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HYDROLOGY OF THE MELTON VALLEY RADIOACTIVE-WASTE BURIAL GROUNDS AT OAK RIDGE NATIONAL LABORATORY, TENNESSEE

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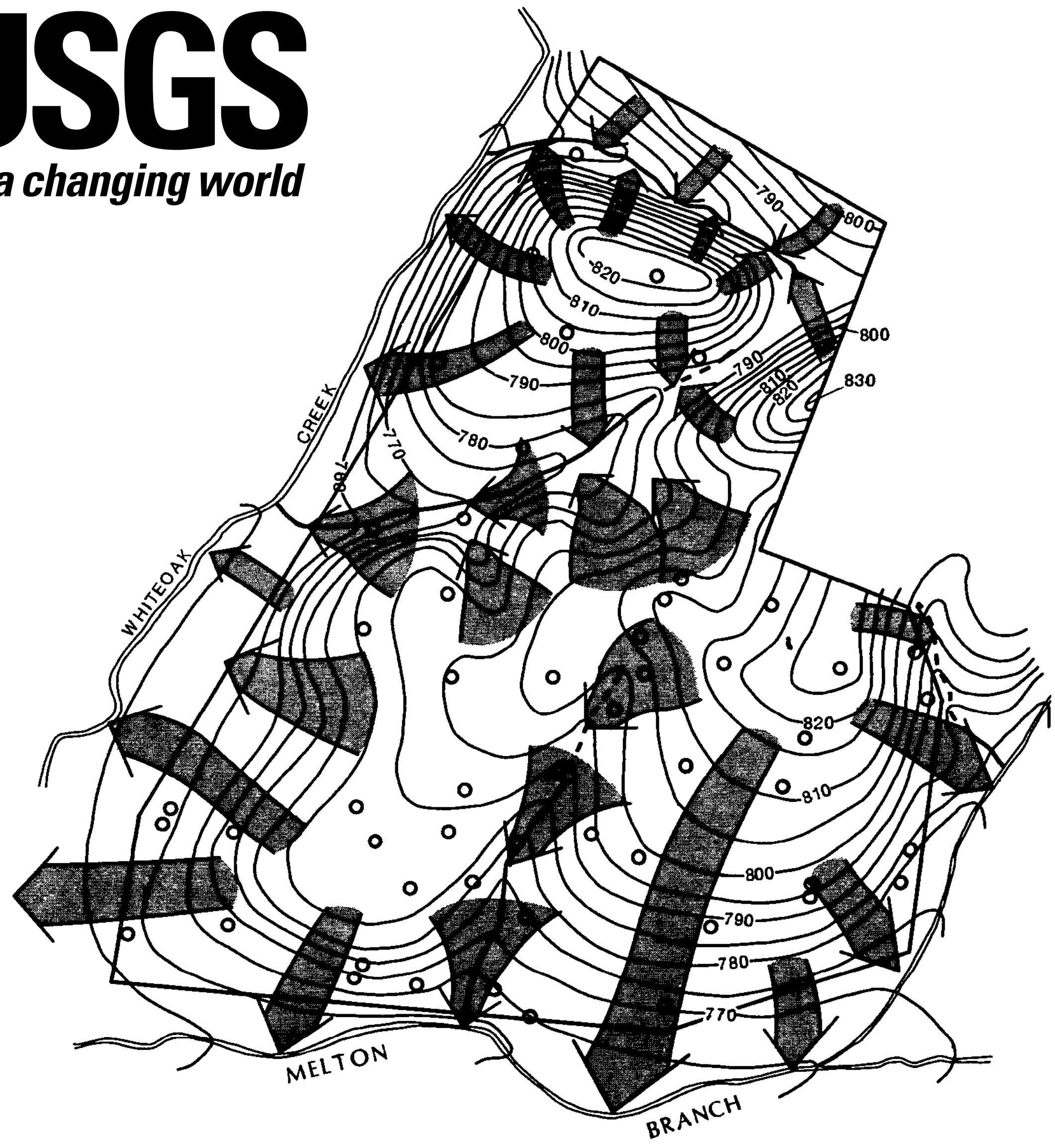

U.S. GEOLOGICAL SURVEY
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traveling along them would discharge to the drainage system in some shorter period of time.

BURIAL GROUND 6

Ground water occurs under unconfined, semi-confined, and perched conditions in burial ground 6. Unconfined and semi-confined conditions are found throughout the site. Perched conditions have been found below the hill in the southwest corner of the site, below the hill along the southeast boundary, and occasionally in new trenches. It is likely that perched water also occurs temporarily in many of the closed trenches that are above the water table.

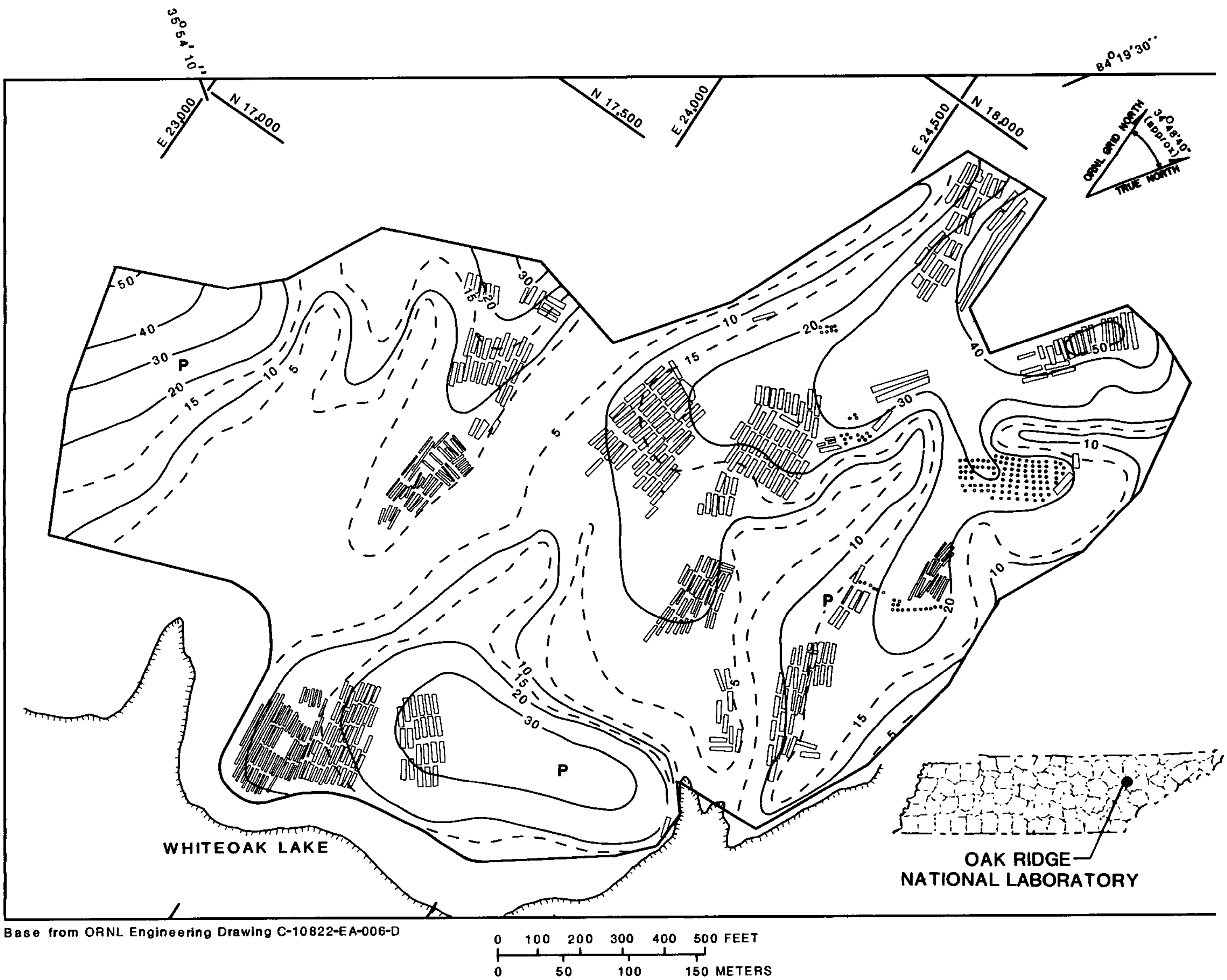
The depth to the water table is related to topographic location and season, as it is in burial ground 5. In winter, the depth ranges from essentially land surface along the drainages within the site to about 45 feet below the summit of the hill in the southwest corner. In fall, the range is about 1 to 2 feet to nearly 60 feet at these same locations.

Perched water occurs at shallower depths. Water is found in some of the shallow wells on the hill in the southwest corner of the site at as little as 5 feet depth after storms, and locally (well 351) at as little as 10 feet depth below the hill near the southeast boundary. Water commonly is perched above the water table in some of the trenches about 5 to 6 feet deep that contain compacted waste, located between wells 343 and 355. Water also has been reported perched in several of the trenches in the 49-trench area (in the vicinity of wells 107 and 317; Arora and others, 1981, p. 20-25), although the liquid in many of these trenches could result from a seasonal rise of the water table.

The depth to the water table on May 31, 1978, a date typical of mid-season conditions, is shown in figure 18. Depth at that time of year is 15 feet or less through as much as half of the area within the burial ground. Wastes have been buried in this zone, but most of the trenches have been cut to depths of less than 15 feet. Some trenches in this area, however, are known to penetrate the water table seasonally, if not perennially. Most trenches between the 5-foot and 10-foot contours contain animal tissue having very low levels of radiation. Trenches with this category of waste are shorter, narrower, and shallower than those containing other forms of contaminated waste. Wastes with elevated levels of activity have been buried in the topographically higher areas of the site. These wastes rest in trenches generally about 10 to 35 feet above the water table.

Water levels in wells fluctuate from less than 1 foot to perhaps as much as 20 feet annually. Minimal fluctuations are associated with the wells near drainages; maximum fluctuations are associated with the wells on the hill in the northwest corner of the site. In the latter area this range includes perched water. Actual fluctuation of the water table below the higher areas of this hill is about 10 to 12 feet annually, and is the maximum water-table fluctuation for the site.

Hydrographs of the shallow wells in burial ground 6 generally resemble those of burial ground 5, and again reflect the lithologic and hydrologic properties of the aquifer. The character of the individual hydrographs commonly



EXPLANATION

—5— **LINE OF EQUAL DEPTH TO WATER**--Interval 10 feet. Supplementary intervals at 5 feet and 15 feet. Datum is land surface

P **AREA WHERE PERCHED WATER OCCURS AT SHALLOWER DEPTH THAN CONTOURS INDICATE**

▭ **TRENCH WITH RADIOACTIVE WASTE**--Information current through July, 1985

∴ **AREA WHERE WASTE HAS BEEN BURIED IN AUGER HOLES**--Pattern denotes areas, not individual holes. Information current through 1983

—— **SITE BOUNDARY**

N 17,500 **OAK RIDGE NATIONAL LABORATORY GRID COORDINATE**

Figure 18.--Depth to water table at burial ground 6, May 31, 1978.

grades from one well to another, which probably reflects gradational changes in the lithology and the aquifer.

Slug tests were completed in 16 of 20 wells tested at this site. The wells were constructed into the Maryville Limestone and Nolichucky Shale. Results of the tests are given in table 5. Apparent transmissivities range from 1.2 to 68.2 ft^2/d; apparent hydraulic conductivities range from 5.6×10^{-2} to 6.7 ft/d. Taking the mean of the 6 wells (TR6-4 to TR6-10) in the tracer-test array as a single well so as not to give that area undue weight, the geometric mean of the hydraulic conductivities is 4.5×10^{-1} ft/d. This approximates that of burial ground 5's 5-south area, which is based upon data from nearly twice as many wells.

Data of the slug tests in burial grounds 4, 5, and 6 suggest that wells open to regolith derived primarily from shale formations have a lower hydraulic conductivity than wells open to regolith derived from limestone formations. This is

Table 5.--*Aquifer-test data of wells completed in the regolith at burial ground 6*

[Formation: Cnl, Nolichucky Shale; Cmr, Maryville Limestone]

Well No.	Formation	Apparent transmissivity (ft2/d)	Apparent hydraulic conductivity (ft/d)
368	Cmr	68.2	5.4
371	Cnl	1.6	1.6×10^{-1}
372	Cnl	2.6	1.3×10^{-1}
37	Cmr	3.5	2.8×10^{-1}
376	Cnl	17.3	2.2
379	Cnl	3.2	3.0×10^{-1}
380	Cnl	20.4	1.2
381	Cnl	2.2	1.7×10^{-1}
383	Cnl	1.9	2.2×10^{-1}
385	Cmr	1.2	5.6×10^{-2}
6-4	Cnl	28.6	6.2
6-5	Cnl	33.3	6.7
6-6	Cnl	3.9	1.1
6-8	Cnl	12.5	2.4
6-9	Cnl	16.0	1.6
6-10	Cnl	8.3	8.6×10^{-1}

illustrated by figure 19, on which the apparent hydraulic conductivities of all wells in the three burial grounds that yielded data matchable to type curves are plotted on a logarithmic scale versus formation. The geologic map in figure 5 was used to determine the parent lithology for each well. It may be noted that the range in apparent hydraulic conductivities of wells in shale regolith is about the same as that in limestone regolith. It is significant, however, that the low end of the range is dominated by wells in areas underlain by the Pumpkin Valley Shale, a mud shale, and the upper end is dominated by wells both in the Maryville Limestone, which contains the thickest and purest carbonate beds underlying the burial grounds, and the Nolichucky Shale, which has a significant carbonate component within this area. Between these two ends, the values tend to intermix, and reflect the fact that the formations above the Pumpkin Valley are impure mixtures of lithified mud and lime. A clear relationship between hydraulic conductivity and lithology is occluded because so much of the local stratigraphic column, despite the lithotype indicated by formation name, is composed of clastic particles held in a carbonate matrix and carbonate beds containing significant percentages of clastic particles. The relationship probably is further occluded by the non-uniformity in depth and extent of weathering, which influences the development of secondary permeability within each formation.

A water-table contour map of burial ground 6 (fig. 20) indicates that recharge to the regolith is received from areas of higher head underlying the hills to the northwest and from the infiltration of rain that falls upon the site. The principal recharge area within the burial ground is the upland through the north-central part of the site. This includes areas where both the higher activity wastes and low-level wastes have been buried. The hills in the southwest corner and near the southeast border of the site also provide recharge, but probably in amounts subordinate to that through the north-central area.

Bentonitic soil covers have been emplaced over three areas having numerous waste-filled trenches to reduce direct infiltration through the waste. The bentonitic caps likely have little effect on total recharge to the site as infiltration that is not absorbed by the clays or lost by evapotranspiration must move laterally, either as shallow subsurface flow or as overland runoff. It then has potential to infiltrate downward after passing the perimeter of the treated areas.

The general direction of ground-water flow is shown by arrows on figure 20. Again, flow in local areas may be diverted from the directions shown to a direction closer to formation strike by beds resistant to weathering and gradients within subsurface structural features. During winter, a ground-water mound develops below the hill along the southeast boundary, and the flow pattern in this area changes from that shown. The mound dissipates by flow in all directions. That part of the mound facing northwest drains to the two small streams to its north and west. Seasonally high potentials in this area also cause flow from the north-central part of the site to be diverted to these same drainages at that time.

A French drain (fig. 20) installed in late-1983 also can be expected to cause local distortions to the flow pattern shown. The drain is about 30 feet deep near its elbow, from which

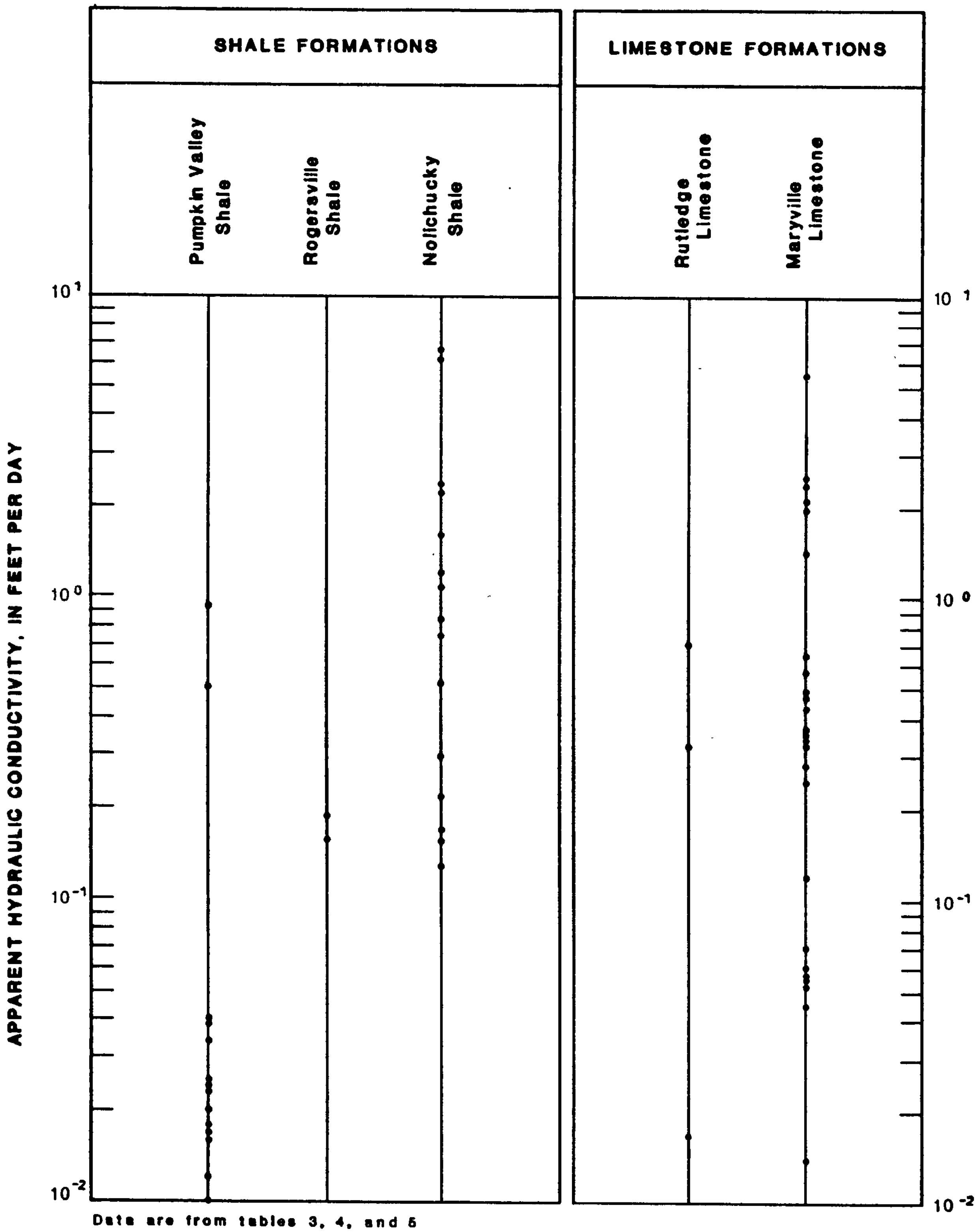
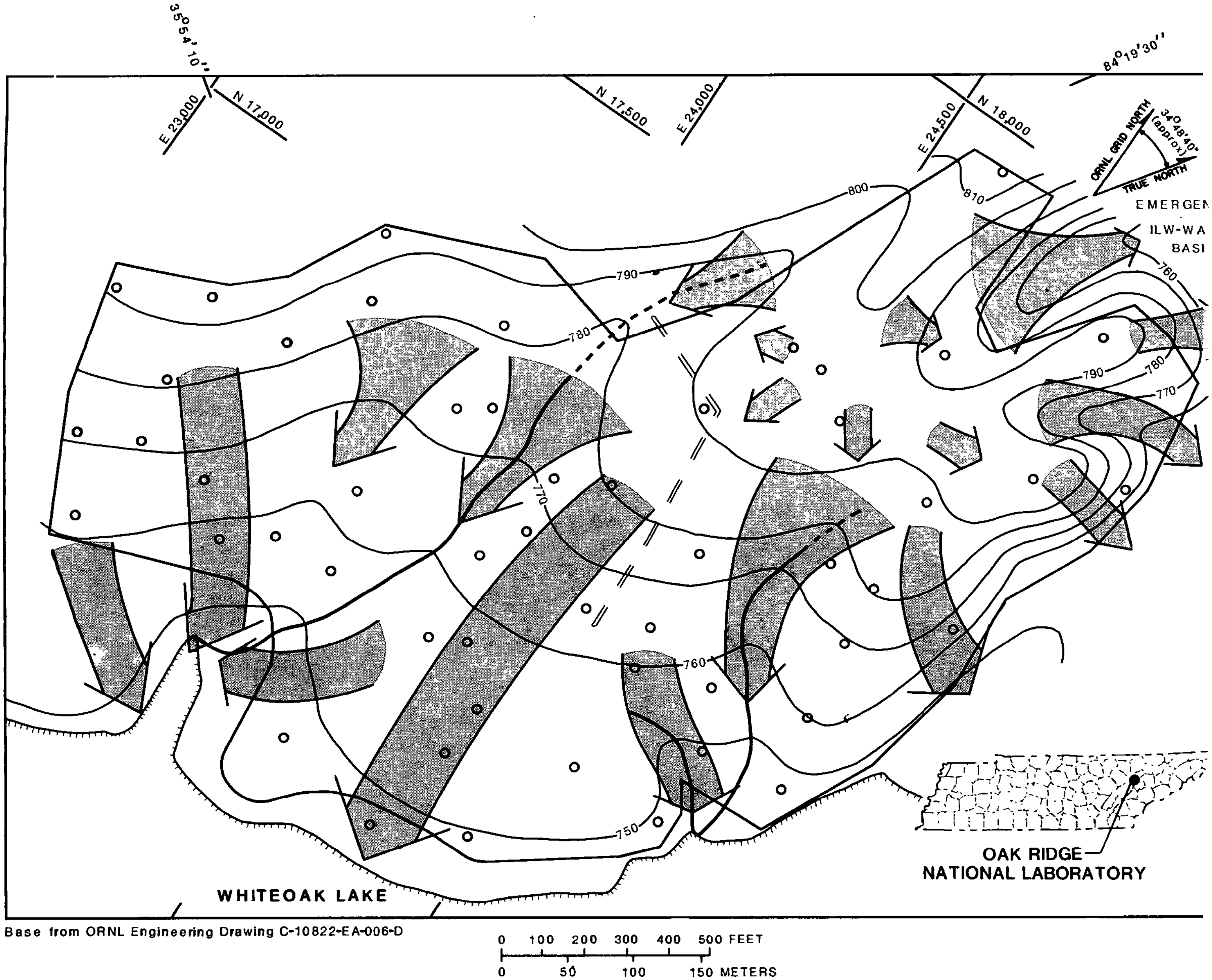


Figure 19.--Logarithmic distribution of apparent hydraulic conductivities by formation.



EXPLANATION

- —760— WATER-TABLE CONTOUR--Shows altitude of water table. Contour interval 10 feet. Datum is sea level
- o WELL
- - - — DRAINAGE
- WHITEOAK LAKE SHORELINE (1978)
- SITE BOUNDARY
- = FRENCH DRAIN--Installed in 1983
- GENERAL DIRECTION OF GROUND-WATER FLOW IN REGOLITH
- N 18,000 OAK RIDGE NATIONAL LABORATORY GRID COORDINATE

Figure 20.--Water-table contours at burial ground 6 for typical mid-season condition, May 31, 1978, and general direction of ground-water flow.

point both limbs extend down-gradient at a slight angle to terminate at, and to discharge their fluid upon land surface. Where the drain is below the water table the equipotential lines may shift northerly, and where the unlined section of the drain is above the water table, and at both ends, the equipotential lines may shift southerly as a result of ground-water recharge. Regardless, flow lines adjusted for this influence would still lead to the two small drainages to the west and south of the drain.

It is of interest to note that excavation of the drain revealed unrippable beds at two points on the north limb (Davis and Stansfield, 1984, p. 24-26). These beds probably are limestone, and likely represent local barriers to flow across them. Where the inferred water-table gradient crosses them, the beds will divert flow to a point where they are fractured or sufficiently weathered to permit the passage of water through them. They provide an example of zone 2 of the conceptual model of flow through the regolith.

Discharge from the regolith of this burial ground is to the drainages within the site, the drainage along the northeast boundary, and directly into Whiteoak Lake. Thus, all discharge from the regolith of this disposal site is into the Whiteoak Creek system. The contour pattern indicates that discharge is disseminated along the lengths of the drainages and the lake's shoreline without its being concentrated along any particular reach.

Unlike burial grounds 4 and 5, trenches at this site do not overflow. This appears to be a result of restricting trench length, depth, and location. However, one seepage into the drainage has been found west of well 279 (Cerling and Spalding, 1981, p. 79).

Average velocity of flow through much of the site can be estimated by substituting the following values in equation (1):

K = 0.45 ft/d, representing the geometric mean of the hydraulic conductivities of wells tested;

n = 0.03, derived from the ground-water tracer tests in this burial ground; and

dh/dl = 0.055, the average hydraulic gradient through the central and western sectors of the site.

A velocity of 0.82 ft/day is indicated for midseason.

The slope of the water table below the east end of the site where the higher-activity wastes have been buried is about four times greater than that to the west, which implies greater velocity of flow. The transmissivity of the regolith in this area, though, probably is less because the depth to water is greater, and therefore, the saturated thickness of the material is less. Unfortunately, only two of the four wells (368 and 385) tested in this area yielded usable data, and the results differ by two orders of magnitude. If a hydraulic conductivity of 1.0×10^{-1} ft/d, which is thought reasonable, can be assumed "average" for the greater depth, a flow velocity no greater than that of the area to the west results.

The time required for a particle of water to travel along the longest flow path from point of recharge to point of discharge into Whiteoak Lake at the indicated velocity would be 5 to 6 years. Actual time of travel may be considerably less because of seasonally higher gradients, interception of a more highly permeable pathway, geologic structures that could divert flow to a shorter pathway, and a French drain that could intercept flow and discharge the particle almost immediately. The indicated time of travel from all other points within the burial ground would be less than that calculated because of shorter distances to points of discharge.

HYDROLOGY OF THE BEDROCK

BACKGROUND AND METHOD OF INVESTIGATION

From prior studies it had been generally thought that radionuclides dissolved in ground water are unlikely to be transported into the bedrock because of the high sorption and ion exchange potential of the weathered Conasauga Group and the very low permeability of the underlying bedrock. In 1976, as a part of this study, geophysical logs were made of the small number of wells that had been drilled into the bedrock underlying burial grounds 5 and 6, and of one well in the ILW area during earlier years. Gamma logs revealed anomalous concentrations of gamma activity as much as 100 feet below the top of bedrock; spectral logging identified the activity as cesium-137 in the burial-ground wells and cesium-137 and cobalt-60 in the ILW-area well. Both isotopes are associated with nuclear waste, thereby implying subsurface transport of those contaminants through bedrock from point of disposal to the wells. Because of the finding of radionuclides in a medium that hitherto had been thought to be virtually immune to them, the scope of this work was expanded in 1977 to include consideration of ground-water flow and radionuclide transport through the material underlying the regolith. The objective was not to hypothesize and test a different concept of flow than previously conceived, but to build upon it with information useful for further describing flow in the bedrock.

Additional information requirements for the expanded study were the lithology and structure of the rock, the extent of secondary openings in the rock, the transmissivity of the material, the vertical and lateral hydraulic gradients, and the magnitude and extent of present contamination. The hydrologic information was obtained by constructing new wells as piezometers and monitoring potentiometric heads in them, installing packers in five existing wells to obtain supplemental data on head relationships, performing aquifer tests, logging numerous wells in Melton Valley with geophysical instruments, and obtaining radiochemical analyses of water from the piezometers. Much of the geologic information necessary was developed by ORNL scientists under a related program.

RESULTS

Piezometers

Five clusters of piezometers were constructed in burial ground 5 between 1977 and 1982. They are referred to as the north, south, east, west, and central clusters; their locations are shown on the well location map of burial ground 5, figure 7. The north cluster includes wells 469A, 470, 471, 472; the south cluster, wells 461, 462, 463, and 464; the east cluster, wells 473, 474, 475, and 476; the west cluster, wells 465, 466, 467, and 468; and the central cluster, wells 458, 459, 460, 439, and 440. The depth interval open to each well is given in table 7 (except the regolith wells) and in the appendix.

Potentiometric-head data were collected from wells in the first cluster during two long interruptions in their construction between 1977 and 1979, and after their completion in 1979. Data collection at the other piezometers was initiated upon their completion in late 1982. The periods of record have been interrupted by pumping the wells in 1979 (two wells only), 1983, 1984, and 1985 to obtain water samples for chemical analyses. Record collection was resumed in most of the wells before the water surfaces had reached their static level, but because the period of recovery at a few wells is of several months duration, the record of meaningful head relationships at those wells contains large hiatuses. At this time (1985) a complete data set for the entire suite of piezometers and water-table wells is not available for any one date. Consequently, altitudes of the static, potentiometric surfaces at a few piezometers as noted have been estimated on the basis of other record and relationships in order to complete the relationship within the cluster, to relate clusters, and to develop the conceptual model of flow described subsequently.

At the north cluster (fig. 21), a difference in heads of 7 to 9 feet drives water downward from water-table depth to the 100-foot level. A small difference of less than 1 foot exists between the 100- and 150-foot levels. The vertical component of flow in this interval is downward for several months of the year, but may reverse during the spring months owing to the deeper zone's slow recovery from its seasonal decline in potential. With such a small difference in heads, water in this interval probably has a larger component of lateral flow than vertical flow. A more substantial head difference of 4 to 6 feet exists between the 150- and 200-foot level, giving water between these depths a downward component of flow. The data indicate that the shallow and deeper rock at this site are in ground-water recharge zones; the rock at intermediate depth (100 to 150 feet) probably is in a divide between recharge and discharge zones.

At the south cluster (fig. 22) the vertical component of ground-water flow is upward relative to the water table, and is evidenced by piezometers that were flowing wells before their casings were extended. The ranges in difference in the potentiometric heads between the water table and the 100-, 150-, and 200-foot zones are about 4 to $5^1/2$ feet, 6 to 8 feet, and $4^1/2$ to 9 feet, respectively. The higher heads with increasing depth provide a driving force upward to horizons having lower head, indicating that this cluster is in a ground-water discharge area. An exception to this relationship exists for a few months during early winter when the potentiometric head in the 150-foot zone recovers from its seasonal decline before that of the 200-foot zone, causing the 150-foot zone temporarily to have a higher potentiometric pressure than that of the underlying zone. During these months pressure in the 150-foot zone precludes an upward component of water movement from the lower strata in this

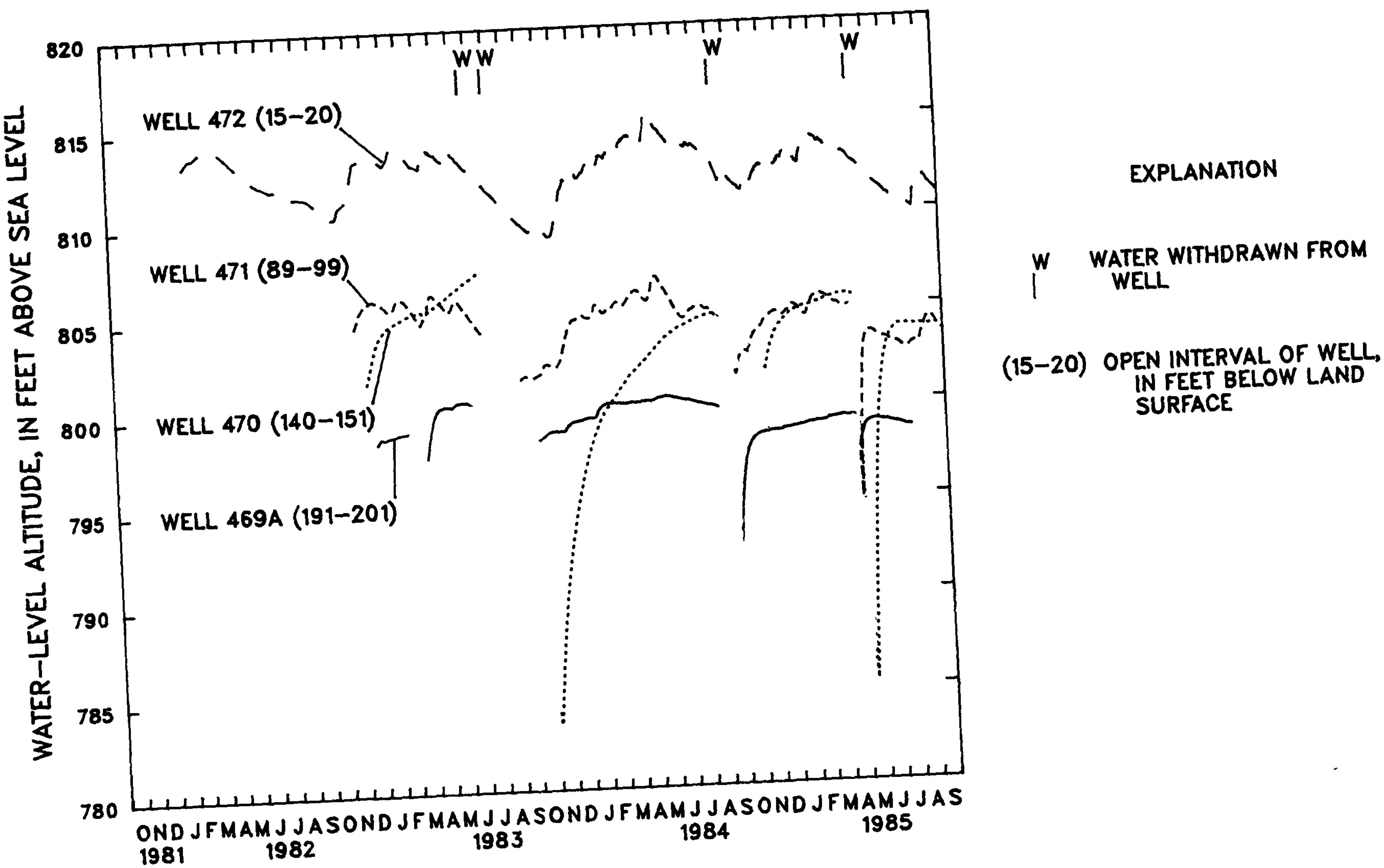


Figure 21.--Hydrographs showing head relations with depth at the north well cluster, burial ground 5.

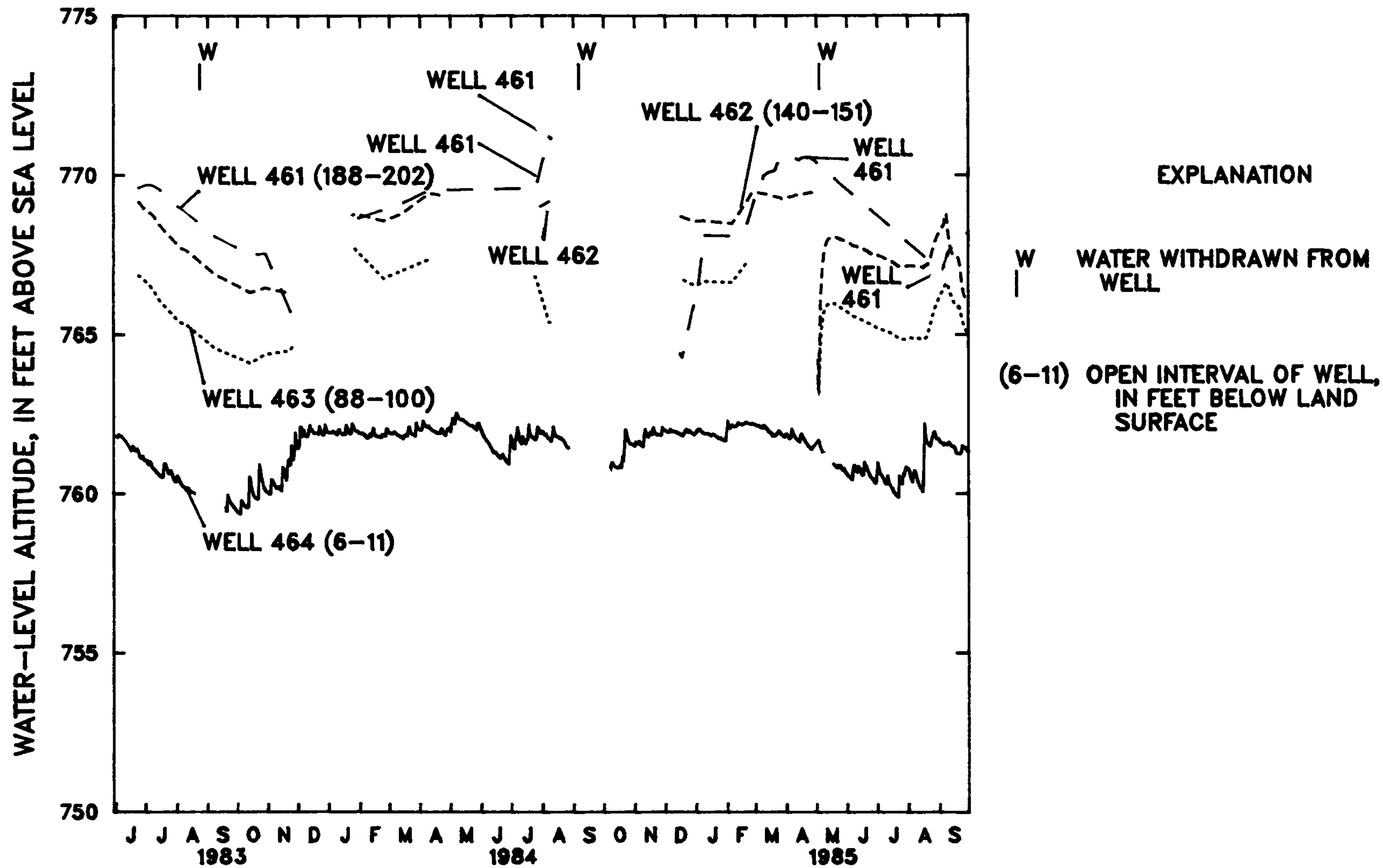


Figure 22.--Hydrographs showing head relations with depth at the south well cluster, burial ground 5.

area, even though the head relationship between the water table and the 200-foot zone has not changed.

The potentiometric-head relationships of the water-table well and the piezometers of the east cluster (fig. 23) indicate that this site also is in a ground-water discharge area. Differences in heads between the water table and the 100- and 150-foot piezometers range from about $^1/_2$ to 4 feet and $3^1/_2$ to 7 feet, respectively. The usable record of well 473 (the 200-foot piezometer) is short. From March to July 1983 the static water level in this well stood about 1 to 2 feet higher than that of well 474, 3 to 6 feet higher than that of well 475, and 3 to 8 feet higher than that of well 476. A higher potential of this well relative to the other three also is indicated by the record of mid-summer 1984 before the well was pumped. An upward component of flow from all four horizons thus is characteristic of this site.

At the west cluster, the 100-foot piezometer has a potentiometric head that is 2 to 6 feet lower than the water-table well and $1^1/_2$ to 3 feet lower than the 150-foot piezometer (fig. 24). Several more months must pass before the water surface in the 200-foot piezometer reaches its static level. In order to complete the characterization of this cluster, it is estimated that the altitude of the static potentiometric surface in the 200-foot piezometer stands 2 to 3 feet higher than that of the 150-foot piezometer. This estimate is based on the general similarity between the topographic position of this site with that of the south and east clusters, and the short distance between the site and the principal stream of the area. Thus, the vertical component of flow at this site is downward toward the 100-foot zone from the water table, and inferred to be upward toward the 100-foot zone from the 200-foot zone. The shallow rock is in a recharge area, whereas the deeper rock is in a discharge area.

The central cluster is located on a slope. Because of a 6- to 7-foot difference in water-table altitudes in the two shallow wells (wells 439 and 440), it is necessary to calculate water-table altitudes at a single point for the period of interest. For this purpose, altitudes have been computed for a point midway between the two wells. This point lies a short distance north of well 460, the 100-foot piezometer. The hydrograph of the water-table well shown on figure 25 thus is not that of an actual well, but a synthesized hydrograph based on the data of wells 439 and 440 for a well if constructed at this point. If the water table at points represented by the 150- and 200-foot piezometers (wells 459 and 458, respectively) is compared to the potentiometric surface in those same wells, the water table will stand somewhat higher, and the differences between the water table and potentiometric surface will be correspondingly greater than that shown in figure 25.

The highest potentiometric head is found in the 140-foot piezometer and the second highest in the water-table well, indicating a downward component of flow from the regolith to the 100-foot zone and an upward component of flow from the 140-foot zone to the 100-foot zone. The lowest head in the group is found in the 200-foot piezometer, indicating another downward component of flow between 140 and 200 feet. It also may be noted that during the interruption in construction during 1977-78, the potentiometric head in well 458, open at that time from 100 to

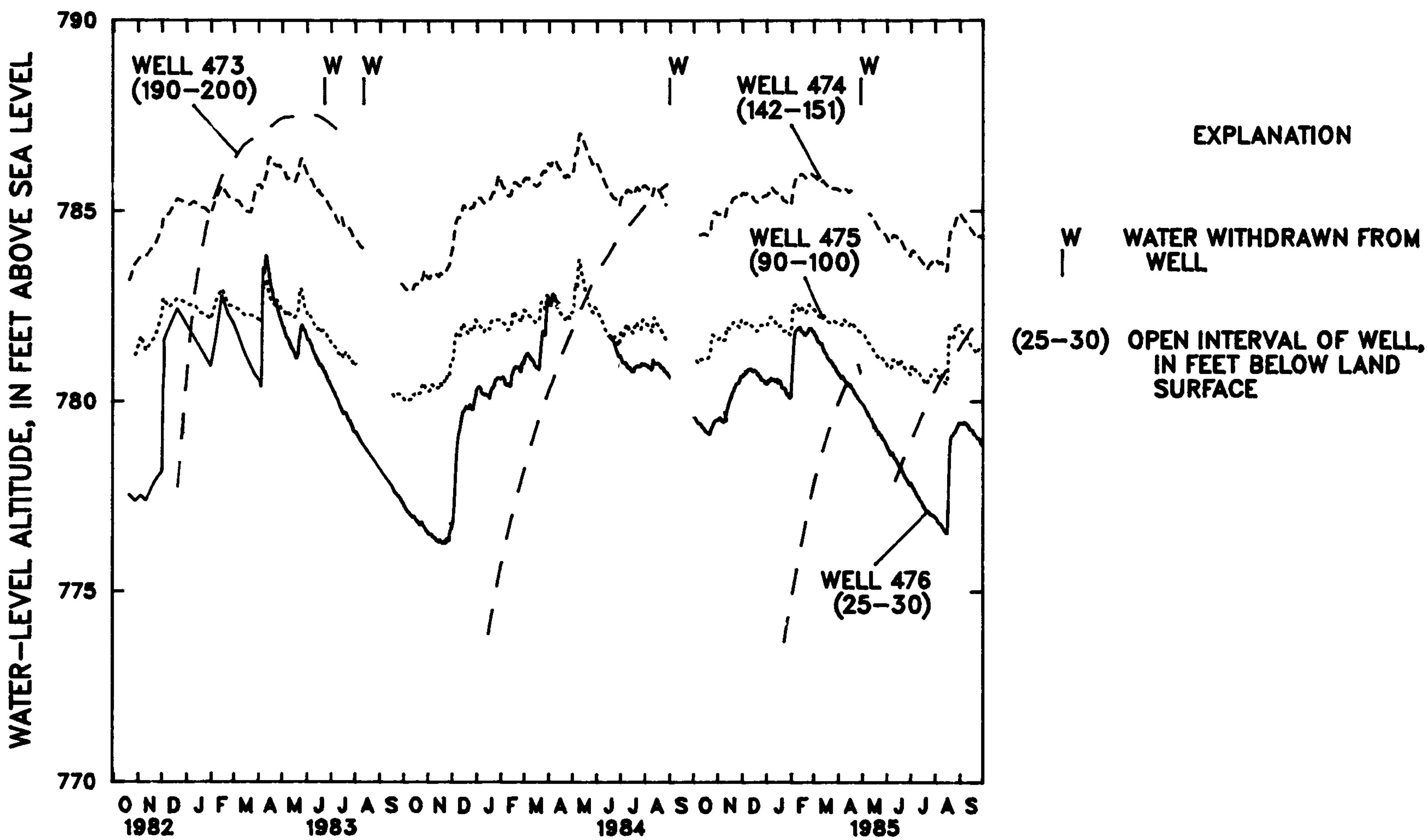


Figure 23.--Hydrographs showing head relations with depth at the east well cluster, burial ground 5.

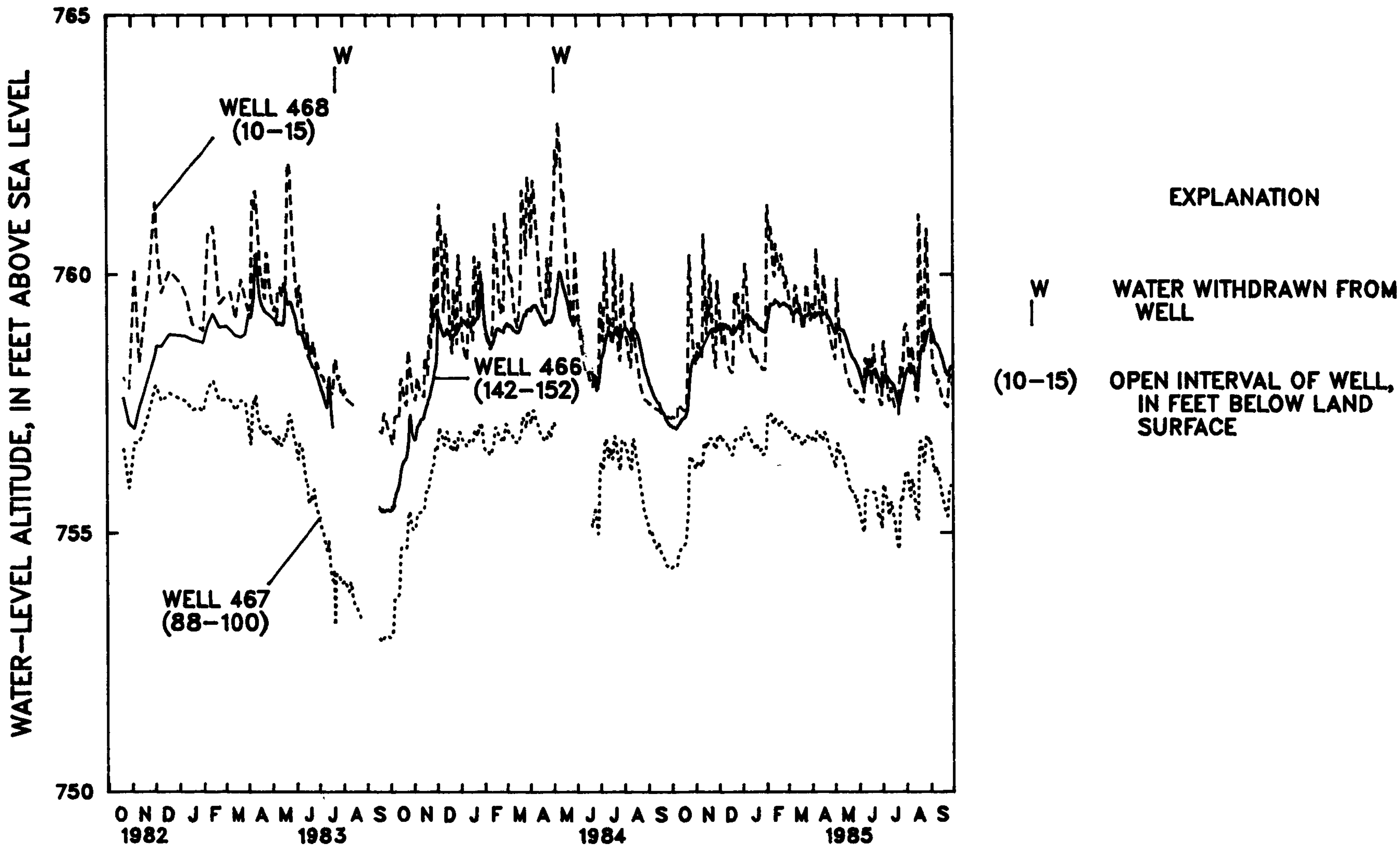


Figure 24.--Hydrographs showing head relations with depth at the west well cluster, burial ground 5.

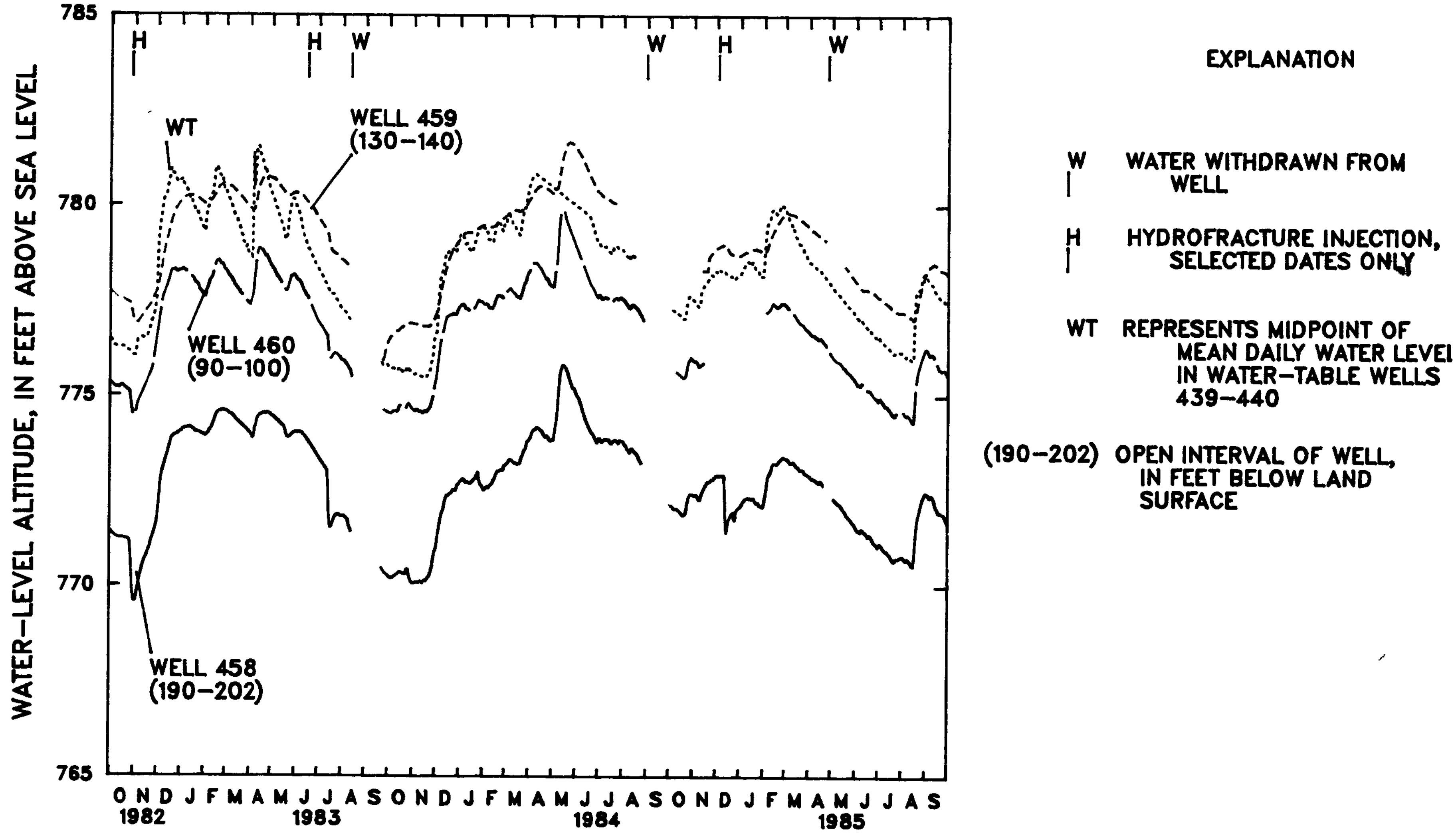


Figure 25.--Hydrographs showing head relations with depth at the central well cluster, burial ground 5.

150 feet, indicated an upward component of flow relative to well 460, open from 44 to 100 feet. It appears that at this site the rock at shallow depth (above 100 feet) is in a ground-water recharge zone; the rock at intermediate depth (100 to 150 feet) is in a discharge zone; and the rock at greater depth is in another recharge zone.

Examination of the potentiometric data for these clusters shows two stresses superimposed upon the normal seasonal rise and decline of the water surface in some of the wells. The stresses are considered here because of their potential to alter the basic head relationship between piezometers. The first, of natural origin, is earth tides which result in a diurnal rise and decline of water levels. The patterns of water-level change, time of peaks, and amplitude of the wave from piezometer to piezometer are variable. With a maximum amplitude of about 0.15 foot in those records where this phenomenon is identifiable, the effects of earth tides are of insufficient magnitude to reverse the head relationships at any cluster. The other stress is the hydraulic fracturing of bedrock at a nearby waste-disposal facility (fig. 1, site HF-2). The rock beneath that facility is fractured at depths of about 1000 to 700 feet to enable the injection of liquid radioactive-waste carried in a grout slurry. Pressure created within the rock by fracturing and injecting the slurry has caused the water levels in some of the piezometers to respond, although the responses have been variable.

The effect of recent injections has been to depress water levels in piezometers in the central cluster, and to raise water levels in some of the piezometers of the west, north, and east clusters. Inasmuch as the south cluster was not instrumented until 1985 the effects in that area are not yet determinable. The largest impact recorded was at well 458 (the 200-foot piezometer) in the central cluster where a 1.5-foot decline resulted from fracturing on July 12, 1983, and pressure of slurry injection 1 to 2 days later (fig. 25). The water levels in wells 459 and 460 (the 150- and 100-foot piezometers, respectively) each declined about 0.5 foot as a result. The pattern of response was for declining water levels over a period of several days, followed in well 458 by a partial recovery for a shorter period of time. Smaller changes that were more quickly assimilated were associated with the other clusters. Although water-level records for all clusters during injection events are incomplete, it appears that the direction of change (that is, either up or down) is consistent for each bedrock well within a cluster. Water levels in the shallow wells that extend only short distances below the water table are not affected by injections. It does not appear that the magnitude of water-level change in the central cluster, the site most impacted by this stress, has been sufficient to alter the basic potentiometric-head relationships between the three piezometers within the cluster, or with those of the other clusters, by the pressures developed.

Packers

To supplement information provided by the piezometers, single packers were installed in each of the five wells (wells 174 through 178) in burial ground 5 that had been drilled into bedrock during the pre-site evaluation of 1958-1960. In three of these wells the packers were set at various depths in bedrock for a few days in order to obtain head relationships above and below the packer. Later, the packers were set for a period of 8 months or longer in the five wells at the first horizon below the bottom of the casing at which a hydraulic seal could be developed. The principal purpose of setting packers at these horizons was to provide data about the head relations near the regolith-bedrock interface.

At well 174 (fig. 26) the top of the packer was set in August 1981 at a depth of about 60 feet, slightly above the existing water surface in the well. In the months that followed, the water surface gradually rose above the packer and finally stabilized at depths ranging from about 38 to 45 feet. The potentiometric surface of the zone below the packer fluctuated within a range of about 53 to 60 feet. A head loss of about 15 to 20 feet between the two zones indicates that water in the regolith and upper bedrock near this well has a substantial downward component of flow. Packer settings at depths of 95, 107 and 115 feet for a few days at each setting also indicated a downward component of flow relative to the intervals above and below the packer. The duration of each setting, however, was inadequate to determine the magnitude of the difference in static potentials between the two intervals.

The comparatively long period of time (about 4 months) taken for the upper water level to stabilize when the packer was set at 60-feet depth suggests that this well, by vertical flow within the well bore, drained the regolith over an area of large radius surrounding it, much the same as a well that is continually pumped causes a cone of depression to develop in the area surrounding it. To investigate this possibility, the water-level in well 445, about 200 feet to the south of well 174 and the closest well to it, was monitored from August 1981 to August 1982. No significant change in water level patterns from that of 1977-79 was found to occur in this well. If local drainage of the regolith did occur through well 174, the area drained did not extend as far south as well 445.

At well 175 (fig. 27) the top of the packer was set at a depth of about 43 feet. The potentiometric surface of the zone below the packer (45 to 148 feet) rose about 2 feet above that of the zone above the packer, indicating a slight upward component of flow from the bedrock into the regolith. The relationship reversed for short periods of time following the more substantial recharge events. Previous packer settings for short periods of time showed that at depths of 108 and 122 feet, very little difference (about one-half foot) existed in the potentiometric surfaces above and below the packer. At 130 feet, however, the potentiometric surface for the zone above the packer stood about 2-$^1/_2$ feet higher than that for the lower 20 feet of the well, indicating a downward component of flow at that depth.

Packers were set in wells 176, 177, and 178 at depths of 53, 61, and 42 feet, respectively. Head relationships between the zones above and below the packer indicated downward components of flow at each well, similar to that of well 174, although of smaller magnitude (figs. 28, 29, and 30). In well 176, additional settings at depths of 95 feet, 110 feet, and 123 feet also indicated downward components of flow at those depths, relative to the zones above and below the packer.

These data show that water in the lower regolith/upper bedrock at each well except well

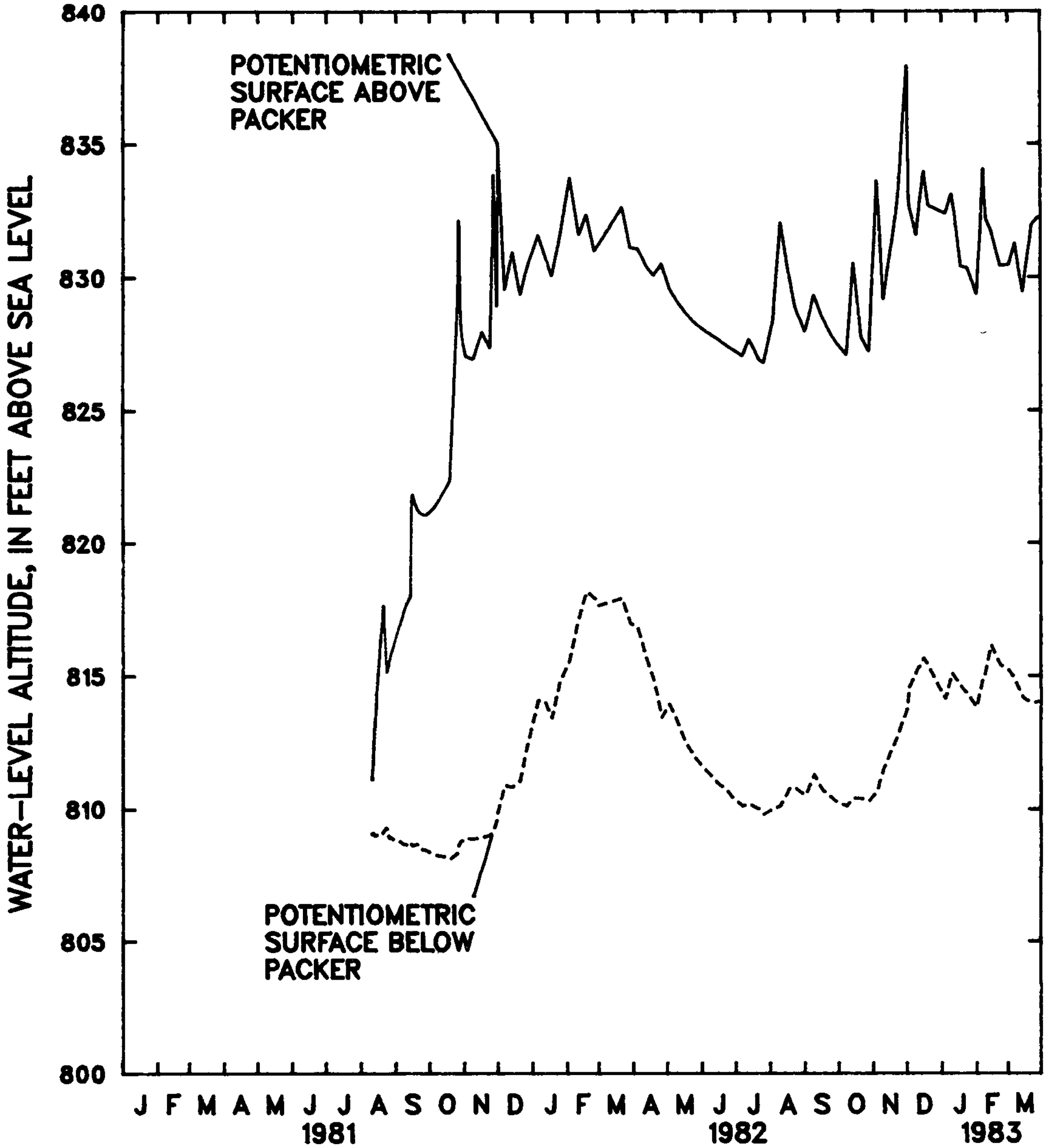


Figure 26.--Hydrographs showing vertical gradient at well 174 with packer set at 60- to 64-foot depth.

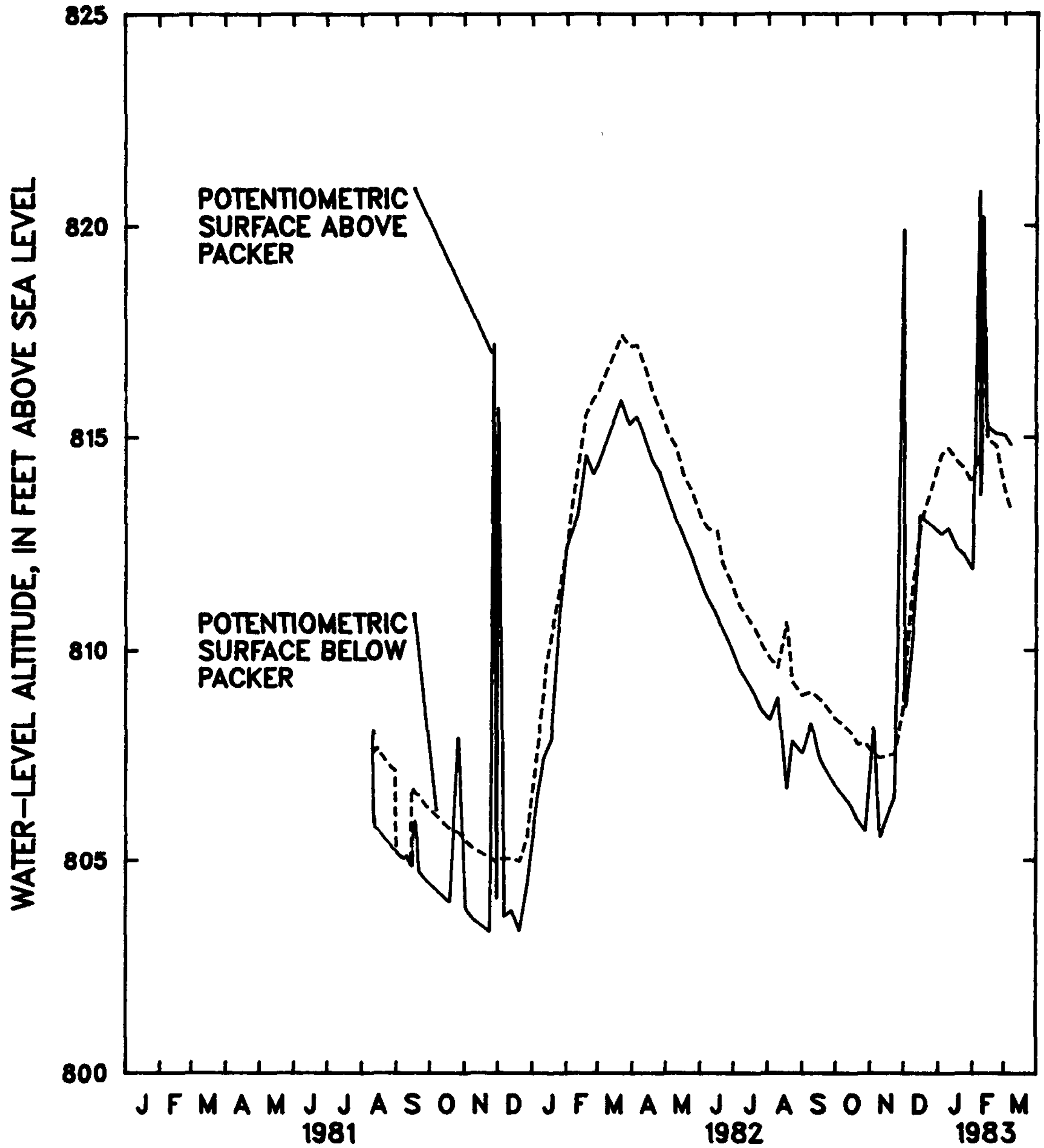


Figure 27.--Hydrographs showing vertical gradient at well 175 with packer set at 43- to 45-foot depth.

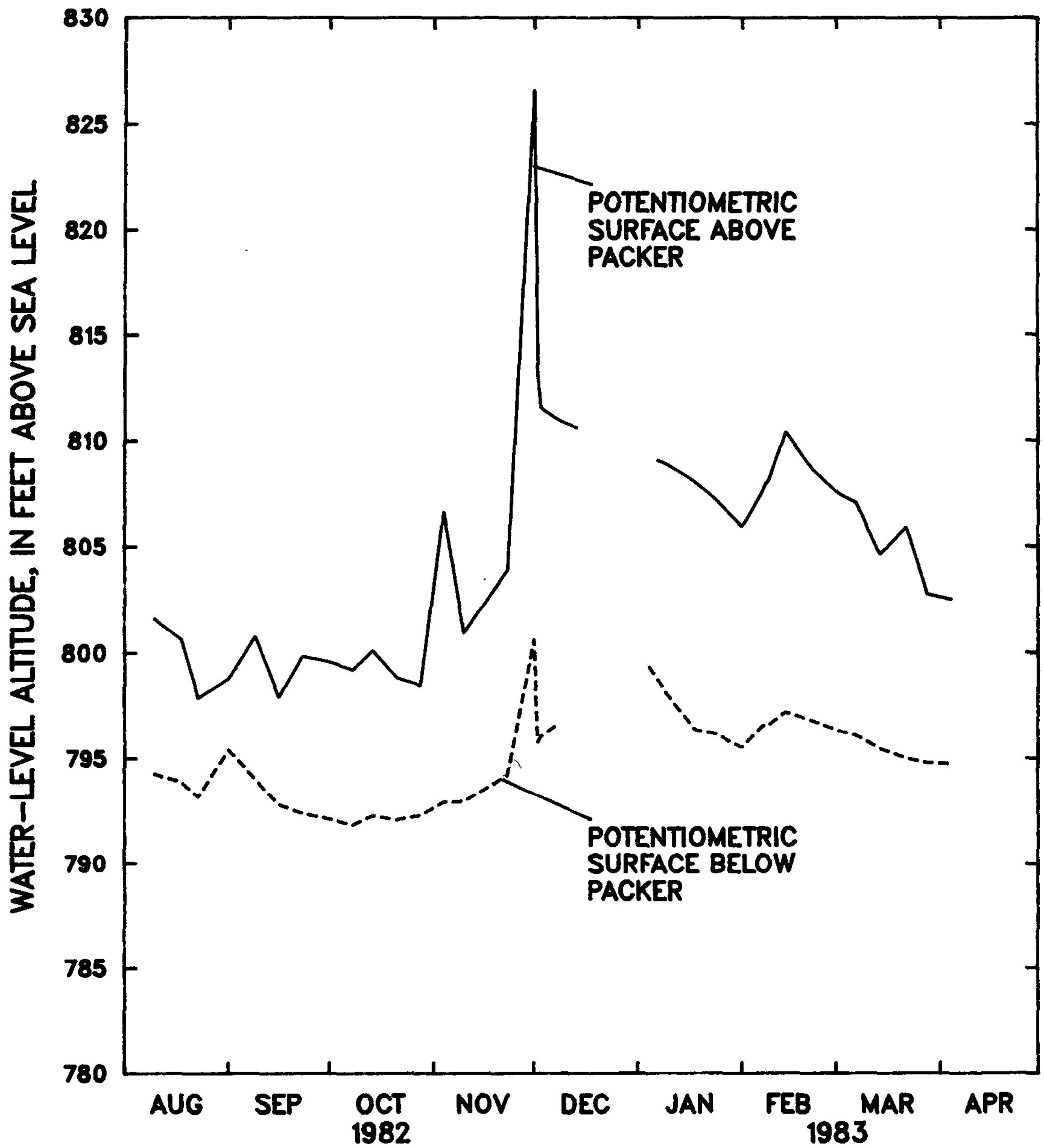


Figure 28.--Hydrographs showing vertical gradient at well 176 with packer set at 52- to 54-foot depth.

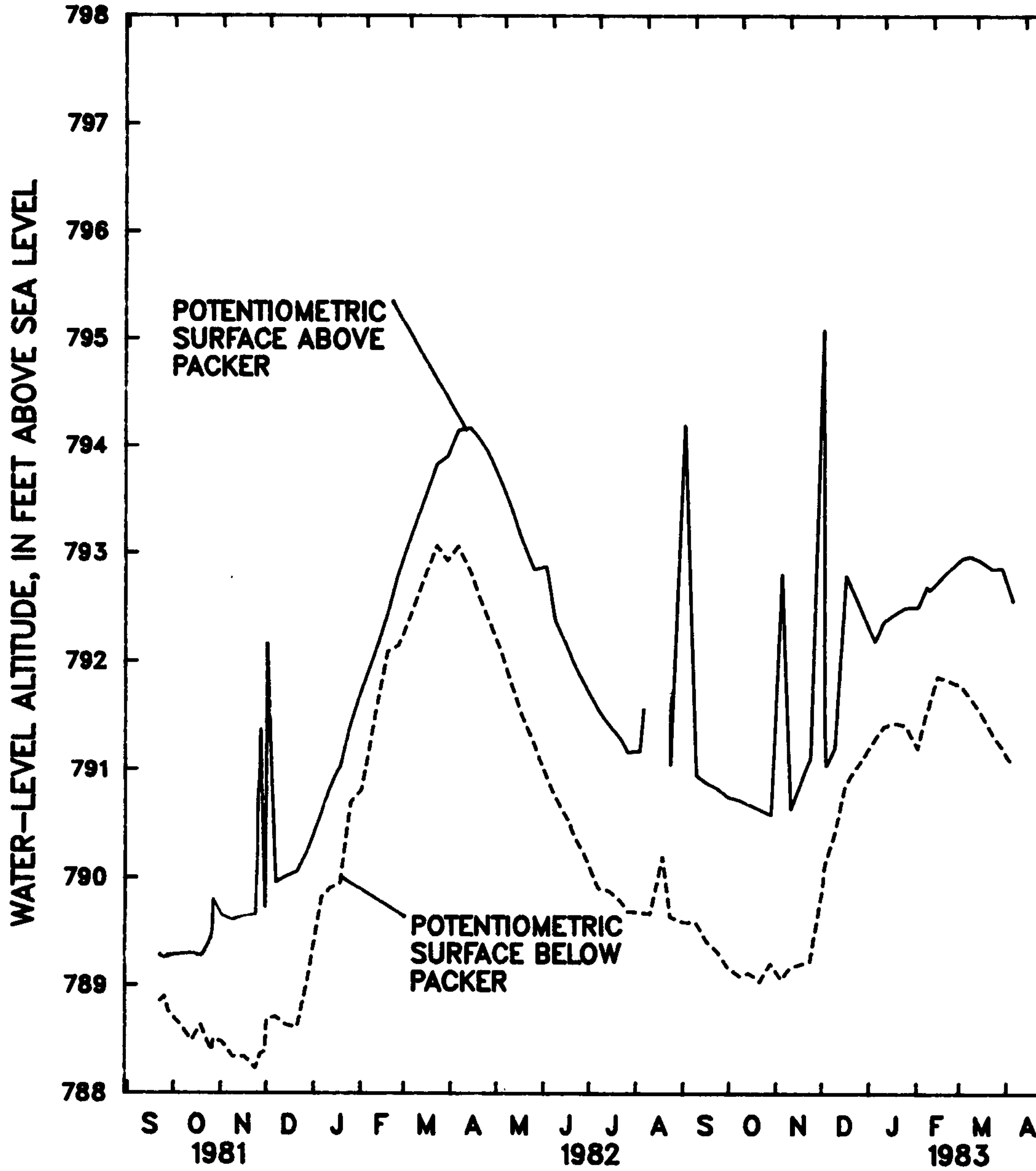


Figure 29.--Hydrographs showing vertical gradient at well 177 with packer set at 61- to 64-foot depth.

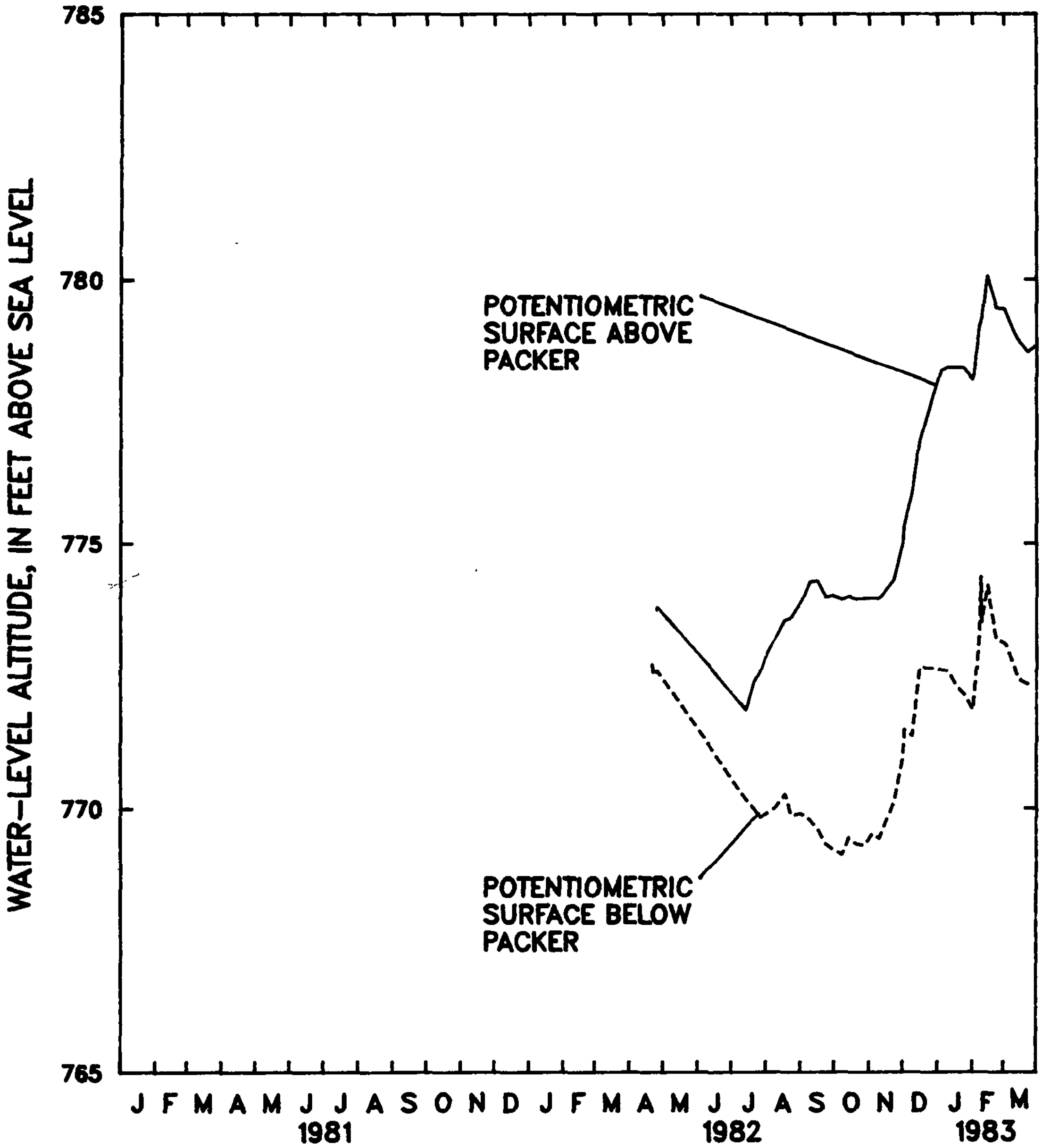


Figure 30.--Hydrographs showing vertical gradient at well 178 with packer set at 42- to 44-foot depth.

175 has a downward component of flow relative to deeper bedrock, that is, these wells are located in ground-water recharge areas. Well 175, with a small upward component of flow, appears to be a local anomaly, possibly related to a structural feature at 70 feet depth or suspected solution channels at 87 and 101 feet depth, shown in the televiewer log.

With packers set near the top of bedrock in each well, the response of water levels in the two zones to the more substantial recharge events was similar, that is, both water levels rose. Response of the zone below the packer, as expected, usually was the lesser of the two. The similarity in response supports the thesis that the regolith and bedrock system are hydraulically connected.

Aquifer Tests

During the interruption in construction of the first piezometer cluster from 1978-79, slug tests were made of the open intervals then in each well (wells 458, 459, and 460) and of the lowermost zone at which a pneumatic packer could be sealed. Results of these tests are given in table 6. Later, pumping tests of 24 hours duration each were performed in wells 458 and 460 to obtain more accurate coefficients of transmissivity and hydraulic conductivity than was then thought to be obtainable from slug tests, and to determine if the water levels in the nearby wells would be drawn down which would indicate hydraulic continuity of secondary openings through the bedrock. At the time of the test, well 458 was open from about 150 to 203 feet, and well 460, from 44 to 100 feet. The pumping rates, determined by analysis of the slug test data, were 0.7 gal/min and 0.385 gal/min, respectively. Analyses of the pumping test data were by the method of Papadopulos and Cooper (1967) for a well in which the well's storage capacity must be considered. The results are included in table 6.

The values given, like those derived from the slug tests, should be regarded as approximations of actual T, S, and K coefficients because the geologic conditions do not conform to the analytical assumptions of a homogeneous and isotropic medium. They are indicative, however, that the coefficients of transmissivity and hydraulic conductivity of the bedrock are quite low, and by comparison, less than the corresponding values for the regolith. The S coefficients have greater potential than those of T and K to be in error because, as noted previously, the method for slug-test analyses is relatively insensitive to changes in S, and 24-hour pumping tests at low yields are of inadequate time to define this coefficient with accuracy.

It was found that both tests influenced the water levels in the other two piezometers then under construction and in some of the other nearby shallow wells, thereby demonstrating that the secondary openings in the bedrock do have hydraulic continuity in the vertical direction.

The analyses for apparent T and apparent K of the two pumping tests approximated those of the two slug tests of the same well interval. The general similarity of values indicated that reasonable coefficients for these parameters could be obtained by slug tests only, which require less time, equipment, and manpower to perform.

Table 6.--*Aquifer-test data of bedrock wells in the central cluster*

Slug tests:			Pumping tests:
Well 458	150-203 foot interval	190-203 foot interval	150-203 foot interval
Apparent T	1.6 ft^2/d	0.3 ft^2/d	1.6 ft^2/d
Apparent S	1.5×10^{-8}	1.6×10^{-12}	1.6×10^{-5}
Apparent K	0.03 ft/d	0.03 ft/d	0.03 ft/d
Well 459	100-150 foot interval	136-150 foot interval*	
Apparent T	1.1×10^{-2} ft^2/d	1.1 ft^2/d	No pumping test
Apparent S	1.6×10^{-4}	1.6 x 10-5	performed of this
Apparent K	2.2×10^{-4} ft/d	8.1×10^{-2} ft/d	well
Well 460	44-100 foot interval	84-100 foot interval	44-100 foot interval
Apparent T	1.4 ft^2/d	0.2 ft^2/d	1.6 ft^2/d
Apparent S	1.6×10^{-4}	1.4×10^{-4}	7.5×10^{-4}
Apparent K	0.02 ft/d	0.015 ft/d	0.03 ft/d

*Results are questionable because of suspected leakage around the packer.

During construction of the piezometers 2 to 3 years later, slug tests were performed in the 50-foot interval before installation of the final string of casing. The final 10-foot interval left open to the aquifer was tested after construction had finished. The apparent hydraulic conductivity values of the two intervals tested in each well are given in table 7. Data of the piezometers in the central cluster and also of the water-table wells in each cluster are included in this compilation to facilitate a comparison of values by location and depth.

The range in hydraulic conductivity spans nearly four orders of magnitude and might even be greater if tests were performed in the wells that recharge very slowly. The range reflects the degree of heterogeneity that exists in the aquifer. Lateral heterogeneity is shown by reading the values horizontally across the table, and is more prominent in the 10-foot intervals than in the 50-foot intervals. Lateral heterogeneity also has been shown by pumping tests conducted during earlier investigations of the Conasauga Group, where the water levels of those wells oriented

Table 7.--*Apparent hydraulic conductivities of wells in piezometer arrays*

Depth interval	Apparent hydraulic conductivities (ft/d) by cluster				
	North	South	East	West	Central
Water table[1]	3.3×10^{-1}	7.6×10^{-1}	*	4.9×10^{-1}	5.8×10^{-1} (Well 439) 5.3×10^{-2} (Well 440)
50 - 100	1.8×10^{-2}	2.2×10^{-2}	8.0×10^{-2}	*	2.5×10^{-2} [2]
100 - 150	1.1×10^{-3}	7.0×10^{-3}	1.0×10^{-2}	1.4×10^{-1}	2.2×10^{-4}
150 - 200	1.3×10^{-3}	1.0×10^{-3}	8.0×10^{-3}	1.0×10^{-2}	3.0×10^{-2} [2]
Water table[1]	3.3×10^{-1}	7.6×10^{-1}	*	4.9×10^{-1}	5.8×10^{-1} (Well 439) 5.3×10^{-2} (Well 440)
90 - 100	4.3×10^{-3}	*	1.0×10^{-1}	1.0×10^{-1}	1.5×10^{-2} [3]
140 - 150	1.5×10^{-4}	1.3×10^{-2}	2.3×10^{-2}	1.9×10^{-1}	8.1×10^{-2} [3, 4]
190 - 200	3.5×10^{-4}	2.9×10^{-4}	**	**	3.2×10^{-2} [3]

*Data do not fit type curve.

**Slug test not performed due to very slow water-level recovery after pumping well.

[1]Depth interval of water-table well varies from cluster to cluster. Refer to Appendix A for open interval of wells 472, 464, 476, 468, 439, and 440, respectively.

[2]Depth interval is 44 to 100 feet in well 460 and 150 to 203 feet in well 458 (Central cluster).

[3]Depth interval is 84 to 100 feet in well 460, 136 to 150 feet in well 459, and 190 to 203 feet in well 458 (Central cluster).

[4]Value is questionable because of suspected leakage around packer.

along strike were drawn down more than those at an equivalent distance across strike from the pumped well (deLaguna and others, 1958, p. 106-107; unpublished manuscript in files of USGS). Vertical heterogeneity is shown by reading the table vertically, either by the 50-foot intervals or by the 10-foot intervals. The overall trend in data demonstrates that hydraulic conductivity decreases as depth increases, although reversals to this relationship may occur at any point in the stratigraphic column. Several reversals are shown by comparing the value of the 10-foot interval to that of the larger 50-foot interval of which it is a part. Of the 11 comparisons that can be made, in 5 wells the hydraulic conductivity of the bottom 10 feet is greater than that of the 50-foot interval. Decreasing hydraulic conductivity with increasing depth was also demonstrated indirectly during the 1950's by measuring the rate of water acceptance in bedrock wells in the ILW area and and in burial ground 5. In these tests measurements were made in 20-foot depth increments and similar occasional reversals to the overall trend were found (deLaguna and others, 1958, p. 107; Cowser and others, 1961, p. 15). The relationship of decreasing hydraulic conductivity with increasing depth is significant to bedrock recharge and discharge.

Values for the 190- to 200-foot interval, with the exception of that for the central cluster, are quite small. The fact that water does recharge wells at this depth, however, indicates that the lower boundary of the aquifer occurs at some greater depth. The variability in recharge rates and K values of that interval implies that the depth to that boundary is variable or, in other words, that boundary is a surface of irregular shape.

Geophysical Logging

Geophysical logs were made intermittenly between 1976 and 1983. The logs include caliper, gamma, gamma-gamma, neutron, acoustic velocity, temperature, televiewer, single-point resistivity, and spectral, but not all of these logs were made of all of the wells. Generally, the logs found most useful to this investigation were the caliper, gamma, neutron, televiewer, and spectral.

Two important applications of logging for investigating ground-water flow in Melton Valley were in establishing the existence and prevalence of secondary features that permit flow through the bedrock, and in identifying certain radionuclides that have been transported by water into bedrock.

The initial logging of the five bedrock wells in burial ground 5 showed occasional zones suggestive of secondary openings in each of the bores. They were also found in nearly all of the piezometers. Logging of the few existing bedrock wells in burial ground 6 also showed their presence there. Additional logging of wells near ILW pits 2, 3, and 4 and of some of the wells used in proving the hydrofracture method of waste-disposal also revealed similar features. Visible secondary openings shown in logs are not numerous in any one well bore, but they are prevalent throughout the Melton Valley area. The more common type opening is an enlargement of the well bore indicative of rock weakened by fracturing, folding, or faulting, and easily torn loose as the drill intercepts that stratum. These zones range from a few inches to as much as a few feet in thickness. Some, but probably not all, represent pathways through which water flows. Small partings and fractures that permit the flow of water also are present, but the logs lack sensitivity to show their detail. The presence of these smaller openings, however, is revealed by completion of some of the piezometers in what the caliper and televiewer logs suggest is "solid rock". That these zones have secondary permeability is evidenced by the response of water levels to slug tests and the normal rise and recession of the water surface within the completed well. The less common type of