GROUND-WATER FLOW NEAR TWO RADIOACTIVE-WASTE-DISPOSAL AREAS AT THE WESTERN NEW YORK NUCLEAR SERVICE CENTER, CATTARAUGUS COUNTY, NEW YORK-- RESULTS OF FLOW SIMULATION

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CONVERSION FACTORS AND ABBREVIATIONS

Factors for converting the International System (SI) units used in this report to inch-pound units are shown below.

Divide SI units	By	To obtain inch-pound units
	Length	
centimeter (cm)	2.54	inch (in)
meter (m)	.3048	foot (ft)
kilometer (km)	1.609	mile (mi)
	Area	
square kilometer (km^2)	2.59	square mile (mi^2)
hectare (ha)	0.405	acre
	Flow	
liter per second (L/s)	28.32	cubic feet per second (ft^3/s)
liter per second (L/s)	0.06309	gallon per minute (gal/min)
liter per second (L/s)	43.81	million gallons per day (Mgal/d)
cubic centimeter per day (cm^3/d)	3783.579	gallon per day (gal/d)
cubic meter per second (m^3/s)	0.0283	cubic feet per second (ft^3/s)
	Hydraulic Units	
meter per day (m/d)	0.3048	hydraulic conductivity, foot per day (ft/d)
meter per kilometer (m/km)	0.1894	foot per mile (ft/mi)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	264.20	gallon (gal)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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Abstract

Two adjacent burial areas are excavated in a clay-rich till at a radioactive-waste-disposal site near West Valley in Cattaraugus County, N.Y. One of the burial grounds, which contains mainly low-level radioactive wastes generated onsite by a nuclear-fuel-reprocessing plant, has been in operation since 1966. The other, which contains commercial low-level-radioactive wastes, was operated during 1963-75. Ground water below the upper 3 meters of till generally moves downward through a 20- to 30-meter-thick sequence of tills underlain by lacustrine and kame-delta deposits of fine sand and silt. Ground water in the weathered, upper 3 meters of till can move laterally for several meters before either moving downward into the kame-delta deposits or discharging to land surface.

A two-dimensional finite-element model that simulates two vertical sections was used to evaluate hydrologic factors that control ground-water flow in the till. Conditions observed during March 1983 were reproduced accurately in steady-state simulations that used four isotropic units of differing hydraulic conductivity to represent two fractured and weathered till units near land surface, an intermediate group of isolated till zones that contain significant amounts of fine sand and silt, and a sequence of till units at depth that have been consolidated by overburden pressure.

Recharge rates used in the best-fit simulation ranged from 1.4 centimeters per year along smooth, sloping or compacted surfaces to 3.8 centimeters per year near swampy areas. Values of hydraulic conductivity and infiltration used in the calibrated best-fit model were nearly identical to values used in a previous model analysis of the nearby commercial-waste burial area.

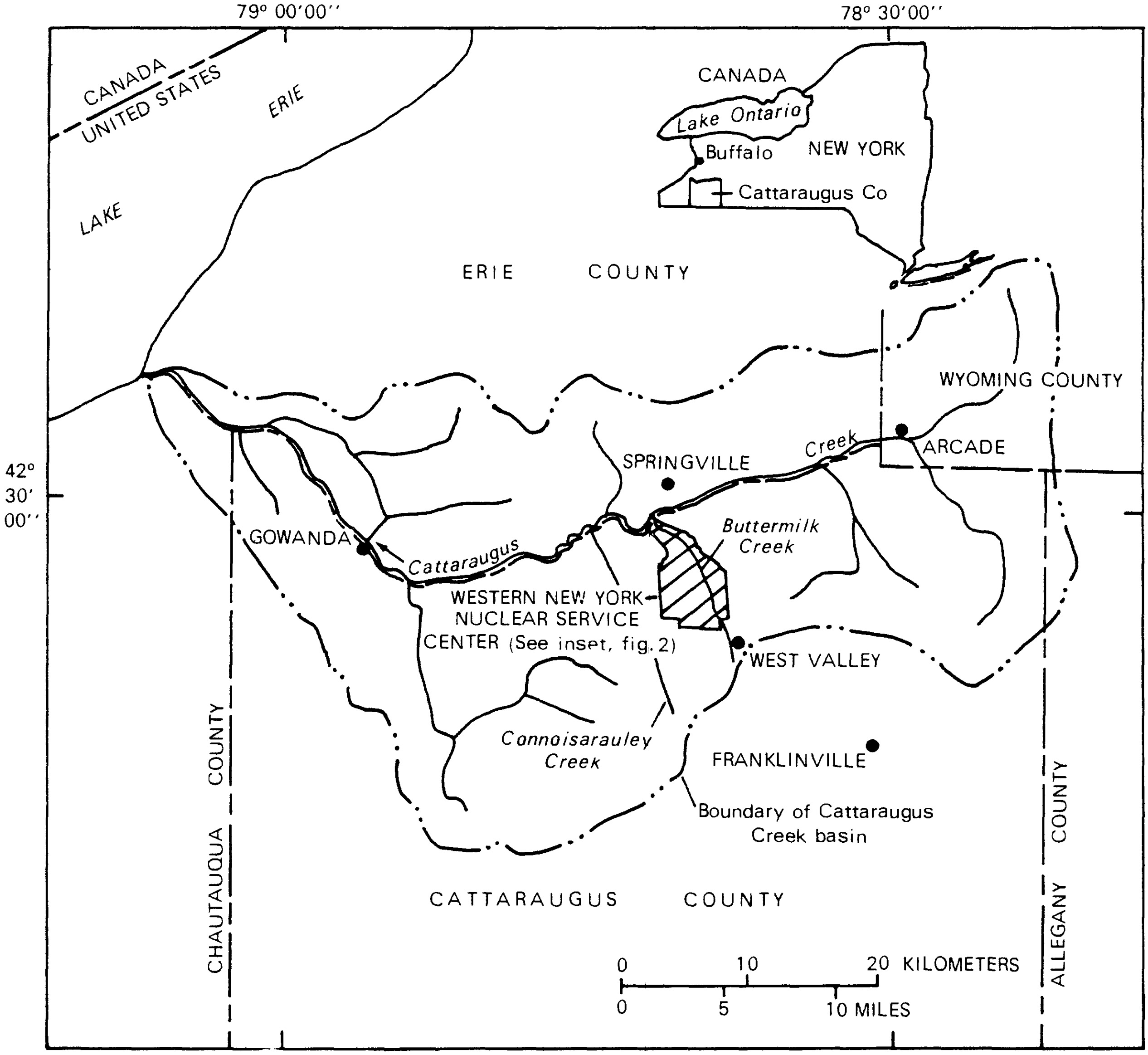
Results of model simulations of a burial pit assumed to be filled with water indicate that water near the bottom of the burial pit would migrate laterally in the shallow, weathered till for 5 to 6 meters before moving downward into the unweathered till, and water near the top of the pit would move laterally less than 20 meters before moving downward into the unweathered till. These results indicate that subsurface migration of radionuclides in ground water to points of dishcarge to land surface is unlikely as long as the water level does not rise into the reworked cover material.

INTRODUCTION

The Western New York Nuclear Service Center occupies 13.5 km^2 in northern Cattaraugus County, about 50 km south of Buffalo, N.Y. (fig. 1). A fuel-reprocessing plant and related waste-management facilities occupy about 1 km^2

within the center on a fairly level plateau on the west flank of the Buttermilk Creek valley (fig. 2). These facilities include an area for receiving and storage of irradiated fuel before reprocessing, an underground storage-tank complex for liquid high-level radioactive wastes generated by the reprocessing, and a low-level radioactive wastewater storage plant (fig. 2).

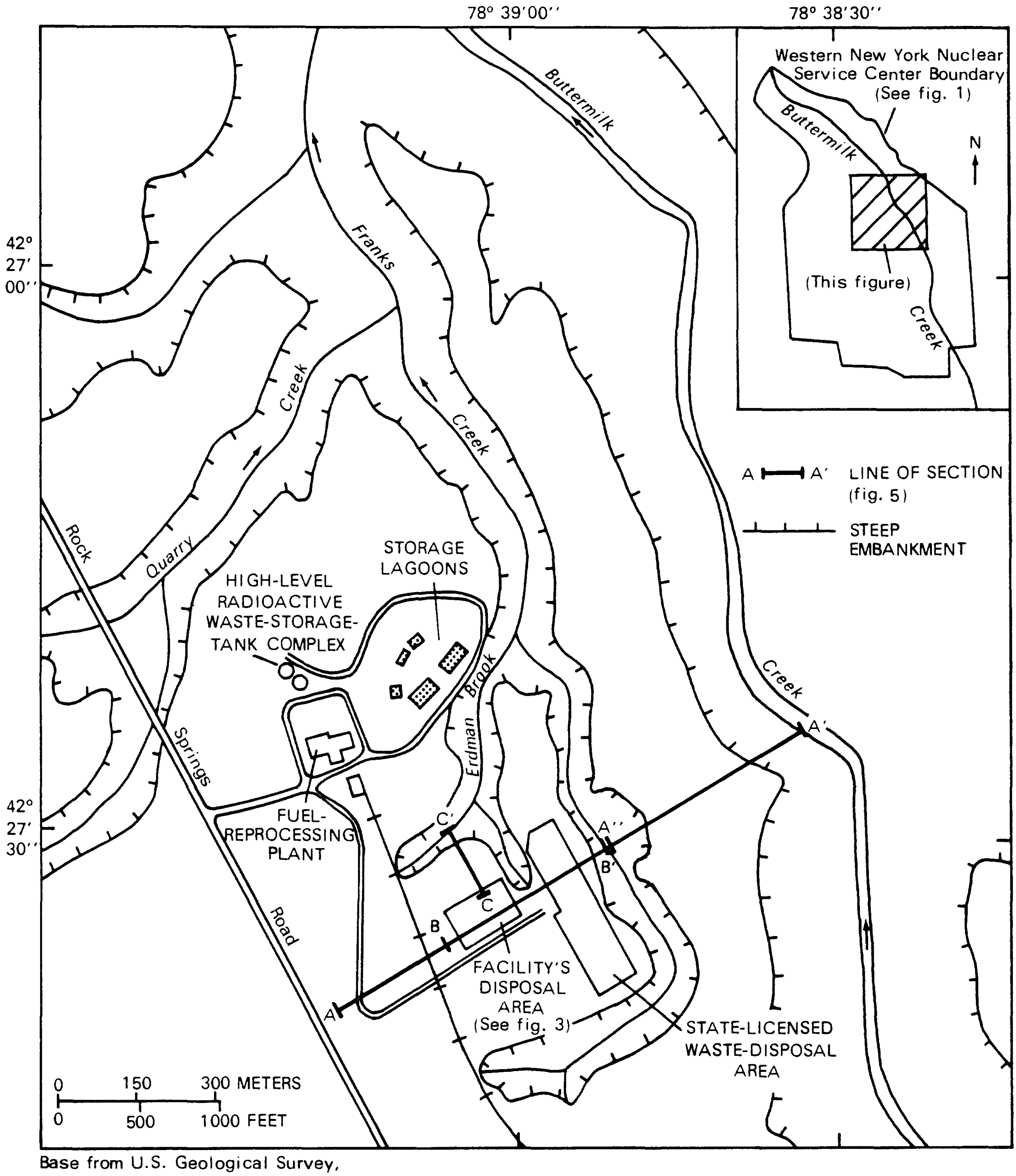
The center contains two separate burial areas for disposal of radioactive waste. One is a 2.2-hectare area previously licensed by the U.S. Nuclear Regulatory Commission for disposal of waste generated on site by the nuclear-fuel-reprocessing plant, hereafter referred to as the facility's disposal area. The other, just east of the facility's disposal area, is a 7-hectare area that was licensed by the State of New York for burial of commercial low-level radioactive waste and was operated from 1963-75, hereafter referred to as the State-licensed waste-disposal area.



Base from U.S. Geological Survey, 1974, State of New York, 1:500,000

Figure 1.--Location of the Western New York Nuclear Service Center in Cattaraugus Creek basin.

Burial of wastes in the facility's disposal area started in 1966, when the fuel-reprocessing plant began operations. Until 1972, it was used for disposal of radioactive wastes generated by the reprocessing plant, which included spent fuel hulls, fuel assembly hardware, failed process vessels and large equipment, degraded process solvent, and miscellaneous packaged trash, including laboratory



Base from U.S. Geological Survey, Ashford Hollow, 1979, 1:24,000

Figure 2.--Location of the Western New York Nuclear Service Center and associated burial sites. (Location is shown in fig. 1.)

wastes, small equipment, ventilation filters, and other process-related debris (U.S. Department of Energy, 1979). Since 1981, this area has been used for disposal of wastes generated by plant decontamination and decommissioning activities of the U.S. Department of Energy. The disposal area contains a series of trenches and narrow pits excavated in silty-clay till. Trench and pit dimensions range from 1 to 7 m wide, 1 to 30 m long, and 8 to 15 m deep. At present, wastes are buried in 210 separate trenches and pits (fig. 3).

The State-licensed disposal area began operations in November 1963 and continued until May 1975. During this period, 66,500 m3 of wastes containing about 710,000 curies of radioactivity were buried (U.S. Department of Energy, 1980). Buried materials included solid radioactive waste from hospitals, laboratories, industrial facilities, nuclear reactors, and the nuclear-fuel-reprocessing plants. Wastes are buried in 14 separate trenches that are about 6 m deep, 10 m wide at the surface, and 180 m long (fig. 4). The site operator voluntarily suspended operations in May 1975 when overflow of trench water was detected at two trenches (trenches 4 and 5) on the north side of the burial ground.

Two studies during 1975-1980 evaluated the extent of, and potential for, radionuclide movement from the State-licensed disposal area. One, by the U.S. Geological Survey, identified the principal hydrologic and geologic factors that control subsurface movement of radioisotopes from the burial ground (Prudic, 1986); the other, by the New York State Geological Survey under contract with the U.S. Environmental Protection Agency and, later, the U.S. Nuclear Regulatory Commission, evaluated all processes of radioisotope migration at the burial site (Dana and others, 1979). In 1985 the Nuclear Regulatory Commission summarized all its studies dealing with confinement capabilities of the facility's disposal area (Nicholson and Hurt, 1985).

Since 1980, the U.S. Geological Survey has conducted an investigation to complement efforts by the New York State Geological Survey to evaluate the geology, surface and subsurface hydrology, and the extent of, and potential for radioisotope migration from the facility's disposal and reprocessing-plant areas. Both investigations are funded under mutual financial agreements with the U.S. Nuclear Regulatory Commission.

Purpose and Scope

The study described herein is an extension of work by Prudic and Randall (1977) and Prudic (1981, 1986) at the State-licensed disposal area (fig. 2), whose investigations of ground-water movement and radioisotope migration indicated that the low permeability and adsorptive properties of till retard the movement of ground water and the migration of radionuclides to the ground-water system beneath the till. This report presents the results of an effort to delineate the ground-water-flow patterns and to define the hydraulic properties of the silty-clay till that blankets the bedrock of the area. (All burial trenches and pits at the disposal site are excavated into this till.) This report also (1) describes the geologic and hydrologic characteristics of the facility's disposal area, (2) presents results of mathematical model simulations of ground-water flow near both the facility's disposal area and the State-licensed disposal area, (3) gives vertical sections that show hydraulic properties of the till units used in the model and the results of the calibrated model runs, and (4) contains a section on the model results of hypothetical migration of ground water from the disposal pits in the facility's disposal area into the surrounding till and Erdman Brook, 100 m to the north.

Methods of Investigations

Information on the geology and ground-water flow conditions near the facility's disposal area was derived from test holes drilled and augered during 1980-82 (fig. 4). Cores were collected and examined to define the physical characteristics of unconsolidated deposits. Hydraulic properties of the material were calculated from laboratory analyses of selected core samples.

A two-dimensional finite-element model developed by Reeves and Duguid (1975) and modified by Yeh and Ward (1980) was used to simulate ground-water flow in the vicinity of the facility's disposal area. Results from this simulation were used to identify the principal factors that control the movement of ground water in the area and the potential for radionuclide migration.

From one to five piezometers were installed at increasing depths at selected test-hole sites to determine the horizontal and hydraulic head distribution and to verify that the hydraulic properties of the facility's disposal area are similar to those at the State-licensed burial ground. Most piezometers were 2.5 cm in diameter and contained a screen 60 cm long. Each screen was finished in a sand envelope 70 to 80 cm thick. At least 1 m of bentonite gel was placed above the sand envelope, and the remainder of hole annulus was grouted with cement to land surface.

Each piezometer was identified by a number representing the last two numbers of the year in which it was drilled, followed by a hyphen and a combination of numbers and letters. The number after the hyphen refers to the test-hole site number; the letter refers to the relative depth of the piezometer. Piezometers at each test hole site were lettered sequentially from shallow to deep. For example, piezometers at test hole site 5, which was drilled in 1982, were identified as 82-5A, 82-5B, and 82-5C. Well 82-5A is the shallowest, and well 82-5C is the deepest. At some sites, piezometers were completed at the same depth as adjacent piezometers and were numbered sequentially; for example, 82-4A, 82-4A2, and 82-4A3.

Ground-water flow was simulated along a northeast-southwest vertical section that extends from an area 230 m west of the facility's disposal area, through the north trenches of the nearby State-licensed disposal area, to Buttermilk Creek (section A-A', fig. 2). This section includes and expands a cross section through the north trenches that had been simulated by Prudic (1981, 1986). The section simulated by Prudic was evaluated, and some elements thereof were incorporated into this study. Ground-water flow along a vertical section that extends northwest from the facility's disposal area to Erdman Brook was also simulated (section B-B in fig. 4).

Acknowledgments

The U.S. Nuclear Regulatory Commission provided funding for this study and helped the U.S. Geological Survey obtain access to the site. West Valley

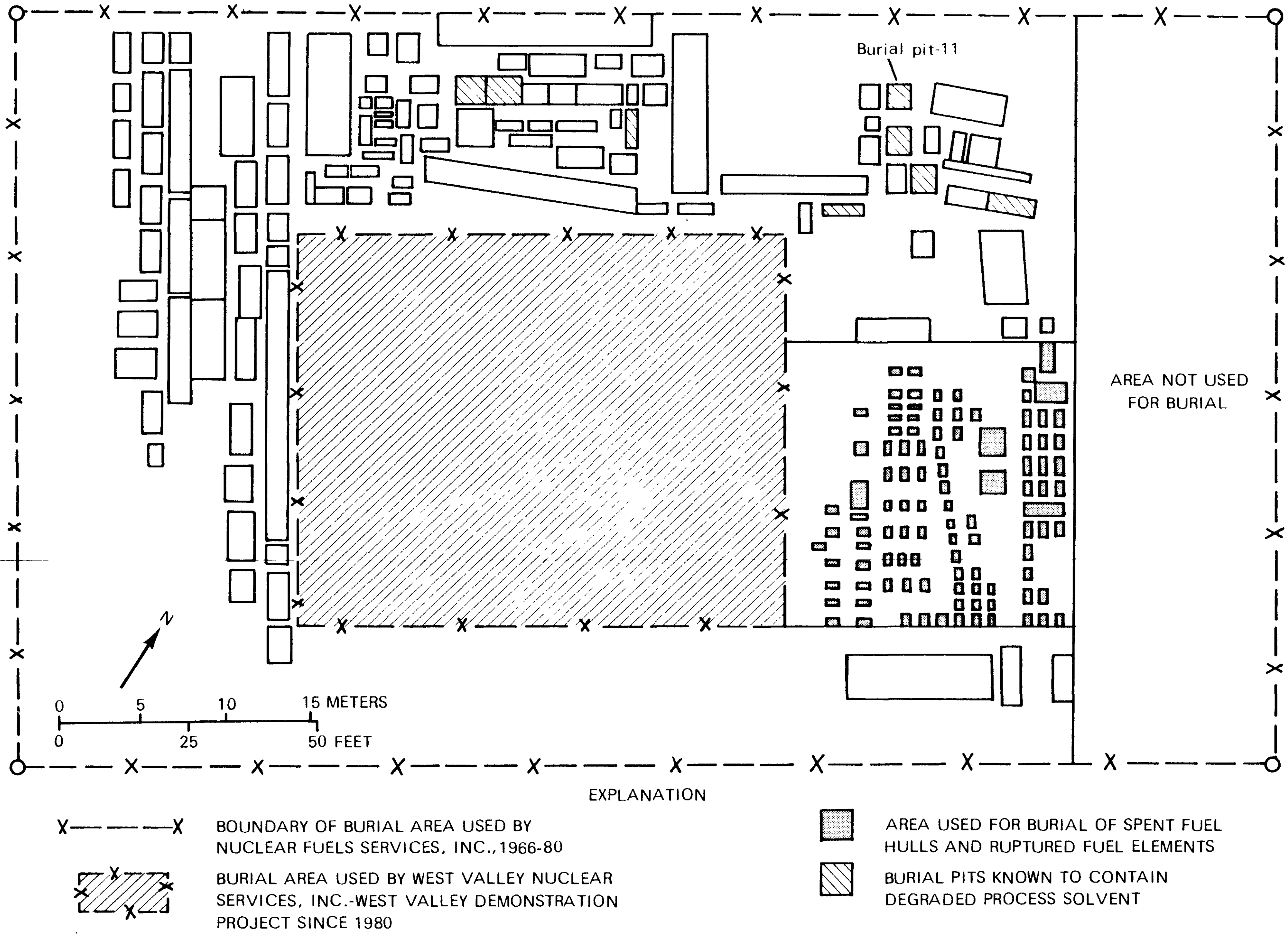


Figure 3.--Location of burial pits and trenches within the facility's disposal area. (Location is shown in fig. 2.)

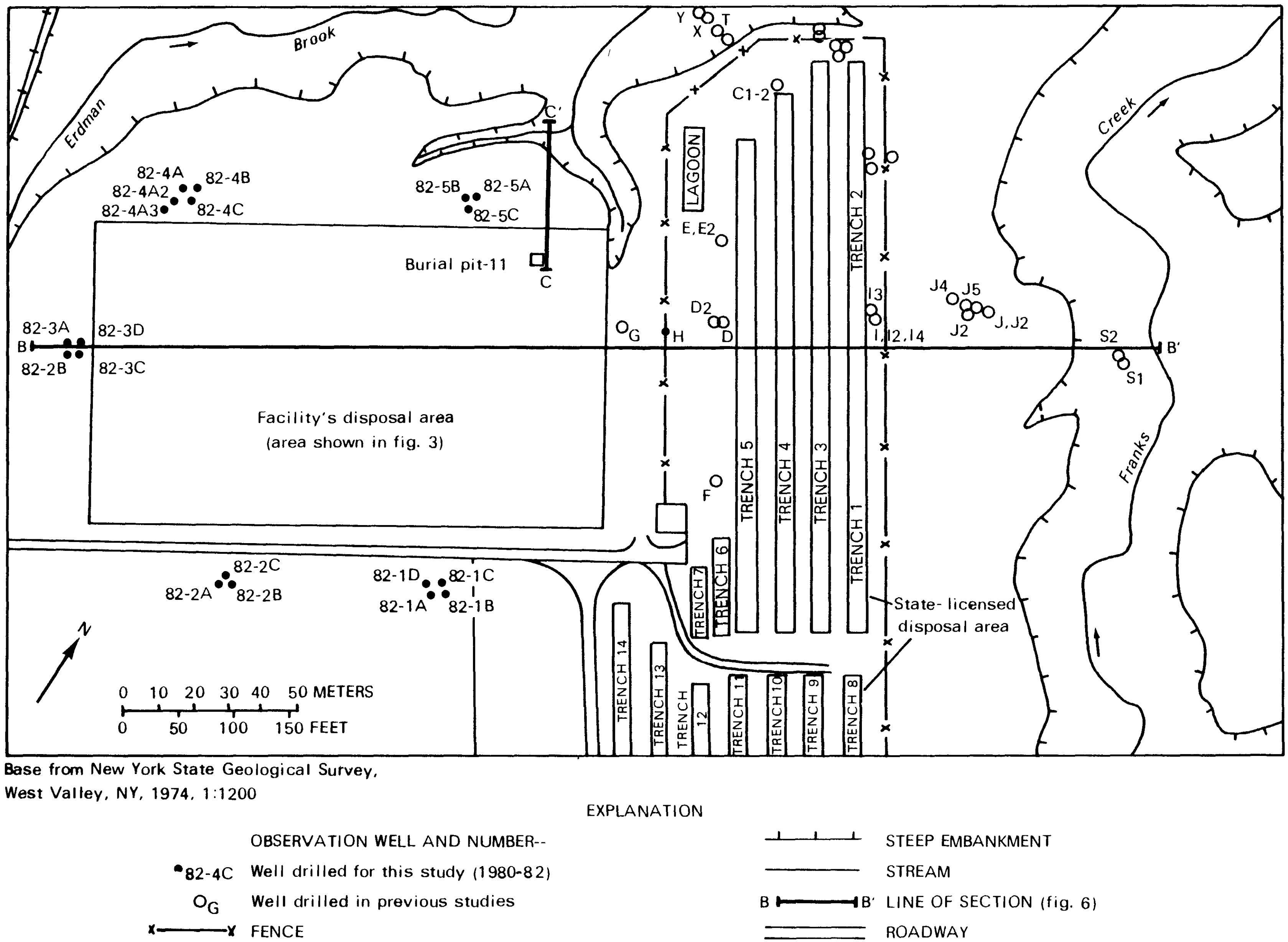


Figure 4.--Location of test holes and wells with piezometers used to monitor water levels near the two nuclear waste-disposal areas. (Location is shown in fig. 2.)

Nuclear Services Inc., the present (1985) site operator, provided staff to monitor radiation levels and escort U.S. Geological Survey personnel and their contractors during work at the site. The U.S. Department of Energy provided funding for test drilling in areas west of the facility's disposal area. The New York State Geological Survey, under a mutual funding agreement with the U.S. Nuclear Regulatory Commission, assisted in the interpretation of the site geology, provided personnel (Steven M. Potter and Theodore Robak) for data collection and geologic logging, and shared resulting data. Joseph Hutchinson and Dr. John Matuszek of New York State Department of Health, Radiological Sciences Laboratories, advised on special handling of core and water samples for radionuclide analysis. All radionuclide analyses were performed by the New York State Department of Health under contract with New York State Geological Survey.

HYDROLOGIC SETTING

Geology

The burial trenches and pits are excavated into a clay-rich till that ranges from less than 20 m thick west of the facility's disposal area to as much as 30 m thick beneath Franks Creek (fig. 5). The till is a valley facies that has been found over wide areas in the Cattaraugus Creek basin. Grain-size analyses of 15 core samples collected near the facility's disposal area show that, on the average, the till contains 50 percent clay, 30 percent silt, 10 percent sand, and 10 percent gravel. These values are in agreement with those reported by Prudic and Randall (1977) and Prudic (1986) for core samples collected near the State-licensed burial area.

The till is unsorted and typically dark gray, pebbly, and contains slightly to severely deformed, discontinuous wisps, pods, lenses, and stringers of silty to fine sand and, rarely, coarse sand and gravel. Prudic and Randall (1977) estimated that well-sorted material made up about 7 percent of cored footage that was logged near the State-licensed area. The uppermost 2 m of till is grayish brown and weathered and contains a network of intersecting, oxidized horizontal and vertical fractures and root tubes. Fractures and root tubes within oxidized till have been observed in boreholes and trench excavations to depths of 4 m. Some of the observed fractures extend into the unweathered till below these depths. Dana and others (1979) reported that the number of fractures and the degree of the openness decrease with depth. Fickies and others (1979) estimated from laboratory depth studies that the theoretical limit to which a fracture could penetrate the till is about 15 m.

Beneath the surficial till is a sequence of lacustrine and kame-delta deposits that consist of 10 to 20 m of fine sand and silt (LaFleur, 1979) (fig. 5). These deposits also contain beds of varved clays in some areas and locally are capped by gravel (LaFleur, 1979).

Thick glacial deposits below the lacustrine unit, 150 m below land surface, are poorly documented. A test hole (DH-7) about 600 m north of the burial areas penetrated two additional sequences of silty clay till below the lacustrine and kame deposits that were separated by fine sand and silt (Bergeron and others, 1987). Bedrock, which consists of Devonian shale and sandstone, lies at depths that range from 150 m below land surface in the deepest part of the bedrock valley to less than 1 m along hillsides west of the main plant facilities. Bedrock is exposed on hilltops west and south of the site and in stream channels along Quarry Creek (fig. 2), northwest of the site.

Head Gradients

A total of 19 piezometers (fig. 4) were installed at various depths in test holes adjacent to the facility's disposal area to determine patterns of ground-water flow and to monitor water-level changes within the till. Water levels in these piezometers and in piezometers at the nearby State-licensed burial ground (fig. 4) were used to determine the horizontal and vertical hydraulic head distribution along a southwest-northeast vertical section through both burial areas. Horizontal and vertical head gradients observed in March 1983 (fig. 6) indicate that water percolating below the root zone moves vertically downward through the till, even below small streams bordering the burial grounds.

Pressure heads (as defined in Freeze and Cherry, 1979, p. 19-22) measured in piezometers screened at several depths in the till ranged from near zero to 5 m. Some piezometers (82-3A, 82-3B, 82-4C, and 82-2C, fig. 4) have never contained water since their installation. Prudic and Randall (1977) found that pressure heads were low beneath steep, smooth slopes and other areas where the upper layers of soil had been scraped away to allow rapid runoff, and were higher where water had accumulated above the till, in trenches, or in natural depressions at land surface (near holes J and G in fig. 6), or adjacent to areas containing uncompacted fill (near hole 82-4 in fig. 6).

The total head distribution shown in figure 6 is based on the assumption that pressure head in the "dry" piezometers is zero. An absence of water in the lower lacustrine unit (fig. 5) was postulated by Prudic (1986) to be caused by very low vertical permeability of the till and thus low recharge through the till rather than high horizontal permeability in the lacustrine unit. This same situation is assumed to prevail near other "dry" piezometers in this study. Localized lenses of very low permeability could cause unsaturated conditions; damage or clogging of the piezometers during placement also could account for the "dry" conditions. No data are available to confirm these reasons for "dry" piezometers, however.

Hydraulic Properties of the Till

The vertical hydraulic conductivity of the till was obtained from laboratory analyses of several undisturbed till cores. A total of five weathered, oxidized till samples, analyzed with a constant-head permeameter with back-pressure saturation, yielded an average vertical hydraulic conductivity of 4.3×10^{-5} m/d, with a range of 2.1×10^{-5} to 1.0×10^{-4} m/d. Analysis of five samples of unweathered till yielded average vertical hydraulic conductivity of 2.4×10^{-5} m/d and values that ranged from 1.8×10^{-5} to 3.7×10^{-5} m/d, or about half that of the weathered till samples.

Six additional samples were analyzed to determine the effects of increased confining pressures due to overburden on hydraulic conductivity. An average decrease of 13 percent was observed at pressures equivalent to a depth of 20 to 22 m. These results are consistent with those of Prudic (1981), who performed consolidation tests on similar till samples.

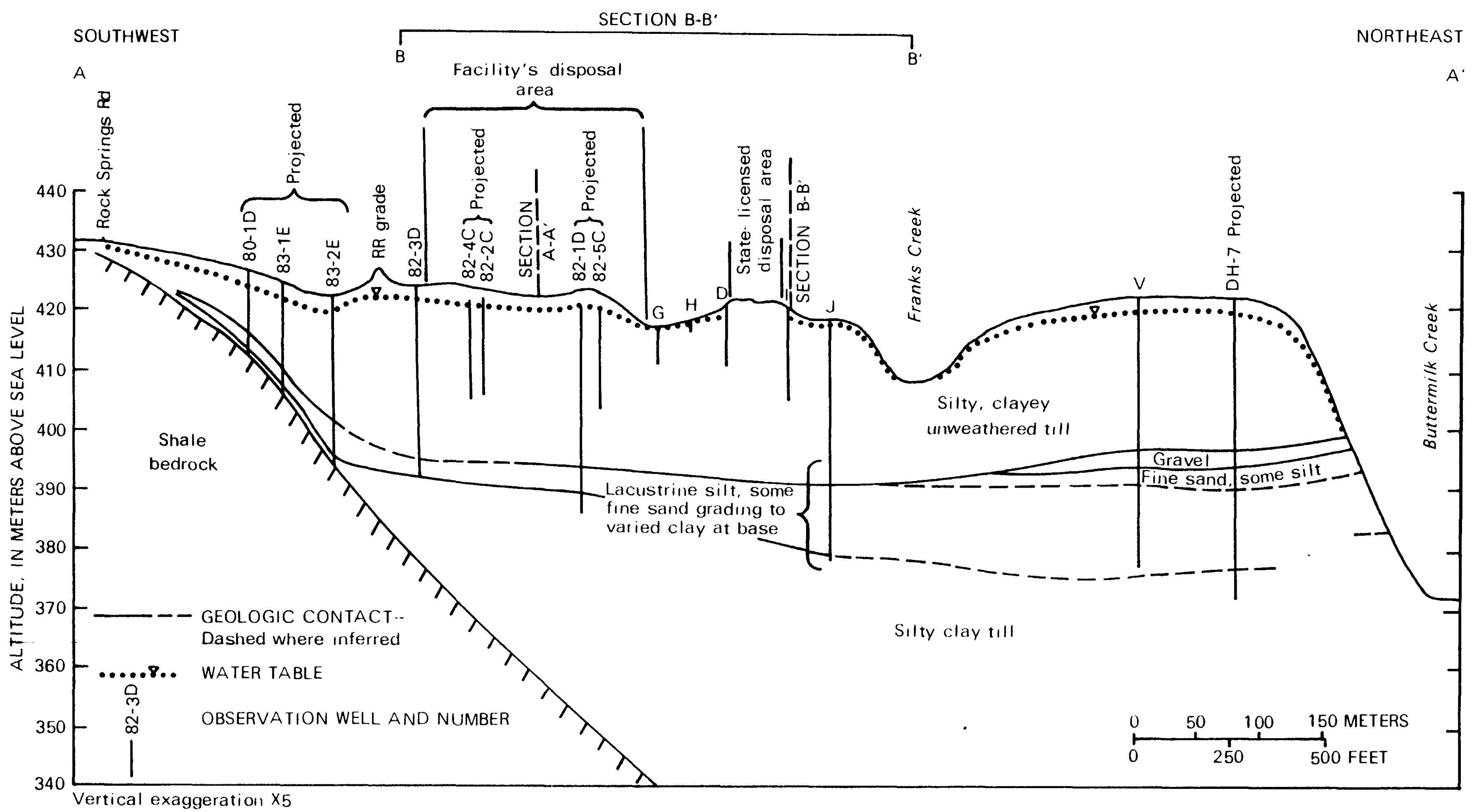


Figure 5.--Geologic section A-A' showing major lithologic units from Rocky Springs Road through the burial areas to Frank's Creek. (Location of section is shown in fig. 2.)

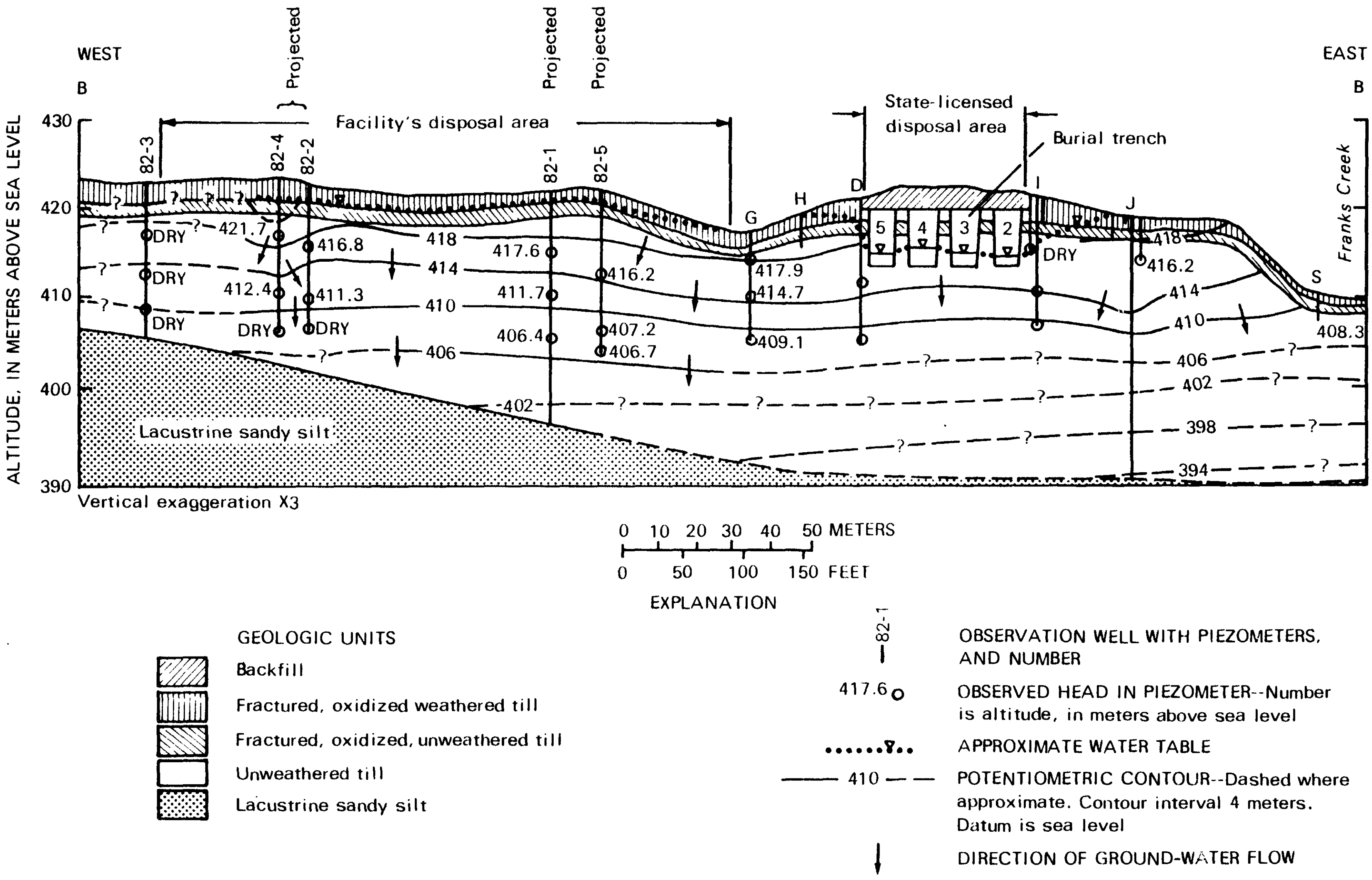


Figure 6.--Vertical section B-B' showing distribution of water levels and direction of ground-water flow based on March 1983 measurements. (Location of section is shown in fig. 4.)

The horizontal hydraulic conductivity of the clay-rich till was obtained by analysis of water-level-recovery data from aquifer tests of five piezometers through methods of Cooper and others (1967) and Hvorslev (1951). The values calculated by both methods averaged 1.7×10^{-5} m/d and ranged from 6.9×10^{-6} m/d by the Cooper method to 8.6×10^{-5} m/d by the Hvorslev method. These values are similar to the vertical hydraulic conductivity values obtained from laboratory tests, which suggests that the till is nearly isotropic.

The hydraulic conductivity of small lenses of silt and sand were evaluated by Prudic (1982) in field permeability tests at five piezometer locations, also through methods of Cooper and others (1967) and Hvorslev (1951). Hydraulic conductivity calculated by Cooper's method was 1.5×10^{-2} m/d; that by Hvorslev's was 4.4×10^{-2} m/d. The effective hydraulic conductivity of the till, which takes into account the permeability of the sorted material, was estimated by Prudic (1986) to be between 1.9×10^{-5} and 5.5×10^{-5} m/d. Steady-state simulations near the facility's disposal area by Prudic (1981) indicated that overall hydraulic conductivity of the weathered till is 5 to 10 times higher than that of the unweathered till.

The model used in this study simulates unsaturated as well as saturated conditions. Consequently, functions relating the volumetric moisture content and hydraulic conductivity to soil-moisture tension were needed. The functions used in the model (fig. 7) were calculated by Prudic (1981) from pore-size-distribution curves developed from mercury porosimeter tests of seven core samples of till. Both functions were assumed to be nonhysteretic.

Storage properties of the till were estimated in previous studies. Specific storage values, calculated by Prudic (1981) from four consolidation tests, averaged 8×10^{-6} cm^{-1} and consistently decreased with increasing confining pressures. Specific storage values ranging from 8×10^{-6} to 12×10^{-6} cm^{-1} were used by Prudic (1981) in transient-state model simulations that accurately duplicated changes in head after removal of water from one of the trenches in the State-licensed disposal area.

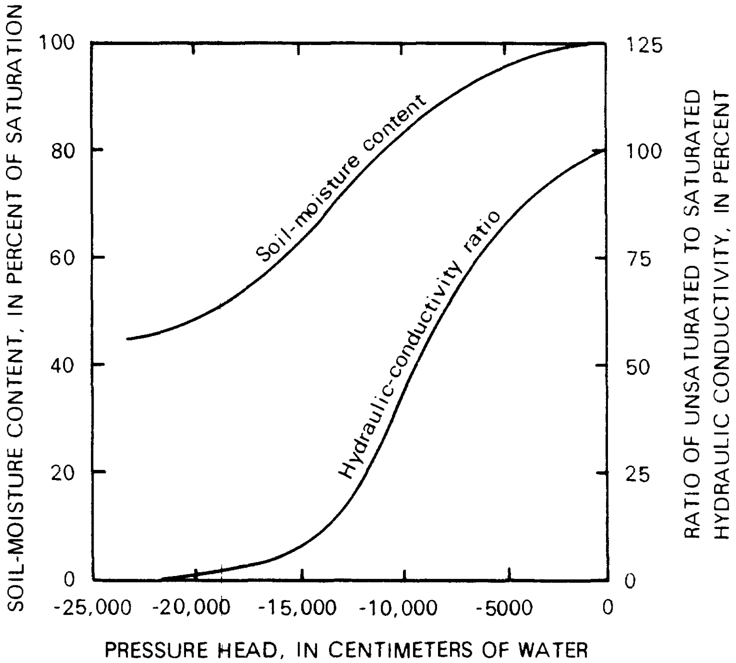


Figure 7.

Soil-moisture content and ratio of saturated to unsaturated hydraulic conductivity in relation to pressure head. (From Prudic, 1981, p. 14.)

SIMULATION OF GROUND-WATER FLOW

Model Selection and Design

A two-dimensional model of ground-water flow through saturated and unsaturated porous media developed by Reeves and Duguid (1975) and later modified by Yeh and Ward (1980) was selected to simulate ground-water-flow conditions near the burial areas. This model was selected because it had been successfully used by Prudic (1981) near the State-licensed disposal area, where conditions are similar.

The model uses the Galerkin finite-element method to solve the governing equations that describe the pressure field of a two-dimensional subsurface system. These equations can be combined and expressed in the following form:

$$\left[\frac{\Theta a'}{n} + \Theta b' + \frac{\partial \Theta}{\partial h}\right] \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left[\vec{K}\left(\frac{\partial h}{\partial x}\right)\right] + \frac{\partial}{\partial z}\left[\vec{K}\left(\frac{\partial h}{\partial z} + 1\right)\right] \qquad (1)$$

where: Θ = volumetric moisture content, dimensionless ratio;
n = porosity, dimensionless ratio;
b' = modified coefficient of compressibility of the water, L^{-1};
a' = modified coefficient of compressibility of the medium, L^{-1};
$\frac{\partial r}{\partial h}$ = change in moisture content with respect to pressure head, L^{-1};
$\frac{\partial h}{\partial t}$ = change in pressure head with respect to time, LT^{-1};

$\vec{K}$ = hydraulic conductivity tensor, LT^{-1};
h = pressure head, L;
z = vertical distance, L; and
x = horizontal distance, L.

This equation reduces to the elastic storage equation for saturated flow and to Richard's equation for unsaturated flow (Reeves and Duguid, 1975). Because the model solves for total head, both equations are automatically satisfied.

Equation 1 is nonlinear because the hydraulic-conductivity tensor is dependent on pressure head in the following manner (see fig. 4):

$$\vec{K} = \vec{K}_s \cdot K_r(h) \qquad (2)$$

where: $\vec{K}$ = hydraulic-conductivity tensor, LT^{-1}
$\vec{K}_s$ = saturated hydraulic-conductivity tensor, LT^{-1}; and
$K_r(h)$ = relative hydraulic conductivity as function of pressure head, dimensionless.

Modifications by Yeh and Ward (1980) to the original Reeves and Duguid version by finite-element methods have eliminated the inherent discontinuities in the velocity field at nodal points and element boundaries and have reduced the mass-balance error.

Two separate finite-element grids were used in the model analysis (figs. 8, 9). The first grid was designed to simulate flow along section A-A" (fig. 2)

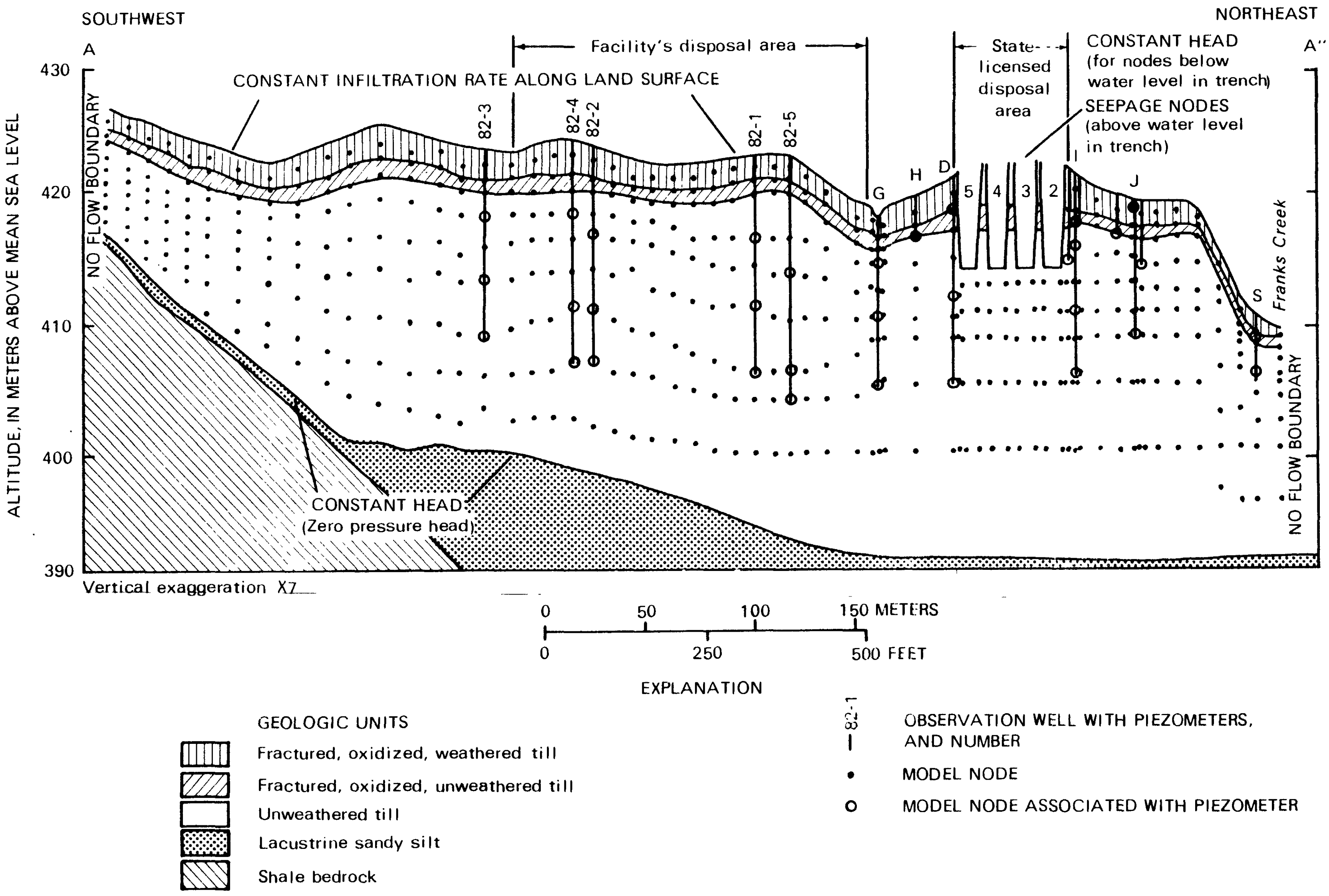


Figure 8.--*Section A-A' from near Rock Springs Road northeastward to Franks Creek showing arrangement of finite-element nodes and boundary conditions. (Location of section is shown in fig. 2.)*

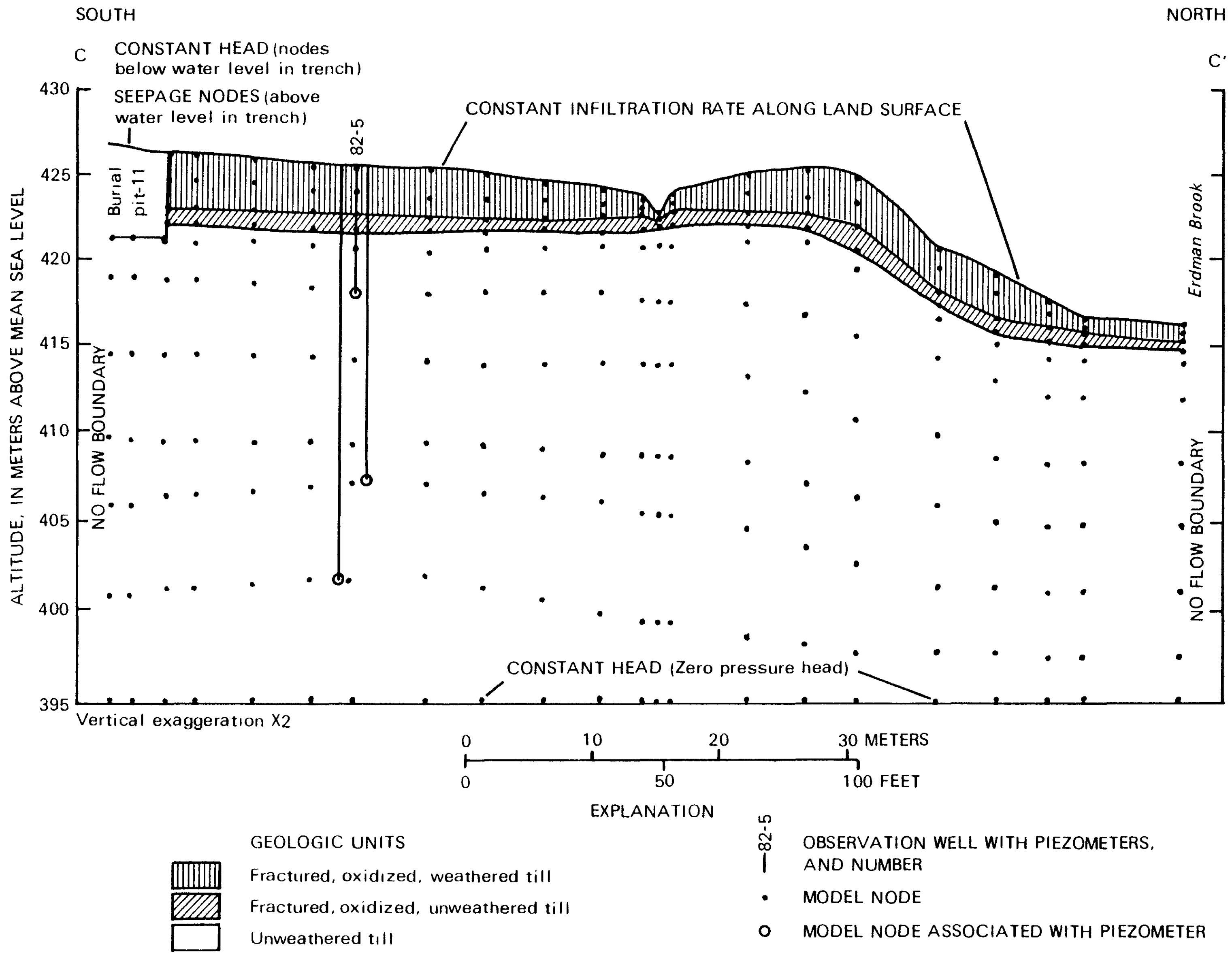


Figure 9.--Section D-D' from burial pit 11 (in facility's disposal area) to Erdman Brook, showing arrangement of nodes and boundary conditions. (Location of section is shown in fig. 4.)

from east of Rock Springs Road northeastward through the facility's disposal area and the north trenches of the State-licensed disposal area to Franks Creek (fig. 8). This section was selected to coincide with the vertical section simulated by Prudic (1981) across the north trenches of the State-licensed disposal area and was extended southwestward. The section was used in steady-state simulations that were representative of March 1983 conditions.

The second finite-element grid (fig. 9) was developed to assess the potential for lateral ground-water flow northward from the facility's disposal area to the nearest stream. The grid was designed to represent flow along section D-D' (figs. 2 and 4), which extends northwestward from a burial pit 11 in the northeast quadrant of the facility's disposal area to Erdman Brook, a tributary to Franks Creek.

Boundary conditions that were used by Prudic (1981) near the facility's disposal area were also used in all simulations in this study. These conditions were as follows:

(a) No-flow boundaries were assigned to both sides of each section because hydraulic gradient in the till is essentially vertical.

(b) A constant pressure head of zero was assigned to the base of the till to represent the apparent unsaturated condition that prevails at the top of the underlying lacustrine and kame-delta deposits.

(c) Infiltration from precipitation was kept at a steady rate sufficient to saturate the till to land surface but was decreased in some areas to simulate local unsaturated conditions.

(d) Constant heads within the trenches of the facility's disposal area were made equal to heads measured in March 1983.

(e) A horizontal hydraulic conductivity of 5.2×10^{-5} m/d was assigned to the unweathered till; this value represents a weighted average hydraulic conductivity of the till and the sorted material as estimated by Prudic (1986).

A more detailed account of the boundary conditions used, computer model assumptions and limitations, and the conceptual ground-water flow-system model is given in Prudic (1981, 1986).

Ground-Water Flow Near the Disposal Areas

Steady-state simulations along section A-A" (fig. 8) were run to evaluate the relative significance of anisotropy, variations in hydraulic conductivity caused by fracturing, weathering, and increasing confining pressure, and recharge from precipitation. An integral part of this analysis was an assessment of whether the values of hydraulic conductivity and recharge used by Prudic (1981) for the State-licensed disposal area could be applied with some consistency to the extended part of the cross section in the facility's disposal area. All simulations were calibrated to match heads measured in March 1983 as closely as possible.

Variations in Recharge and Hydraulic Conductivity

Initial simulations used a recharge distribution similar to that of Prudic (1981). Infiltration rates used in subsequent simulations were greater than those used by Prudic in most areas along the section because the till in March 1983 was saturated to land surface. Rates similar to those used by Prudic were used in a few locations, such as near the 82-3 nest of piezometers and near holes D and I, to simulate local unsaturated conditions of March 1983. Final infiltration rates ranging from 1.4 cm/yr to 3.8 cm/yr (fig. 10) were in close agreement with values used by Prudic (1981).

The distribution of hydraulic-conductivity values used in the best-fit simulation is depicted in figure 10; the distribution of heads is shown in figure 11. The final distribution of hydraulic conductivity in the best-fit simulation was similar to Prudic's (1981) except in the lacustrine silt unit at the base of the unweathered till below hole G. Prudic (1981) assumed the top of the lacustrine unit to be at an altitude of 391 m along the entire length of his section. Test holes drilled for this study (82-1D and 82-3D, fig. 4) indicate, however, that the top of the lacustrine unit might be higher at hole G. The thickness of the overlying till decreases rapidly west of hole 82-3D, as shown in figure 5 (p. 10). To compensate for that and the gradual thinning of the lacustrine unit west of Franks Creek, and to more closely simulate measured heads near hole G, the hydraulic conductivity of the basal till unit directly beneath hole G was decreased to 0.4 times that of the weathered till.

Decreasing the hydraulic conductivity of the till beneath hole G was necessary to match observed heads in piezometers in that hole. Why the till would be less permeable beneath hole G and not elsewhere is unknown. The heads in piezometers in hole G could have been duplicated if the altitude of the top of the lacustrine unit were decreased to 389 m. The exact altitude of the top of the lacustrine unit at G is uncertain; it is based on projections from nearby test holes that penetrate the lacustrine unit.

The till units used by Prudic (1986) to account for increasing overburden pressure were extended only about 50 m west of the facility's disposal area (fig. 10) because the till thins to less than 20 m thick at that location, and its base rises above 400 m, the altitude below which Prudic (1981) simulated the till unit of lowest hydraulic conductivity.

Distribution of Head and Ground-Water Velocity

A comparison of calculated with average observed heads (table 1) indicates that the best-fit steady-state simulation was in close agreement with conditions observed in March 1983. The difference between calculated and observed heads was generally less than 50 cm over 55 percent of the model cells where data were available and less than 100 cm over 88 percent of these areas. The mean absolute value of deviation was 56.7 cm. Negative pressures or pressures near zero were simulated at nearly all locations where piezometers were dry.

The water table was simulated close to land surface in most places but was simulated below land surface at a few locations to reflect unsaturated conditions observed locally. Two areas where the water table is significantly

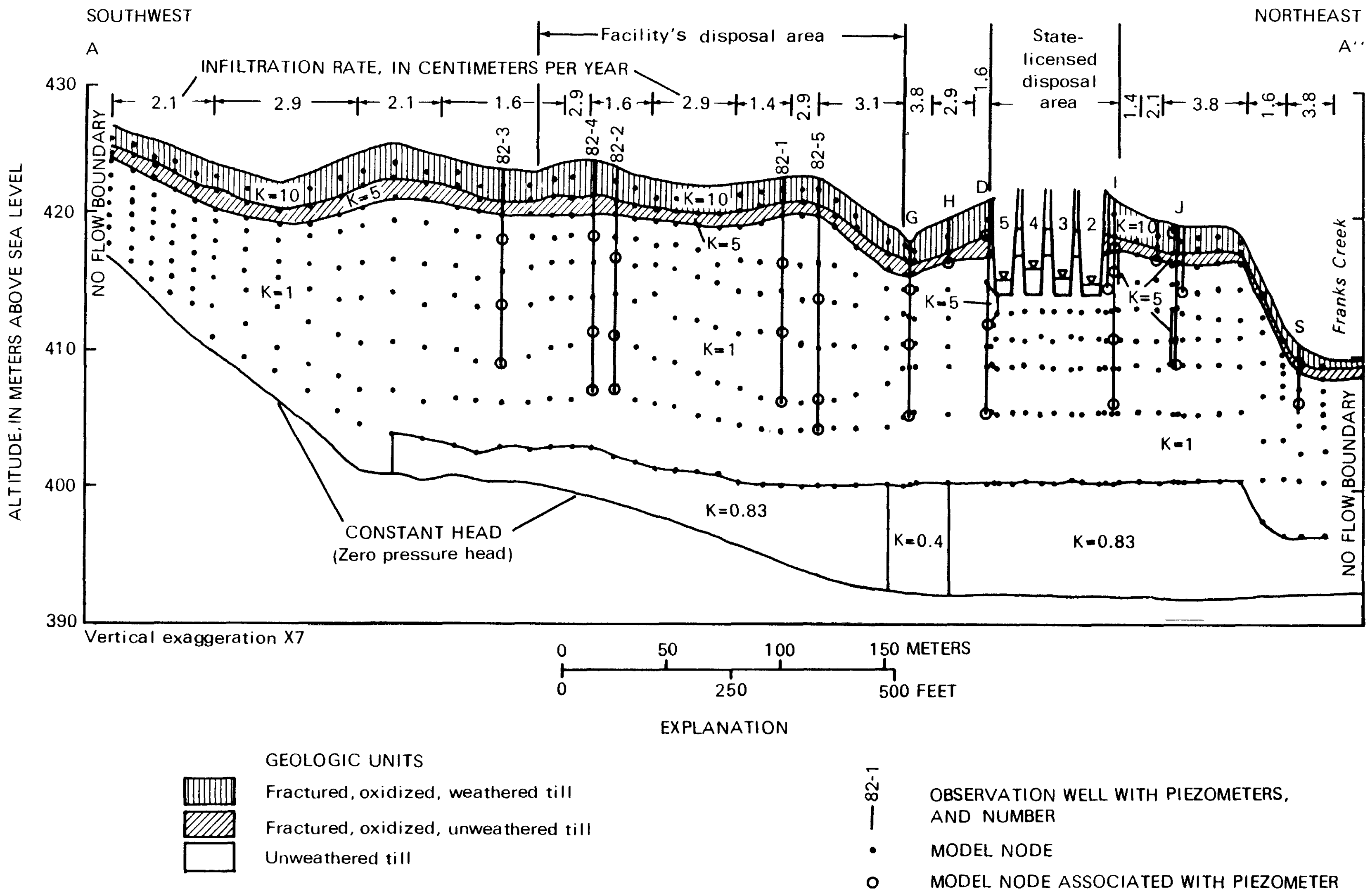


Figure 10.--Section A-A' from near Rock Springs Road to Franks Creek showing arrangement of nodes, boundary conditions, relative hydraulic conductivity, and recharge used in best-fit model simulation of the present study. (Location of section is shown in fig. 2.)

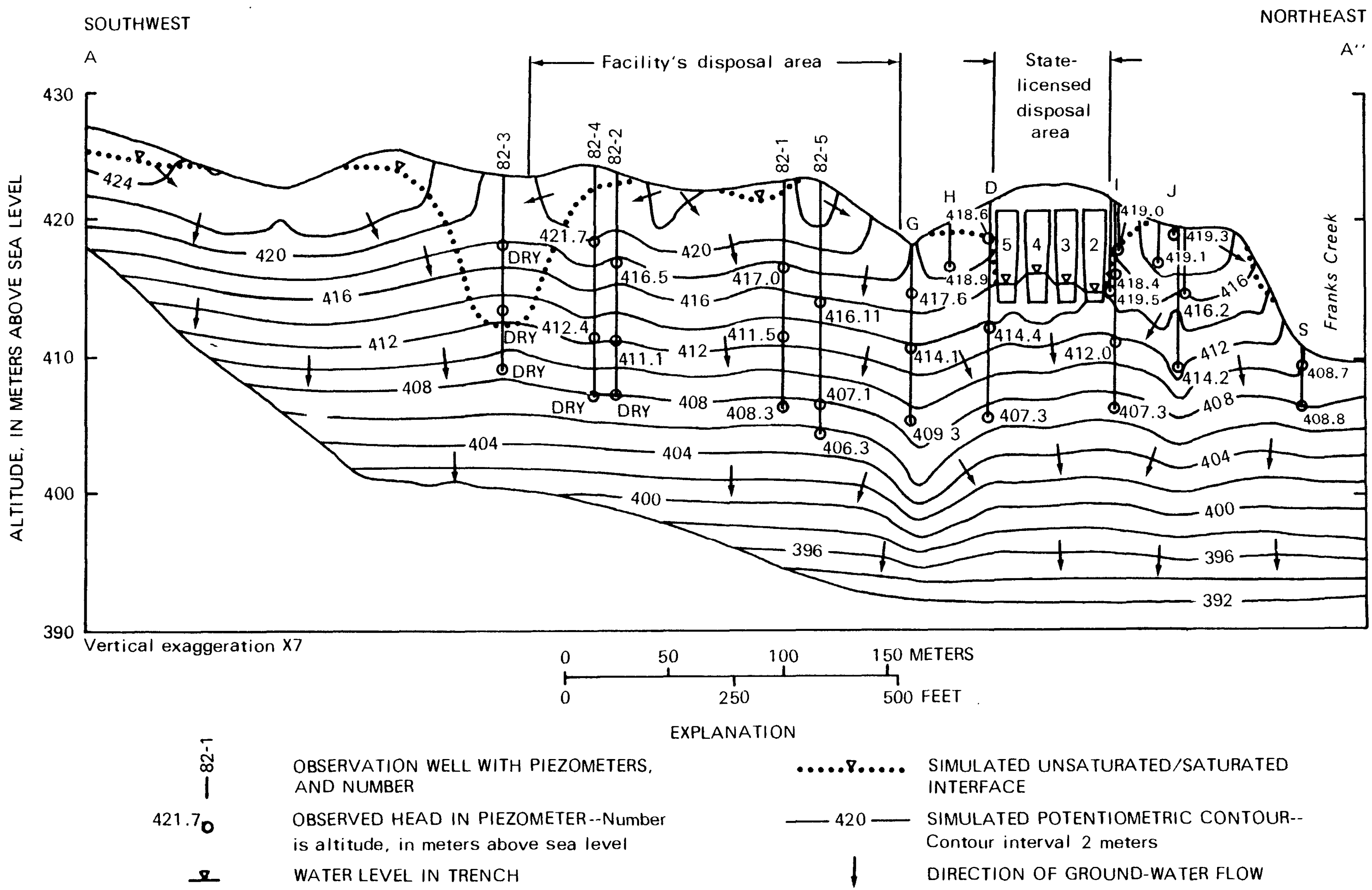


Figure 11.--Section A-A' from near Rock Springs Road to Frank Creek showing distribution of head based on the best-fit steady-state simulation of March 1983 conditions. (Location of section is shown in fig. 2.)

below land surface are evident near the State-licensed disposal area and near well 82-3 (fig. 11). Piezometers at depths of 6 m, 10.9 m, and 15.2 m at test hole 82-3 have not contained water since their installation but are assumed to be operating properly.

Table 1.--Comparison of simulated heads derived from the best-fit steady-state simulation to those observed in piezometers during March 1983.

[All head values are in centimeters. Piezometer locations are shown in fig. 4.]

Piezometer number	Node location	Simulated heads from best-fit steady-state run: Pressure head	Simulated heads from best-fit steady-state run: Total head	Observed head (March 1983)	Absolute departure of total head from observed head
82-3A*	172	-40.9	41722.1	41763.4	41.3
82-3B*	170	-11.5	41236.5	41248.3	11.8
82-3C*	169	9.7	40855.7	40846.0	9.7
82-4A	216	174.2	41984.2	42172.7	188.5
82-4B	213	116.1	41236.1	41243.4	7.3
82-4C*	212	96.4	40786.6	40643.8	142.8
82-2A	226	79.7	41729.7	41650.9	78.8
82-2B	224	98.3	41198.3	41109.9	88.4
82-2C*	223	93.8	40793.8	40744.1	49.7
82-1A	315	151.7	41751.7	41697.9	53.8
82-1B	313	145.1	41245.1	41145.0	100.1
82-1C	312	130.0	40720.0	40633.2	86.8
82-5A	336	209.5	41549.5	41611.6	62.1
82-5B	334	163.5	40763.5	40712.7	50.8
82-5C	333	151.6	40551.6	40629.2	77.6
G-1	403	315.0	41722.0	41758.8	36.8
G-2	401	363.5	41389.5	41410.0	20.5
G-3	399	440.7	40986.7	40926.7	60.0
H**	416	223.6	41895.6	41890.0	5.6
D2**	427	1.7	41823.7	41860.0	36.6
D-1**	435	216.9	41370.9	41440.0	69.1
D-2**	432	172.2	40706.2	40780.0	73.8
I3**	557	53.0	41467.0	41450.0	17.0
I-1**	568	5.4	41528.4	41540.0	11.6
I2**	566	117.9	41153.0	41300.0	147.1
I-2**	564	123.3	40715.3	40730.0	14.7
I4*	580	-111.6	41646.4	41700.0	53.6
J4	603	218.3	41914.3	41910.0	4.3
J5	615	47.1	41894.1	41917.3	23.2
J-1	620	466.0	41330.0	41473.5	143.5
J2	634	252.3	41609.3	41618.6	9.3
S2	703	152.4	40978.4	40995.3	16.9
S1	700	262.7	40818.7	40820.6	1.9

Mean absolute value of error = 56.7 cm***

* Piezometers were dry. Observed head is computed from a zero pressure head.

** Heads from estimated measurements from previous invstigations.

*** Mean absolute value of error calculated from piezometers with water.

The distribution of heads and the direction of ground-water flow within the till (fig. 11), based on the best-fit steady-state simulation, indicates that water at shallow depths of 2 to 3 m below land surface, where the till is fractured and weathered, contains root tubes, and generally has a higher permeability, moves laterally from topographically high areas to adjacent low-lying areas and then moves downward. In contrast, water below the first 2 or 3 m of till moves essentially downward, even below small streams.

Water discharges to land surface at three locations--a low-lying area between the burial areas west of hole G, the land-surface depressions directly east of the north trenches of the State-licensed disposal area, and the base of the slope incised by Franks Creek. Ground-water discharge computed by the model in these locations amounted to about 1.5×10^{-4} $(m^3/d)/m^2$ and was distributed over small areas. As Prudic (1981) pointed out, these discharge rates are small and cannot be verified in the field because flow in nearby streams cannot be measured with sufficient accuracy to substantiate them. Flows in nearby streams during base-flow periods in the spring are generally less than 8.5×10^{-3} m^3/s, and, during the summer, these discharge areas are marshy and remain saturated even though streams are not flowing, which may be indicative of ground-water seepage.

The magnitude of specific discharge (Darcian velocity) from the model ranges from 0.02 cm/yr at the base of the till to 5 or 6 cm/yr at nodes near discharge areas at land surface and at the trenches in the State-licensed disposal area. Average specific discharge within the hydrologic units simulated in the model (table 2) vary less than the flux between nodes. The lowest fluxes, which average 1.4 cm/yr, were found within the till unit of least hydraulic conductivity at the base of the till beneath hole G. The greatest fluxes, which average 3.8 cm/yr, were found in units that represented sand and silt lenses near holes D, I, and J.

Table 2.--Average horizontal, vertical, and composite specific fluxes used within each hydrologic unit in the best-fit steady-state simulation of March 1983 conditions.

	Specific flux (cm/yr)		
Hydrologic unit	Horizontal	Vertical	Composite
Fractured weathered till	1.0	1.8	2.3
Fractured unweathered till	0.6	2.0	2.2
Unweathered till	0.1	2.0	2.0
Unweathered till units used to compensate for overburden pressure			
Unit 1: K = 0.85 K of unweathered till	0.02	1.9	1.9
Unit 2: K = 0.4 K of unweathered till	0.1	1.4	1.4
Fine sand and silt lenses	0.4	3.8	3.9

Sensitivity Analysis

A series of steady-state model simulations was made to evaluate the sensitivity of the model to variations in hydraulic values, including recharge (infiltration from precipitation), hydraulic conductivity, anisotropy, and boundary conditions at the base of the till. When recharge was increased by a factor of 2 (fig. 12A), heads in the model increased to as much as 3 m above calibrated head values. Reducing recharge by a factor of 2 (fig. 12B) resulted in head declines of as much as 7 m below to the calibrated values. When both recharge and hydraulic conductivity were changed proportionately, however, the results were nearly the same (fig. 12C and 12D).

Changes in hydraulic conductivity of the various till units were also tested by comparing the resulting head values with the calibrated, best-fit model head values. Increasing and decreasing the hydraulic conductivity of all till units simultaneously while keeping recharge values fixed produced head changes as much

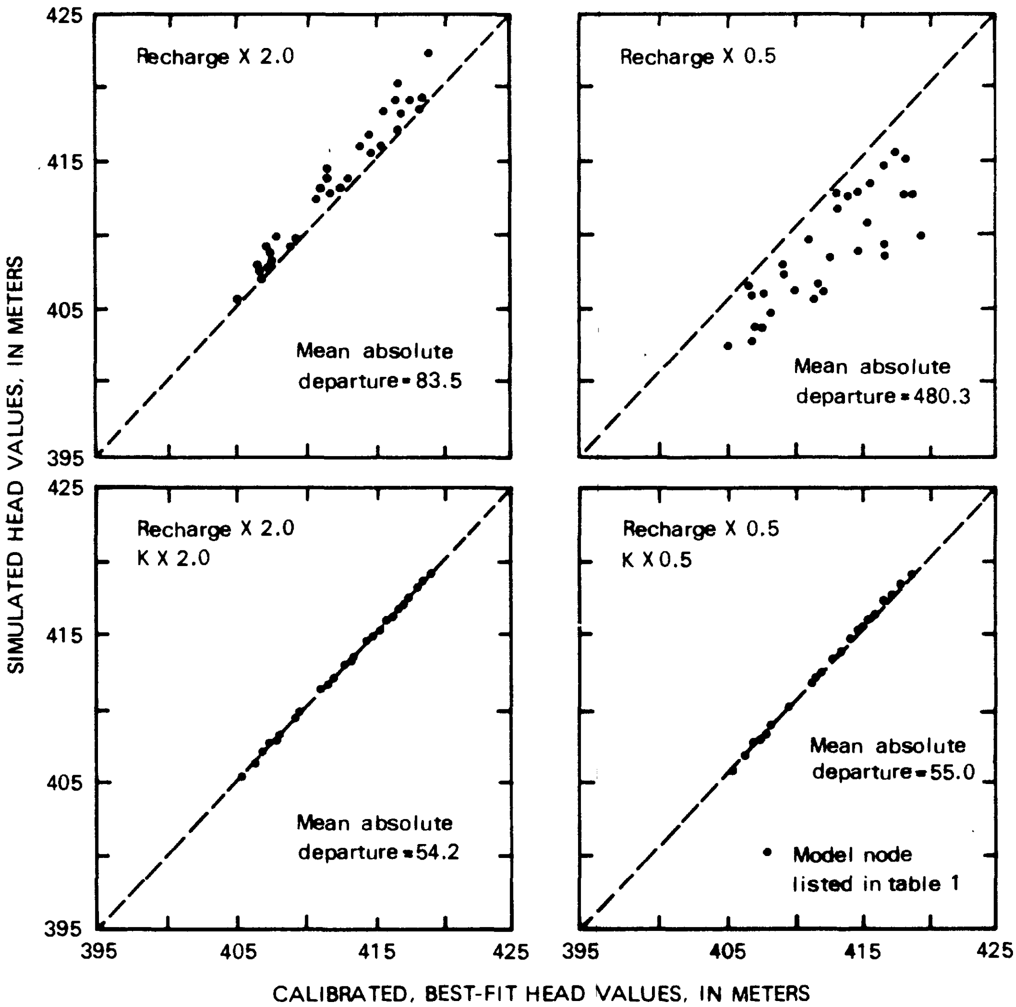


Figure 12.--Comparison of simulated head values in sensitivity analysis, based on calibrated best-fit head values for March 1983 conditions:
A, B. With recharge varied.
C, D. With recharge and hydraulic conductivity varied.

as 4 m below, and 1 m above, the calibrated head values (fig. 13), which is analagous to changing recharge while keeping the hydraulic conductivity values constant. These results suggest that model simulations could not independently define recharge rates or the hydraulic conductivity of the till units nor velocities in the flow field but rather indicate that an estimate of recharge or the hydraulic conductivity of one of the model units is needed for simulation.

Other simulations were run to evaluate the values of hydraulic conductivity for each of the four units used in the model. Increasing the hydraulic conductivity for the fractured, weathered till unit and the fractured, unweathered till unit by factors of 2 to 1,000 increased the mean absolute departure between simulated and observed heads. The mean absolute departure increased from 79 to 118 as the hydraulic conductivities of these two units increased.

Decreasing the hydraulic conductivity of the lowest till unit (the unit with reduced hydraulic conductivity to represent overburden pressures) by factors of 0.40 and 0.20 of the unweathered till's value increased the mean absolute departure between simulated and observed heads to 184.

Changing the hydraulic conductivity of the model unit that represents known sand and silt lenses near holes D, I, and J (figs. 4, 11) affected only the heads near the sand and silt lenses but did not greatly affect the mean absolute departure between simulated and observed heads.

The anisotropy of all till units except those representing sand and silt lenses was evaluated by increasing the ratio of the horizontal to vertical hydraulic conductivity by factors of 10 and 100. In general, increased anisotropy resulted in poorer agreement between the simulated and observed heads; this is consistent with field and laboratory tests and suggest that the till is either isotropic or slightly anisotropic (Prudic 1982, 1986).

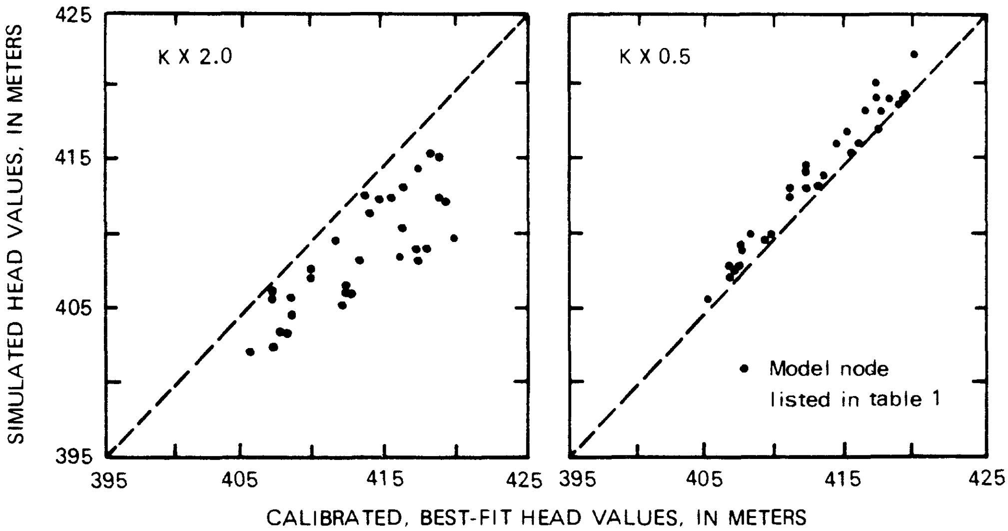


Figure 13.--Comparison of head values from sensitivity-analysis simulations with head values from calibrated, best-fit simulations for March 1983 conditions, with hydraulic conductivity varied.

Assessment of Ground-Water Flow to a Nearby Stream

Field observations and model simulations of the two disposal areas indicate that ground water below the upper 3 m of till moves downward through the till until it reaches the underlying lacustrine silt and kame-delta deposits. Once in these units, it moves slowly northeastward 800 to 900 m toward Buttermilk Creek. Model results also suggest, however, that water in the vicinity of the burial ground has some potential for lateral flow at shallow depths (2 or 3 m), where the till is fractured, weathered, and presumably more permeable than the deeper unweathered till.

Prudic (1981, 1986) addressed the potential for lateral movement of ground water through the upper units of till to adjacent surface-drainage areas and concluded that ground water leaving the burial trenches in both disposal areas will not intersect nearby small streams unless trench-water levels rise to intersect the reworked till that forms the trench covers. Thus, if the trenches fill with water, contaminated water could enter the near-surface layer and flow laterally.

The potential for lateral ground-water flow from the facility's disposal area to nearby steams was evaluated by modeling vertical section D-D' (figs. 2 and 4). The section extends north from burial pit 11 through the 82-5 nest of piezometers to nearby Erdman Brook (fig. 4). This section intersects a shallow gulley that penetrates the shallow fractured and weathered till. The finite-element grid used to represent the cross section is depicted in figure 9 (p.). The section is considered to be parallel to the general flow path of ground water. This assumption is similar to that used by Prudic (1981, 1986) in which ground-water movement is vertical, with no flow normal to the plane of the vertical sections.

Because information on hydraulic head and geologic conditions along this section are limited, results of model simulations along this section are considered as preliminary tests of hypotheses about ground-water flow across this plane. Boundary conditions were the same as those used in the calibrated model. The base of the till was assumed to be at 395 m, the base altitude of the till at nearby test hole 82-1D (fig. 4). Depths of the fractured weathered till and the fractured unweathered till units were estimated from well logs at the 82-5 well cluster and from limited field observations made near the gulley. The distribution of hydraulic conductivity in the model was similar to that used in the model of section A-A' (fig. 11) through the two burial areas. Four different till units were simulated: a fractured weathered till; a fractured unweathered till; an unweathered till; and an unweathered till with permeability reduced to simulate overburden pressure. The distribution of these units is depicted in figure 14.

Infiltration rates were adjusted along the section so that the uppermost nodes were unsaturated. The infiltration rates shown in figure 14 were similar to those used in the calibrated model and ranged from 3.1 cm/yr in the gulley and in Erdman Brook to 1.6 cm/yr along steep slopes bordering the channels. No recharge was applied over the burial pit in initial simulations; initially only 1 m of water was simulated in pit 11.

The distribution of simulated heads when pit 11 was only partly filled with water is shown in figure 15. Ground-water flow in the weathered till is toward pit 11, downward in the vicinity of test hole 82-5 and laterally along the

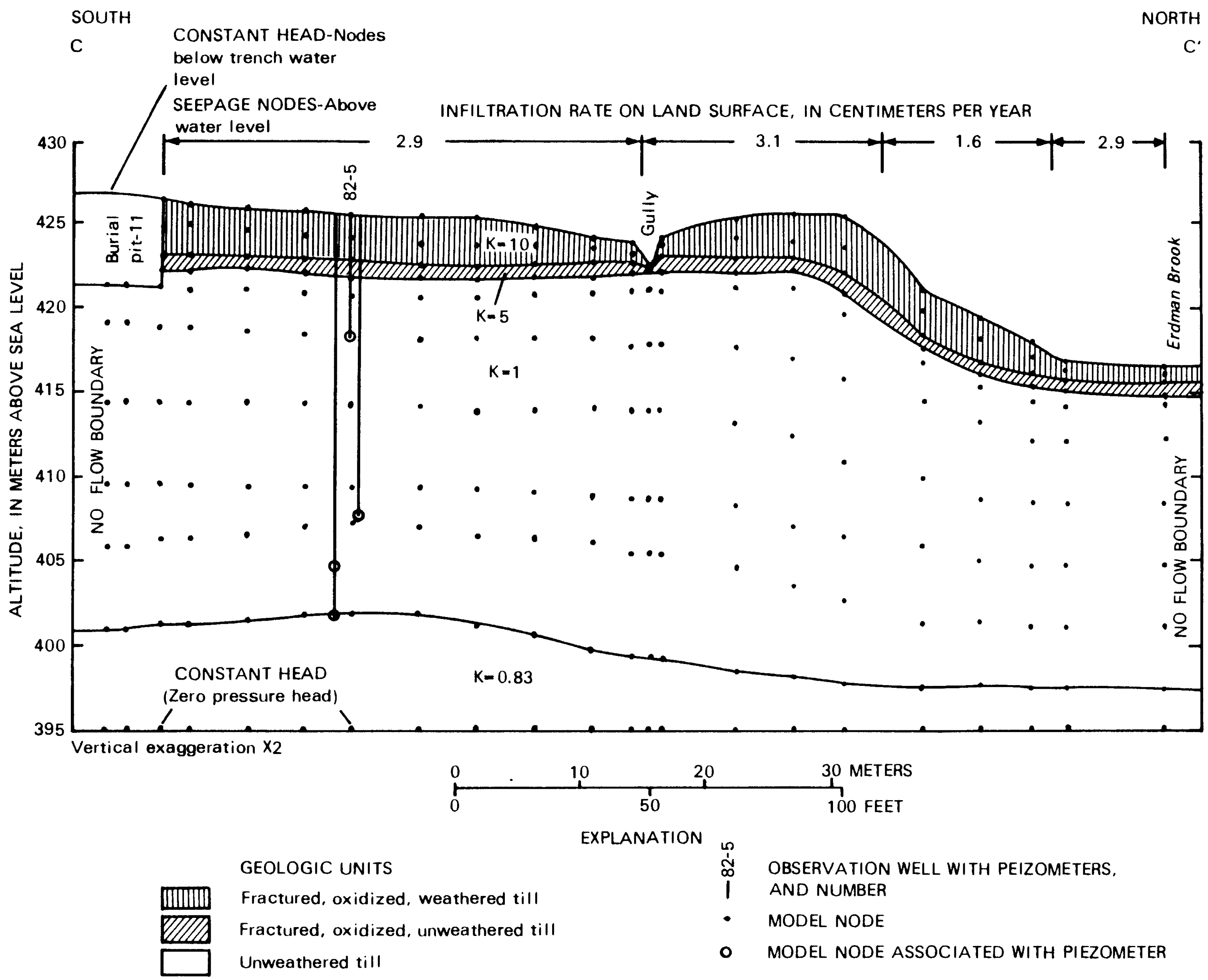


Figure 14.--Section D-D' from Erdman Brook to burial pit 11 showing arrangement of nodes, boundary conditions, relative hydraulic conductivity, and recharge used in the steady-state simulation. (Location of section is shown in fig. 4.)

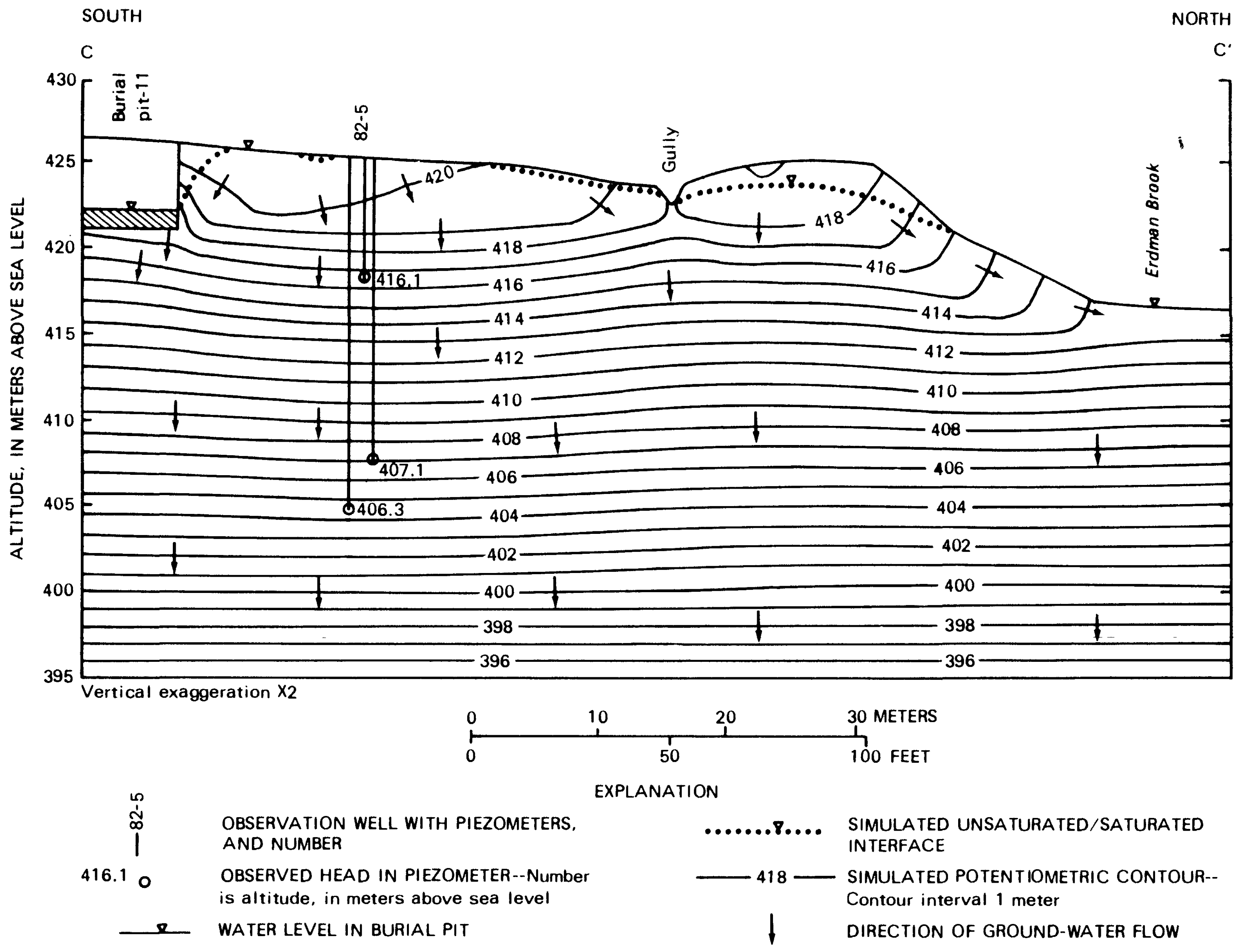


Figure 15.--Section D-D' from Erdman Brook to burial pit 11 showing the steady-state distribution of head and direction of ground-water flow when burial pit 11 is partly filled with water. (Location of section is shown in fig. 4.)

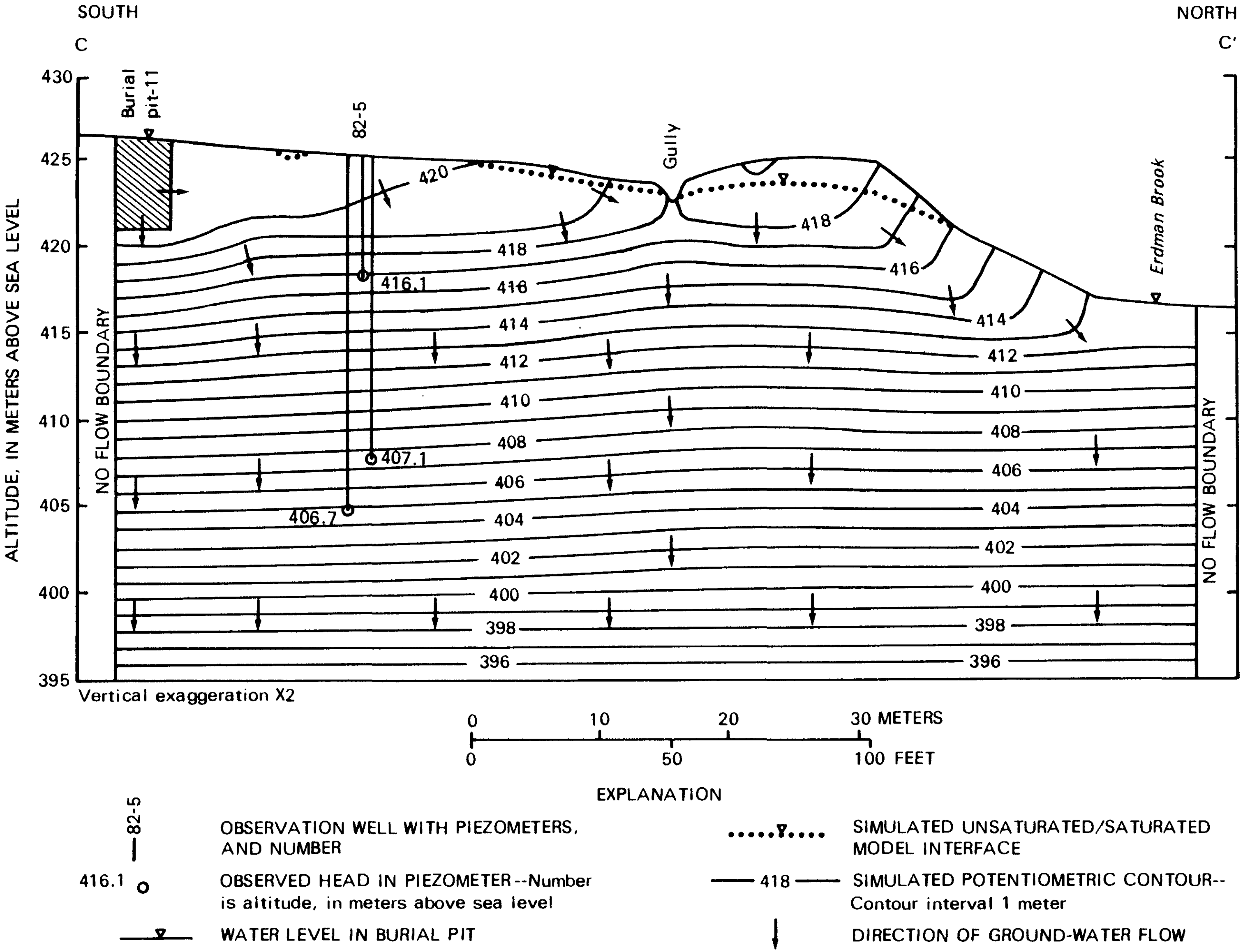


Figure 16.--Section D-D' from Erdman Brook to pit 11 showing steady-state distribution of head and direction of ground-water flow when trench 11 overflows. (Location of section is shown in fig. 4.)

slopes to Erdman Brook. A similar flow pattern was reported by Prudic (1981) in model simulations near this area. The extent of lateral movement may be related to the degree of slope on the land surface. Model results near Erdman Brook, where the land surface slopes steeply, indicate that water in topographically high areas bordering the channel migrates laterally toward the brook. In areas where the land surface is less steep (such as near holes 82-5A, 5B, and 5C, between the gulley and burial pit 11), model results indicate that water migrates laterally only a few meters before moving downward. Because the burial pits are simulated as being only partly filled, ground water above the level of burial-pit saturation discharges into the pit, and water within the burial pit was simulated as not moving laterally in the shallow till.

The modeled section was also simulated on the assumption that burial pit 11 is filled with water to determine whether the water could flow to the nearby gully or Erdman Brook. All other model values remained the same. The distribution of simulated heads and flow directions are shown in figure 16 (p. 27). Water near the bottom of the pit was simulated as moving laterally for a distance of 5 to 6 m before moving downward through the unweathered till. Water near the top of the pit was shown to move less than 20 m laterally but still did not reach the nearby gulley or Erdman Brook.

The lateral flux through the weathered till units was calculated to be about 80 $(cm^3/d)/m^2$. Specific fluxes for the fractured, weathered till and the fractured, unweathered till were 3.2 and 2.4 cm/yr respectively. The values were only slightly greater than the specific flux of 2.0 cm/yr in the unweathered till. Thus, results of the simulation indicated that subsurface migration of radionuclides in ground water to points of discharge near the gulley and Erdman Brook is unlikely as long as water in burial pit 11 does not exceed the pre-burial land-surface altitude.

SUMMARY

Ground water near two radioactive waste-disposal areas within the Western New York Nuclear Service Center moves predominantly downward through 20 to 30 m of clay-rich till before reaching fine sand and silt of underlying lacustrine and kame-delta deposits. The upper 3 m of till is fractured and weathered, which enables ground water at shallow depths to move laterally before moving downward or discharging to local land-surface depressions or stream channels. In general, ground-water below the upper 3 m of till, even below nearby streams, moves downward at average rates of 2 to 3 cm/yr.

The hydraulic conductivity of the unweathered till, which contains small lenses of more permeable, sorted material, is estimated to be between 2 x 10^{-5} and 5.5 x 10^{-5} m/d. Values of vertical and horizontal hydraulic conductivity obtained from laboratory analysis of undisturbed cores and field analyses of piezometer recovery tests suggest that the till is virtually isotropic. Although the hydraulic conductivity of shallow till has not been measured directly, it is probably higher than that of the unweathered till because it is fractured and weathered. Steady-state simulations of ground-water flow indicate that the hydraulic conductivity values of fractured unweathered till and the fractured weathered till are 5 and 10 times greater than that of the unweathered till, respectively.

The calibrated, best-fit model simulations of March 1983 conditions used four isotropic units of differing hydraulic conductivity. Fractured unweathered till and fractured weathered till that extends to 3 m below land surface were represented as two separate units whose hydraulic-conductivity values were 5 and 10 times greater, respectively, than the measured value used for the unweathered till below these units. The hydraulic conductivity of sand and silt lenses near holes D, I, and J were simulated at values 5 times that of the unweathered till. An additional unit was added to simulate the consolidation of the till by overburden pressure below an altitude of 400 m.

Sensitivity analyses were conducted to evaluate the relative effects of recharge, hydraulic conductivity, and anisotropy on hydraulic head. Although simulations indicated that small changes in recharge or hydraulic conductivity caused significant changes in the model head distribution, changing recharge and hydraulic conductivity proportionally caused only minimal changes in the simulated heads, which suggests that model simulations could not independently define recharge or hydraulic conductivity values. Simulations in which higher permeability was used for both fractured weathered till and fractured unweathered till units produced greater deviations for observed heads but also increased ground-water flow through the weathered till. Adding anisotropy in the simulations also increased the deviation from observed heads.

The potential for lateral ground-water flow to the nearest stream was evaluated by simulating hydrologic conditions along a vertical section between burial pit 11 in the facility's disposal area and Erdman Brook. Simulations that used hydraulic-conductivity values derived from the calibrated, best-fit model indicated that ground water leaving a burial pit and moving through the upper layer of till would migrate laterally 5 to 6 meters before moving downward into the unweathered till.

Simulations also indicated that water near the top of the pit would move laterally less than 20 meters before moving downward into the unweathered till. It seems reasonable to assume from the model simulations that subsurface migration of radionuclides in ground water to points of discharge at land surface would be unlikely, given that the water level in the pit does not rise into the reworked cover material capping the pit.

REFERENCES CITED

Bergeron, M. P., Kappel, W. H., and Yager, R. M., 1987, Hydrogeologic conditions at the nuclear-fuels reprocessing plant and waste-management facilities at the Western New York Nuclear Service Center, Cattaraugus County, New York: U.S. Geological Survey Water-Resources Investigations Report 85-4145, 49 p.

Cooper, H. H., Jr., Bredehoeft, J. D., and Papadopoulos, S. S., 1967, Response of a finite-diameter well to an instantaneous charge of water: Water Resources Research, v. 3, p. 263-269.

Dana, R. H., Jr., Fakundiny, R. H., LaFleur, R. G., Molello, S. A., and Whitney, P. R., 1979, Geologic study of the burial medium at a low-level radioactive-waste-burial site at West Valley, New York: New York State Geological Survey Open-File Report 79-2411, 70 p.

REFERENCES CITED (continued)

Fickies, R. H., Fakundiny, R. H., and Mosely, E. T., 1979, Geotechnical analysis of soil samples from test trench at western New York Nuclear Service Center, West Valley, New York: New York State Geological Survey NUREG/CR-0644, 21 p.

Freeze, A. R., and Cherry, J. A., 1979, Ground water: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Hvorslev, M. W., 1951, Time lag and soil permeability in ground-water observations: Vicksburg, Miss., U.S. Army Corps of Engineers Experimental Station, Bulletin 36, 50 p.

LaFleur, R. G., 1979, Glacial geology and stratigraphy of Western New York Nuclear Service Center and vicinity, Cattaraugus and Erie Counties, New York: U.S. Geological Survey Open-File Report 79-989, 17 p.

Nicholson, T. J. and Hurt, R. D., 1985, Information on the confinement capability of the Facility Disposal Area at West Valley, New York: U.S. Nuclear Regulatory Commission, NUREG-1164, 55 p.

Prudic, D. E., 1981, Computer simulation of ground-water flow at a commercial radioactive-waste landfill near West Valley, Cattaraugus County, New York, in Little, C. A., and Stratton, L. E., (eds.), Modeling and low-level waste management--an interagency workship: Oak Ridge, Tenn., Oak Ridge National Laboratory, ORO-821, p. 215-248.

_______ 1982, Hydraulic conductivity of a fine-grained till, Cattaraugus County, New York: Ground Water, v. 20, no. 2, p. 194-204.

_______ 1986, Ground-water hydrology and subsurface migration of radionuclides at a commercial radioactive-waste burial site, West Valley, Cattaraugus County, N.Y.: U.S. Geological Survey Professional Paper 1325, 83 p.

Prudic, D. E., and Randall, A. D., 1977, Ground-water hydrology and subsurface migration of radioisotopes at a low-level, solid radioactive-waste disposal site, West Valley, New York: U.S. Geological Survey Open-File Report 77-566, 28 p.

Reeves, Mark, and Duguid, J. O., 1975, Water movement through saturated-unsaturated porous media--a finite element Galerkin model: Oak Ridge, Tenn., Oak Ridge National Laboratory, ORNL-4927, 232 p.

U.S. Department of Energy, 1979, Western New York Nuclear Service Center study, companion report TID-28905-2: West Valley, N.Y., U.S. Department of Energy, (variable pagination).

_______ 1980, Western New York Nuclear Service Center study, companion report: U.S. Department of Energy, TID-28905-2, 1 v.

Yeh, G. T., and Ward, D. S., 1980, FEMWATER--a finite element model of water flow through saturated-unsaturated porous media: Oak Ridge, Tenn., Oak Ridge National Laboratory, ORNL-5567, 153 p.

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