the vault structure. These pits are reported to be about 4 feet deep and to be covered with rough concrete slabs about 8 feet square. They received both solid wastes such as plutonium-bearing wipe rags and wash water used for decontamination. The wash water may have contained particulate plutonium.

The yard where the pits are located has a gently sloping surface. However, runoff can reach the area from a steep slope north of the facility.

In light of the shallowness of the pits, erosion by surface water or wind may in time release the wastes. The water table is probably on the order of 150 feet or more below the land surface. It may lie either within the unconsolidated deposits or the Yakima Basalt. The concrete slab covers probably have prevented water from infiltrating the ground. The wash water presumably could have carried either dissolved or particulate plutonium into the ground beneath the pits.

Hydrologic factors related to long-term waste storage at burial grounds

The burial grounds in the 100 Areas and the 300 Area have in common the following features: (1) nearness to the Columbia River, (2) unsaturated materials above the water table are mainly coarse-grained glaciofluvial materials, (3) the uppermost part of the saturated zone is mainly in coarse-grained glaciofluvial deposits and the middle conglomerate unit of the Ringold Formation, (4) location on low river terraces that could be flooded and eroded away without the protection provided by upstream dams on the Columbia River or they could be flooded in the event of a rupture of a dam. In the light of the hydrologic setting of these burial grounds in the areas near the river, it can be concluded that they are not suitable for long-term storage of radioactive solid wastes. Radionuclides could conceivably be leached from the wastes by infiltrating water and reach the water table, from which they could reach the Columbia River within several days to several months. Despite the dry climate at Hanford, infiltration and ground-water recharge could occur in amounts of significance to radionuclide transport in the 100 Areas and 300 Area burial grounds. The precipitation is seasonally distributed with about one-half of the average annual precipitation occurring in the winter months when evapotranspiration is negligible and conditions for infiltration are most favorable. These burial grounds are underlain by very permeable deposits, and the water table is relatively close to the surface. The possibility of water infiltrating through the burial grounds and reaching the water table is enhanced if the burial grounds have surface depressions in which water can collect, as some of them do.

The 100 Areas and 300 Area burial grounds would be flooded in the event of the "probable maximum flood" predicted by the U.S. Army Corps of Engineers (1969). However, such a flood would cause much more serious results by inundating reactor and laboratory buildings. The possible flooding of these burial grounds is not as important a factor in their evaluation as is the possibility of the release of radionuclides through the soil water and ground-water systems, which could be a continuous process.

The 300 North and 300 WYE burial grounds are on relatively low river terraces but are at a considerable distance from the Columbia River. Except for their greater distance from the river, they have all the undesirable features of the 100 Areas and other 300 Area burial grounds.

The 200 Areas burial grounds are the most favorably situated for long-term storage of any of the burial grounds in the Hanford Reservation. They lie on a high terrace underlain at depth by fine-grained materials.

The depth to the water table is on the order of 200 to 300 feet. These depths would be greater if waste-water discharge to the ground were stopped and natural ground-water conditions were restored. The great depth of the water table and the fine-grained sediments at depth make it much less likely than in the 100 Areas that infiltrating water would actually reach the water table under present climatic conditions. The fine-grained geologic materials at shallow depth beneath the 200 Areas have been shown to sorb large proportions, but not all, of the radionuclides that have been discharged to the ground in liquid wastes (Brown, 1967). These liquid wastes, however, have been treated to raise their pH to alkaline, which facilitates sorption in the soil. However, in the event of water infiltrating the burial grounds, the resultant chemical character of water-waste mixtures could be expected to be closer to natural conditions. Conceivably, large concentrations of radionuclides could be built up in a particular zone of sediments below a burial ground through sorption. This tendency for radionuclides to be concentrated in particular soil layers has been observed with regard to liquid waste disposal at Hanford (Brown, 1967, 1971). Under some circumstances such a concentration of radionuclides may be particularly hazardous should the materials be breached by erosion or should the burial ground be dug up for removal of wastes. The suitability of the 200 Area burial grounds for long-term storage cannot be evaluated with the data available. The important deficits pertain to the effects of the movement of soil water, as was discussed previously in relation to sorption and infiltration, and to the transport of radionuclides by soil water.

Conclusions and Recommendations

The following actions should be undertaken to assure that the release of radionuclides from the burial grounds will not occur.

100 Areas.--Solid waste burials in the 100 Areas are poorly inventoried for the years prior to 1969. However, file data indicate that most radioactive solid wastes in the 100 Area burial grounds are irradiated reactor components, pipes, and various metal equipment items. Most of the radioactivity in these burial grounds is believed to be in these metallic wastes and is due to cobalt-60 and other activation products. It was estimated by Corbit (1969, p. 61) that the bulk of these radioactive wastes would decay to nonradioactive states by the year 2050 though a small amount would still be considered radioactive through the year 2110. Wastes of this type would release radioactivity slowly even if subjected to continuous percolation of water through them, because the metals would have to corrode in order to release any significant amounts of soluble ions of radionuclides. Because these wastes are relatively insoluble and the radiation is due to fairly short-lived radioisotopes, such wastes probably are not serious environmental hazards. However, a review should be made of the records of disposals to identify those burial grounds or the parts of burial grounds where relatively large quantities of cobalt-60 bearing metallic wastes or other very hazardous wastes are located. At a few sites, mainly older burials, containing hazardous materials, samples should be taken of the soil below the wastes and analyzed to determine if radionuclides are migrating downward to the water table. Wells also should be constructed adjacent

to selected burial sites so as to intercept water moving beneath them in the uppermost part of the saturated zone. They should be sampled regularly and the water analyzed for chemical and isotopic constituents indicative of the waste constituents in the burial grounds. If movement of radionuclides from these burial grounds is detected, a study should be made of the advisability of removing the wastes.

300 Area.--The burial grounds in the immediate vicinity of the 300 Area are reported to contain little radioactivity. None is reported to contain plutonium except burial ground no. 1. If plutonium is present there in other than trace quantities, then removal of the plutonium-bearing wastes should be considered.

300 North and 300 WYE Burial Grounds.--Both of these burial grounds contain fission products and plutonium, apparently in large quantities. Neither can be depended upon to retain these radionuclides through long periods of several hundred to several thousand years, the time required to reduce the activity to innocuous levels. It is recommended that the desirability of removing the plutonium and fission products from these burial grounds be considered.

200 Area Burial Grounds.--The numerous burial grounds in the 200 Areas contain large amounts of plutonium, fission products, and radioactivity and are great potential environmental hazards. It is also pointed out that the high-level liquid wastes stored in the 200 Areas and now being reprocessed to salt cakes, and radionuclides in the soil beneath abandoned cribs and ditches also are a great potential hazard. It is clear that presently there is no means to predict the potential

for movement of radionuclides from the solid waste burial grounds, particularly over the many thousands of years that containment of plutonium would be necessary. The waste management plan for Hanford (Karagianes, 1973, p. 119) calls for environmental studies to determine the safety of long-term storage of the residual salt-cake from high level liquid wastes. Information developed through these studies on water and radionuclide movement through the soils beneath the 200 Areas may have a direct bearing on determining the suitability of the 200 Area burial grounds for long-term storage. In fact, these environmental studies should be designed so as to also provide conclusions directly pertinent to the burial grounds.

213 Area.--The two small burials of plutonium-bearing waste in the 213 Area should be considered for removal as their location and the shallowness of the burials do not assure long-term containment.

General.--Where necessary, the surface characteristics of the burial grounds should be modified to prevent or reduce (1) erosion by local runoff or wind and (2) collection of runoff and precipitation in depressions or swales that will add to the infiltration of moisture.

Temporary storage facilities for relocated solid radioactive wastes.--Solid radioactive wastes containing plutonium and other fission products, removed from burial grounds, according to the recommendations of this report, must be stored so as not to cause environmental hazards. Temporary storage for these relocated wastes should be provided in either or both of the 200 Areas. These areas already contain extensive waste management facilities, personnel security measures are stringent in both areas, and, from a hydrologic standpoint, they are least objectionable for solid radioactive waste storage of any of the facilities areas.

The relocated wastes should be placed in facilities that will prevent any possible release and transport of radionuclides and from which they can be recovered subsequently. Ease of recovery is desirable should later studies lead to the requirement that solid wastes containing transuranium elements and fission products be removed from the 200 Areas and placed elsewhere in a permanent repository. The facilities also should be designed so that they can be stabilized with relative ease if it is later proved that the wastes may be retained with safety in the 200 Areas.

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Appendix

I. List of Hanford engineering drawings applying to radioactive solid waste burial grounds.

100 B Area

H-1-15234 Civil marker installation plan, 100 C burial ground

H-1-15394 Vicinity map, 100 B terminated sites

M-1600-B Topographic map

100 D Area

H-1-14897 Permanent burial grounds, plans and details

H-1-15246 Permanent markers, terminated 100 D sites

H-1-15395 Vicinity map, 100 DR terminated burial sites

M-1600-D Topographic map

100 F Area

H-1-14731 Permanent burial grounds, plans and details

H-1-15244 Permanent markers, terminated 100 F sites

H-1-15396 Vicinity map, 100 F terminated burial sites

M-1600-F Topographic map

100 H Area

H-1-14732 Permanent burial grounds, plans and details

H-1-15245 Permanent markers, terminated 100 H site

H-1-15397 Vicinity map, 100 H terminated burial sites

M-1600-H Topographic map

100 K Area

H-1-12012 100 K Area burial ground

H-1-25189 Site plan

M-1600-K Topographic map, 100 K Area

M-1904-K Outside lines, sewers

100 N Area

H-1-30501 Plot plan - 100 N Area

H-1-30502 Boring location plan

H-1-30543 Civil boring log

H-1-38646 Master plot plan - 100 N Area

H-6-4002 Civil boring log

M-1600-N 100 N Area topography

SK-1-33044 Radioactive effluent control program--general arrangement plan

200 East Area

H-2-124 Burial ground #1

H-2-757 222-B vault

H-2-1938 do.

H-2-2479 Industrial burial ground #2, 2A

H-2-31269 Waste burial sites--plot plan

H-2-32560 Burial ground #12

H-2-33276 Burial ground #12B

H-2-34761 Plot plan - 200 East

H-2-44500 Key plan - 200 East

H-2-44500 Key plan, area map - 200 East

H-2-44501 Detailed area map

H-2-55586 Purex tunnel #1

H-2-55587 Purex tunnel #1

H-2-57849 Burial ground #12

H-2-58025 Industrial burial site #10

H-2-58191 Purex tunnel #2

H-2-58737 do.

200 West Area

H-2-123 Burial ground #1

H-2-1938 222-T site

H-2-2503 Burial ground #2

H-2-2516 Industrial burial ground #1

H-2-3398 Burial ground #3

H-2-5140 222-S site

H-2-5170 do.

H-2-5234 do.

H-2-31268 Plot plan, waste burial sites, 218-W

H-2-31904 Burial ground #4

H-2-32095 Industrial burial ground #2, #3

H-2-32144 Burial ground #4

H-2-32487 Burial ground #4; regulated storage

H-2-33055 Burial ground #2, 4B

H-2-33971 Burial ground #4B

H-2-34375 Burial ground #4B

H-2-34762 Plot plan - 200 West Area

H-2-34880 Burial ground #3

H-2-35279 Burial ground #4B

H-2-44510 Key plan, area map - 200 West

H-2-44511 Detailed area map

300 Area

H-3-7612 300 Area layout map

H-3-9375 Burial pit no. 7

H-3-9921 Burial ground no. 1

H-3-9922 Burial ground nos. 2 & 3

H-3-9923 Burial ground no. 4

H-3-9924 Burial ground no. 8

H-3-20998 As built, 300 West burial ground

H-3-23799 Burial ground no. 7 expansion

H-3-29393 300 Area map

M-3600 Topographic and layout maps

300 North Burial Ground

H-3-9982 300 North burial ground as built

300 WYE Burial Ground

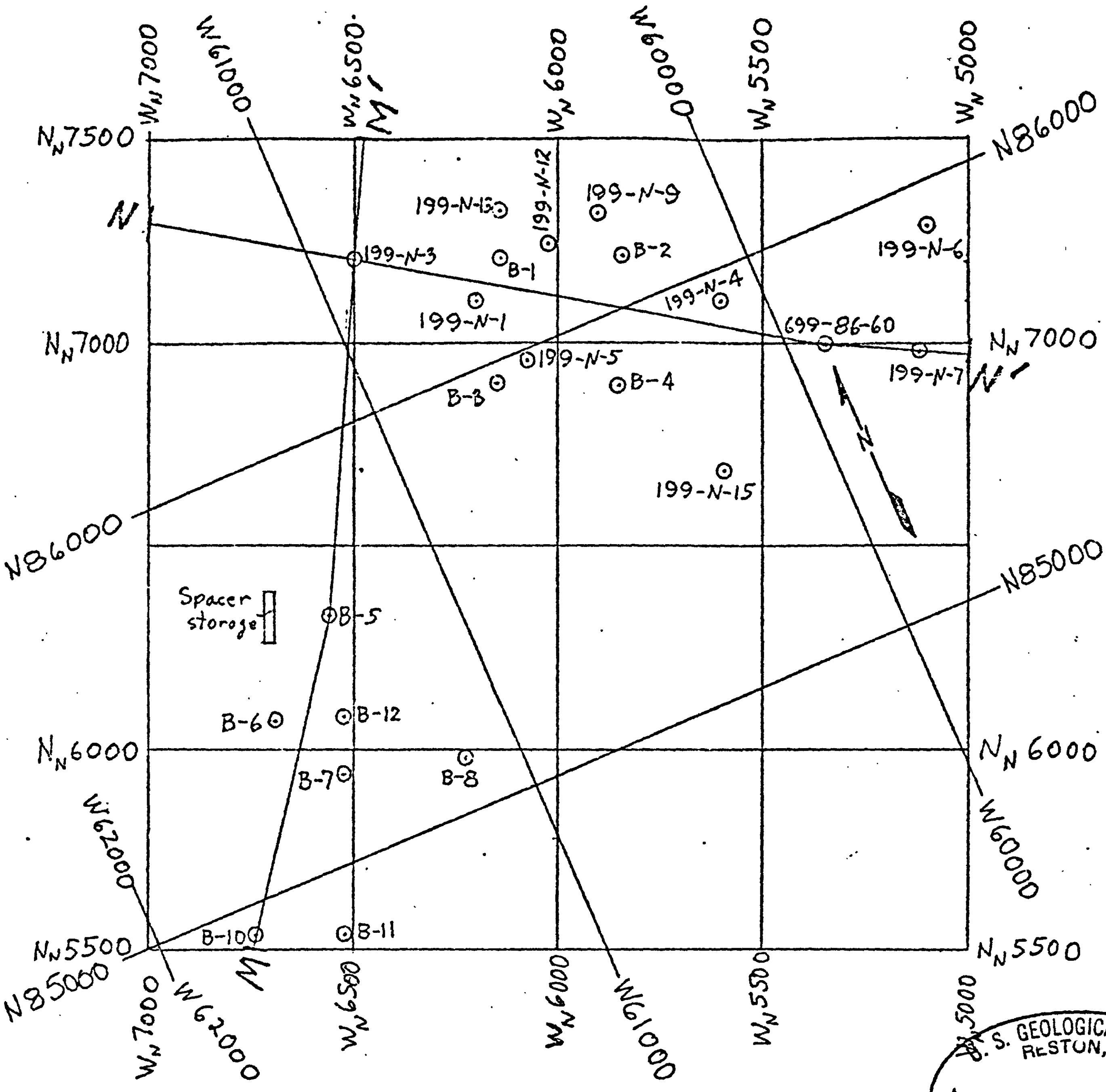
H-3-9951 Plot plan, 300 WYE burial ground

Layout and topographic map series

M-60 Index to M-600 maps

M-600 Inter area layout sheets

M-1600 Topography and culture of areas



Scale 1 inch to 400 feet

Figure 28.--Plan view showing lines of sections M-M' and N-N' and nearby wells and test borings.

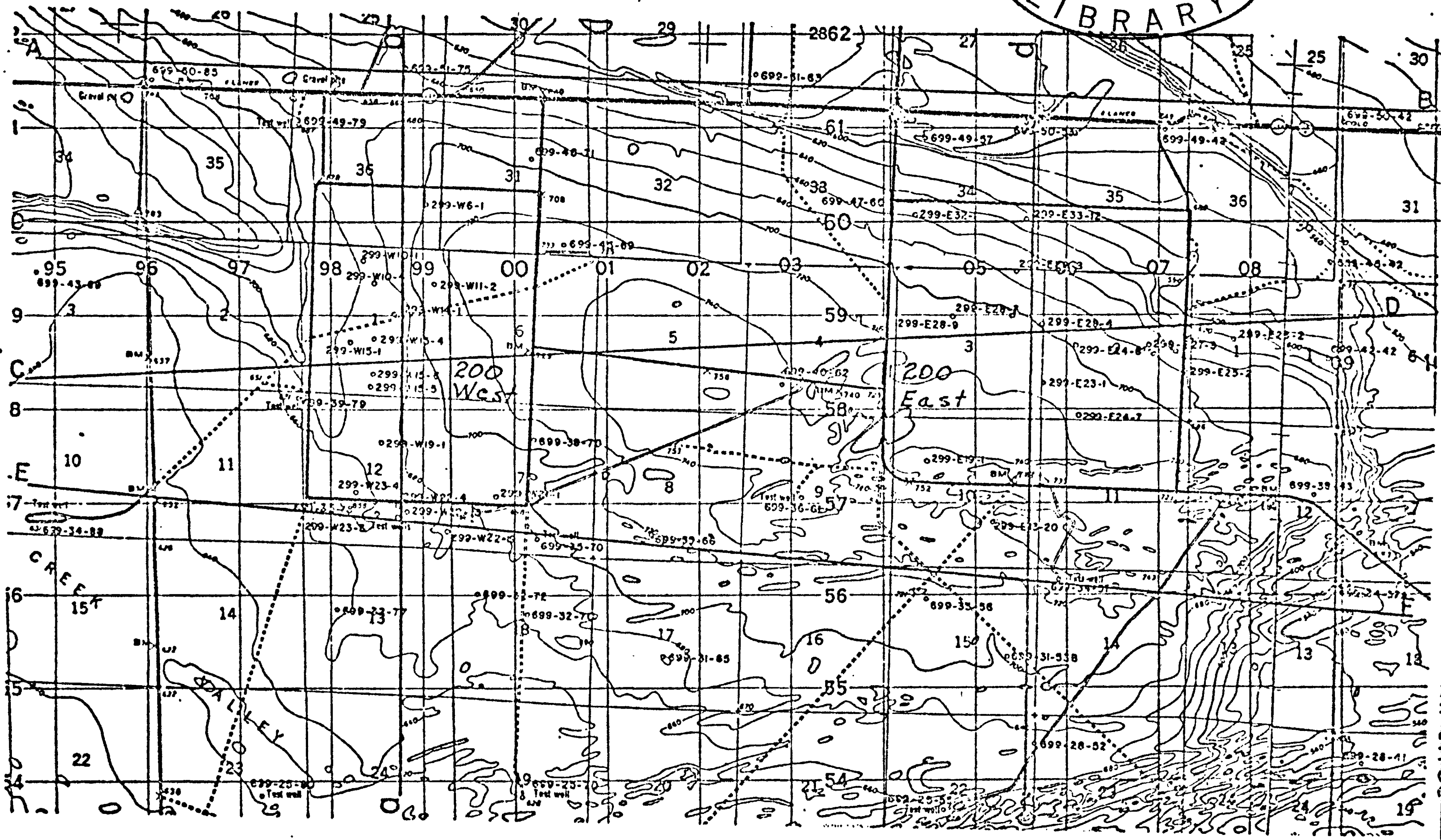


Figure 42.-- Topographic map of the 200 Areas and vicinity showing locations of cross sections and wells (Brown, 1959, fig. 2).

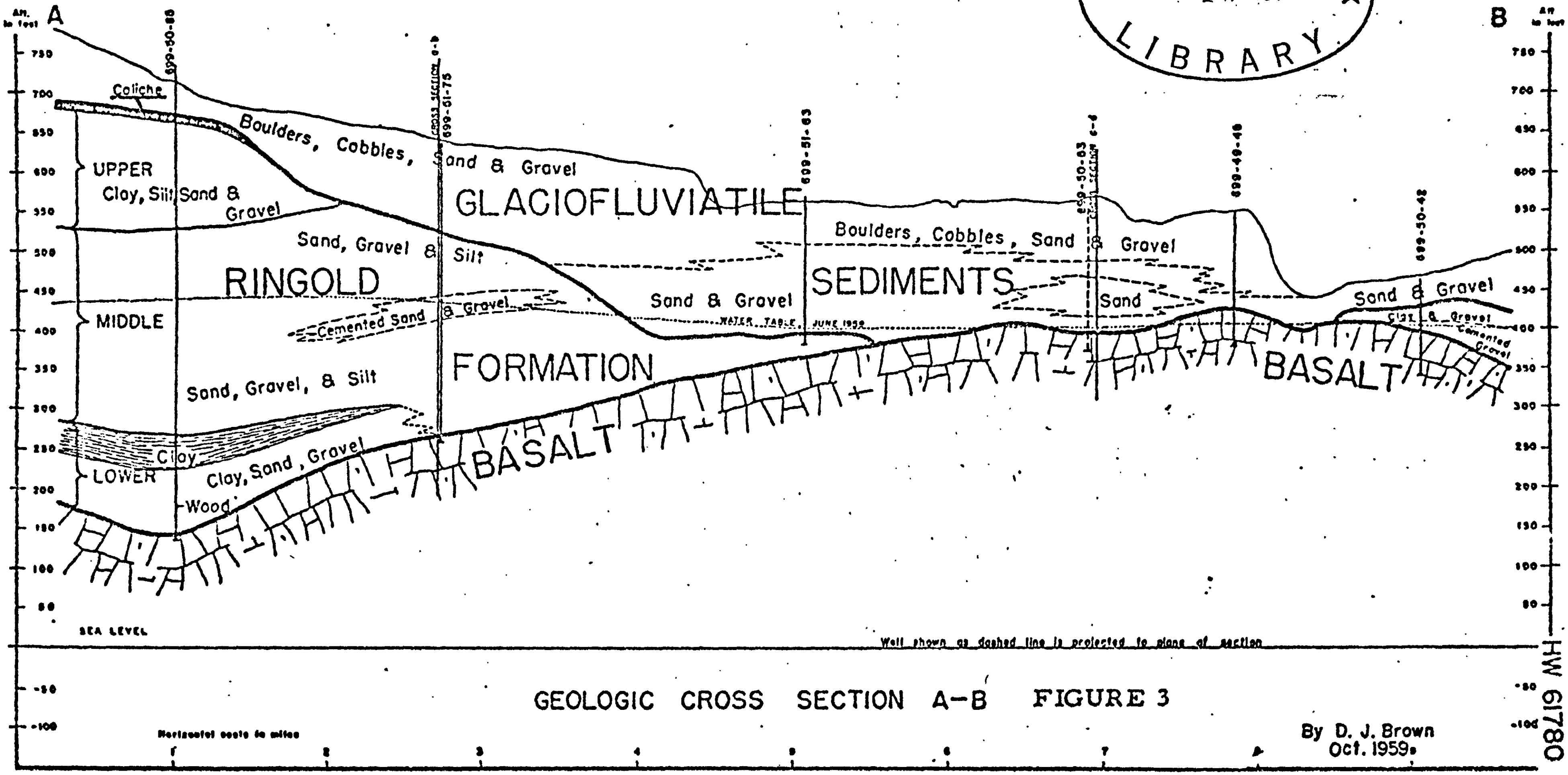


Figure 43.-- Geologic cross section A-B across the 200 Areas (Brown, 1959, fig. 3)

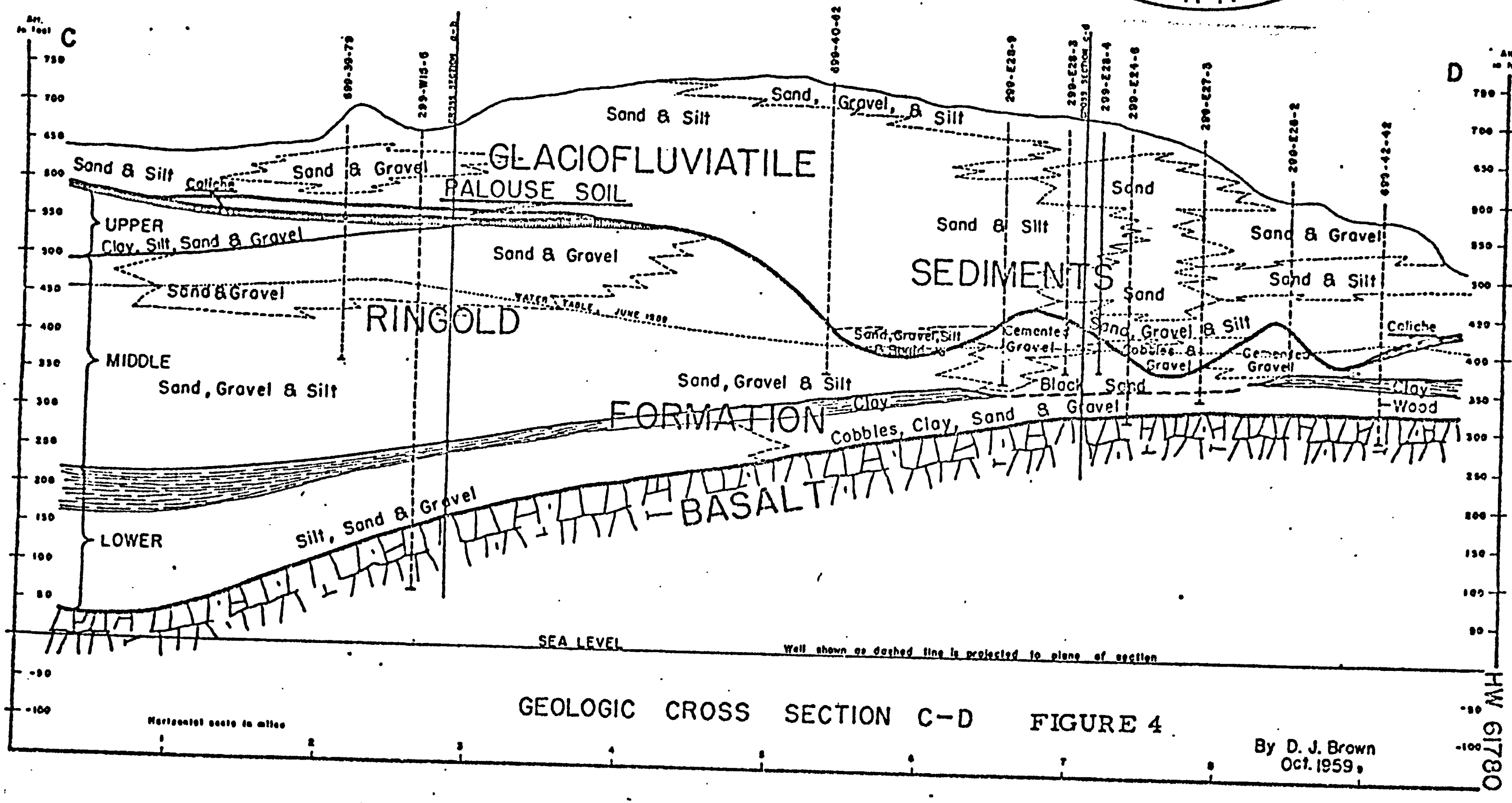
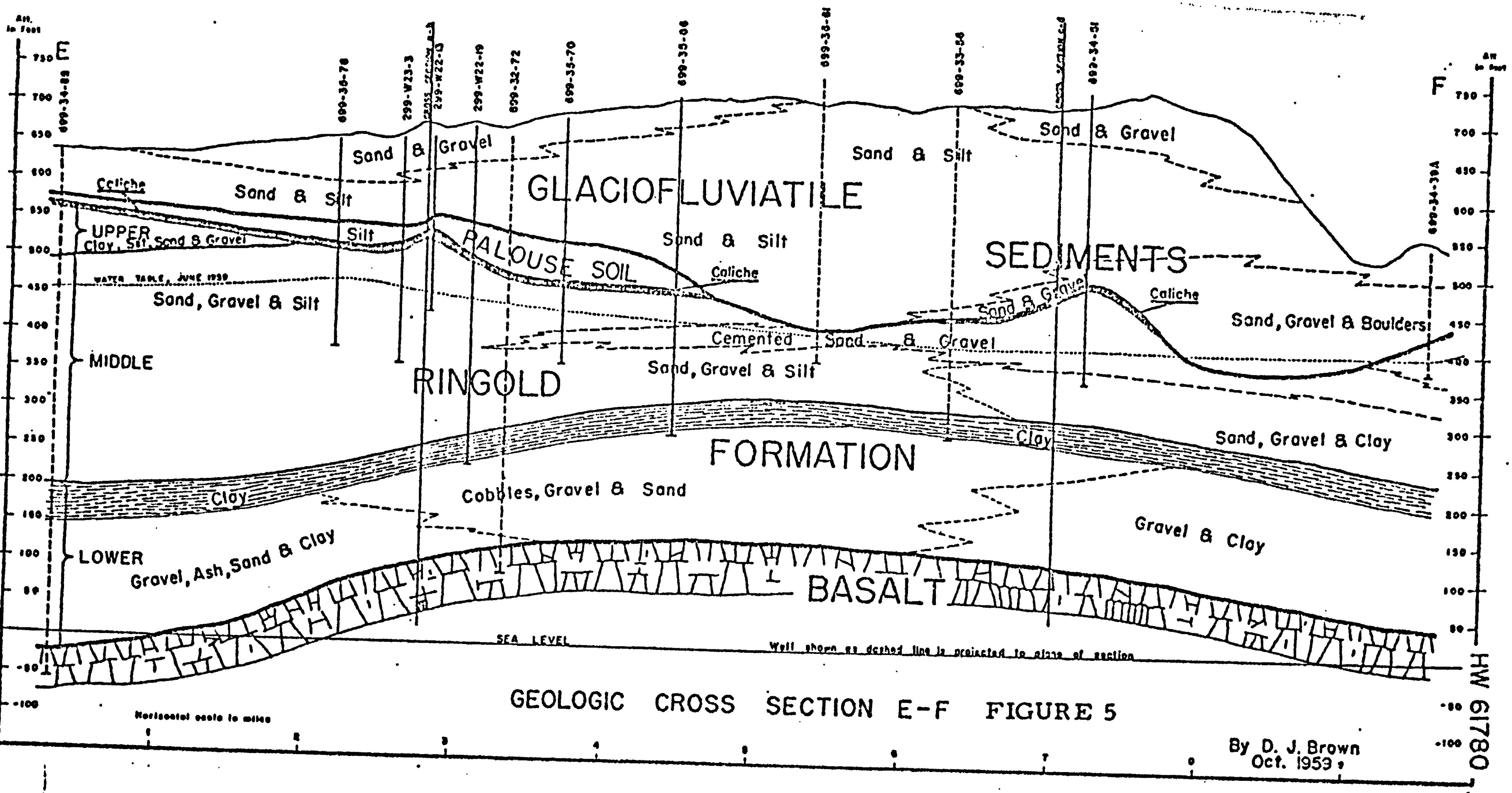
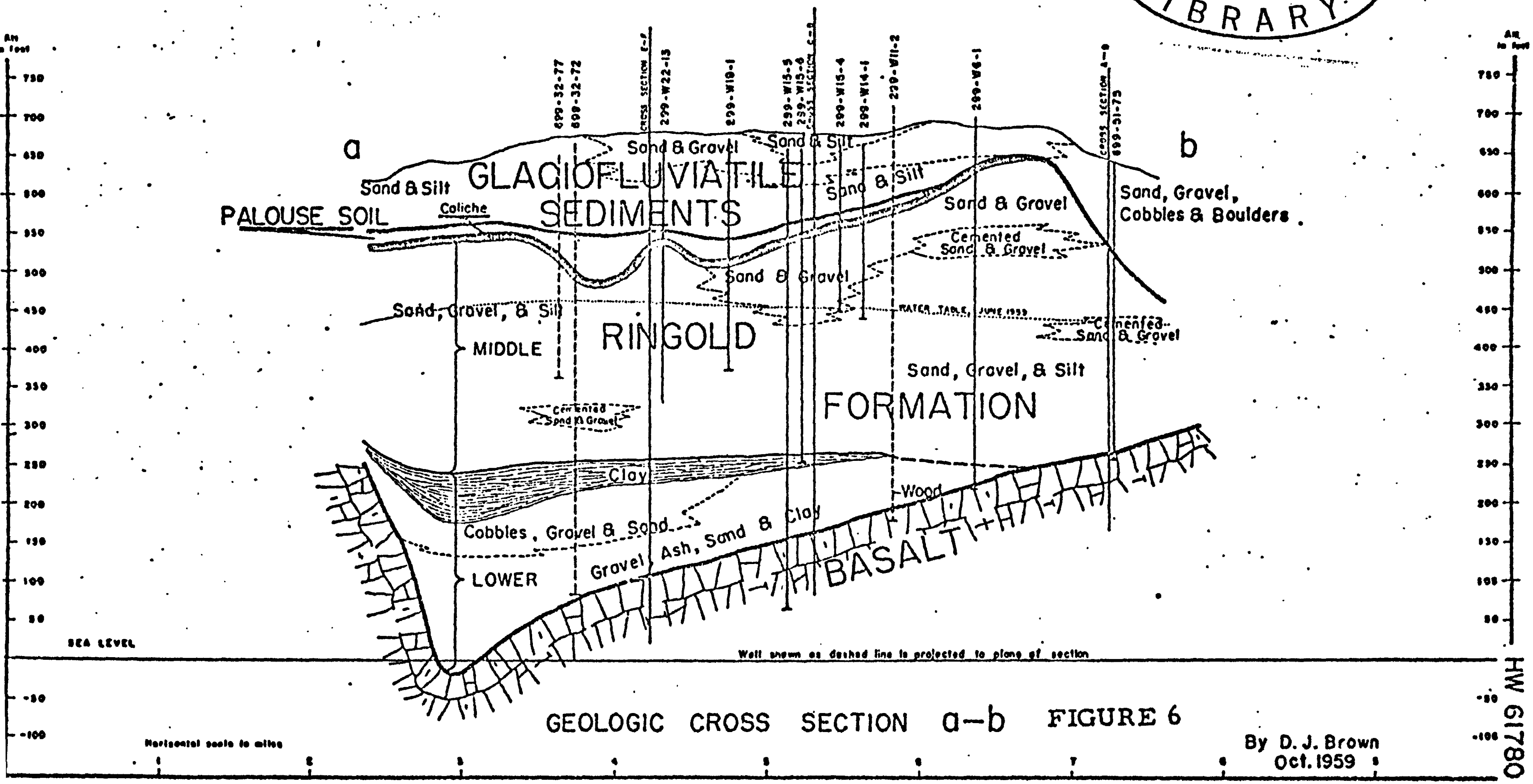


Figure 44.-- Geologic cross section C-D across the 200 Areas (Brown, 1959, fig. 4)



HW 61780

Figure 45.-- Geologic section E-F across the 200 Areas (Brown, 1959, fig. 5)



GEOLOGIC CROSS SECTION a—b FIGURE 6

By D. J. Brown
Oct. 1959

Figure 46.-- Geologic cross section a-b across the 200 Areas (Brown, 1959, fig. 6)

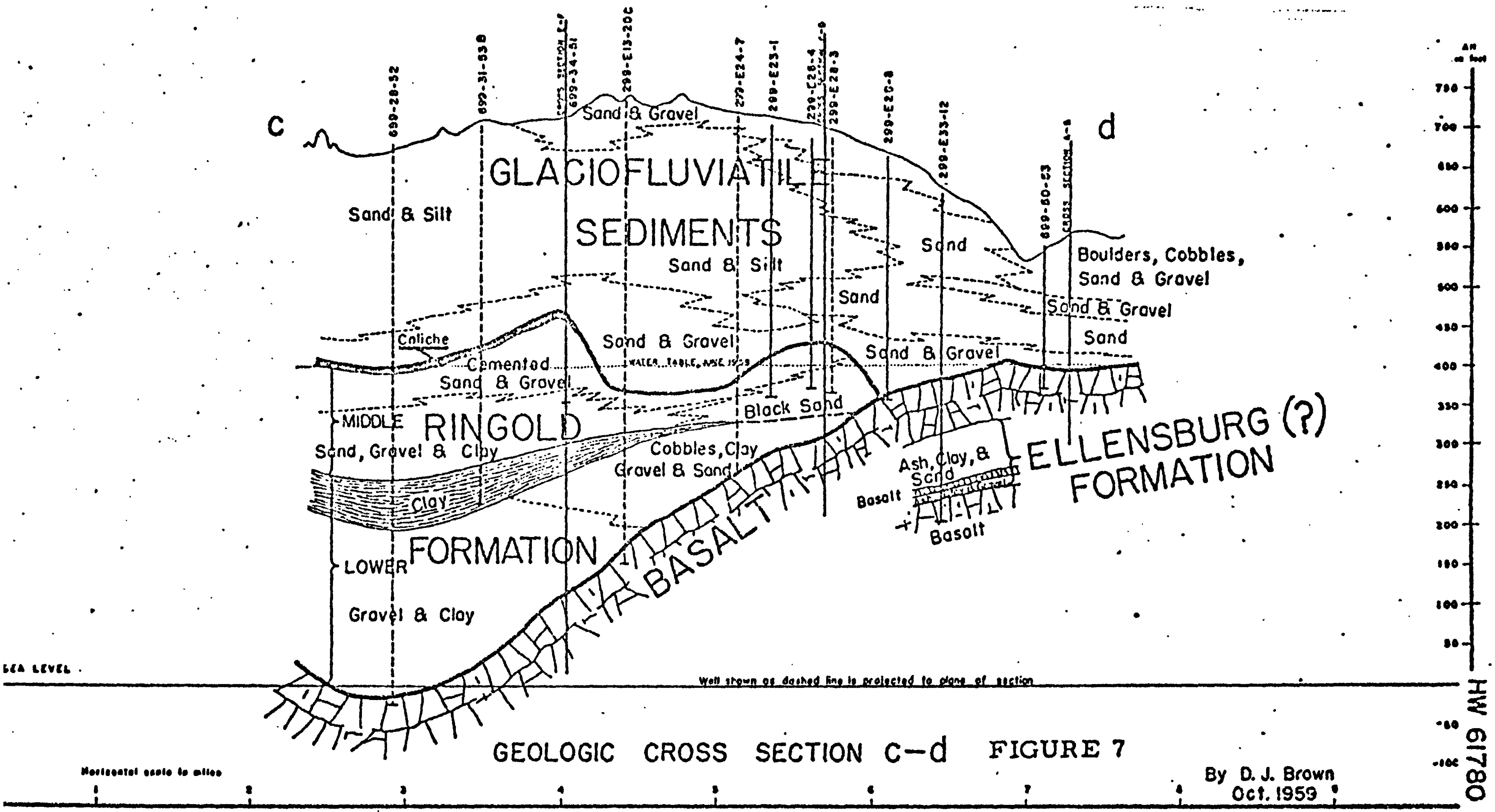


Figure 47.-- Geologic cross section c-d across the 200 Areas (Brown, 1959, fig. 7)